TESIS DE LA UNIVERSIDAD DE ZARAGOZA

2020

15

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Energy modelling and U-value calculation of Scottish house elements: assessment of thermal performance improvements

Departamento

Centro de Investigación de Recursos y Consumos Energéticos (CIRCE)

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ISSN 2254-7606

Prensas de la Universidad
Universidad Zaragoza

ISSN 2254-7606

Universidad Zaragoza

Tesis Doctoral

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2019

Instituto Universitario de Investigación Mixto
circe
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Doctoral Thesis

Doctoral Program in Renewable Energies and Energy Efficiency

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December 2018

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ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude and thank my supervisor, Ignacio Zabalza Bribián, for the patient guidance, encouragement, motivation, immense knowledge, advice he has provided and for the continuous support of my Ph.D study and related research. I am very much thankful to him for picking me up as a student and introducing me to this exciting field of science. I have been extremely fortunate to have a supervisor who cared so much about my work, and who responded to my questions and queries so promptly. As my teacher and mentor, he has taught me more than I could ever give him credit who definitely deserve a big part of the credit of this thesis. I could not have imagined having a better advisor/mentor for my Ph.D study.

I take this opportunity to extend my sincere gratitude and appreciation to the directors and administrative staffs of CIRCE and of the Zaragoza University for the opportunity that they gave me to study my Ph.D. in the university in the friendly work environment during these years.

Nobody has been more important to me in the pursuit of this thesis than the members of my family. I feel a deep sense of gratitude for my parents Manouchehr and Jamileh, and siblings Farhang and Faranak, whose love and guidance are with me in whatever I pursue. I really appreciate your unceasing encouragement, support and attention that have been supportive of my career goals and always believing in me. They are the ultimate role models.

I also would like to pay high regards to those with whom I have had the pleasure to work during the projects in Scotland, people of Edinburgh and twelve kind landlords and their families, who welcomed me and made me feel like home.

At the end of my thesis, it is a pleasant task to express my thanks to all those who contributed in many ways to the success of this study and made it an unforgettable experience for me. I would be grateful to all of my colleagues and professors of master studies courses who helped me.

Last but not least, I would like to thank all the thesis evaluation experts and people who reviewed my thesis. I really appreciate the time you dedicated to read my dissertation and your helpful suggestions thoroughly.

ABSTRACT

Climate change is a tremendous long-term challenge facing the world today (1). According to the International Energy Agency, dwellings account for around 40% of whole world energy consumption (2), and current predictions show that if definitive measures are not taken, the trend will continue. Alongside as declared by Baetens (3), greenhouse gas emissions from houses in developed countries are responsible for around 35% of the emissions. Many efforts are being made worldwide to reduce energy consumption in houses and consequently mitigate global warming. By improving the energy efficiency of buildings, it is possible to reduce total EU energy consumption by 6-7% decreasing as well as CO_2 emissions by about 6% (4). Recently the most outstanding measures are focused on the greater use of renewable technologies (5,6).

The United Kingdom stood at 559 million tons of CO_2 emissions per year, with 28% belong to the energy used in houses. Scottish Government estimates that a third of it approximately could be preserved by upgrading easy energy-saving methods. It consigns Scotland to some of the most ambitious carbon reduction targets in the world including the decrease of greenhouse gas emissions by 42% by 2020, and 80% by 2050, from 1990 levels (7). Traditional houses account for one-quarter of the UK's existing house stock. Careful planning and attention are required to ensure that any proposed works will be beneficial and effective while preserving the historical character of the building. It is essential to understand the kind of structure, the elements used and the probable effect of any proposed changes in these houses. There are over 600 conservation zones and 46,000 listed houses of specific architectural or historical interest in Scotland. The nation as a whole recognises that it is essential due care is given to preserving the character of traditional buildings and areas. Also, in line with national, and international targets on CO_2 reduction, it is essential that renovations of old buildings make the best use of existing and emerging practices to increase energy efficiency. It is fundamental not to do it in a way that compromises the integrity of the houses or the comfort or health of occupants.

Often historical constructions have natural health benefits. Many of them were planned carefully with high levels of natural space, light, and other aspects conducive to well-being. The balance requires being stuck between decreasing carbon emissions and keeping residences healthy. The challenge is to renovate old houses to an energy-efficient standard which promotes and maintains their health benefits. Low energy renovation could have adverse and unintended consequences which imply decreased natural lighting and indoor air quality together with other hazards and overheating. A combination of natural ventilation and radiant heating create more sustainable and healthier environment. Another method to enhance air quality would be to avoid some products and materials which prevent the movement of humidity and emit hazardous chemicals. Most of the literature notice that a significant portion of the energy consumption in houses depends on the energy losses through the house components as a consequence of the negligible thermal performance of the current components, especially the windows (8).

There is a lack of information on health issues and indoor air quality subject. The disadvantage of packing construction that is usually applied to enhance the energy efficiency has not been appropriately evaluated. However, few studies show that renovation can have adverse results which imply decreased lighting, overheating and deterioration of indoor air quality. Regards to the energy balance of the houses, the heat transmission losses in the opaque walls are one of the most important issues (9). Estimate the thermal efficiency of the opaque elements faces the difficulties of lack of appropriate data for simulating the behaviour of energy building with dynamic or static software. Moreover, it is essential to enhance the new energy simulation tools dedicated to traditional houses adding specific databases incorporating thermophysical properties of house elements and more appropriate information referred to traditional construction techniques.

The integration of renewable energies in houses and energy preservation allows going along a path in extending the fossil fuels life and cleaning the environment. Recognition of the particular characteristics of traditional houses and determining how best to meet their needs is a fundamental step towards the better and more sustainable management of the existing resources. Therefore it is essential to take account of the specific circumstances of these houses and to balance all the issues in order to improve both their indoor environmental quality and energy efficiency.

U-value calculations are the basis for house energy assessment and house energy legislation and policy. The thesis addresses the relationship between the age of the house and the U-values of elements and its energy efficiency. There is no scientific paper about the exact relation between the house age and component U-values calculated by energy software. Consequently, this study aims to assess this relation since this is one of the important factors of thermal performance which guides energy efficiency assessments and implementing energy efficiency measures. The study is not limited to U-value measurement alone, but it contributes to a wider study on sustainability together with the effect of insulation on envelopes, energy efficiency and environmental impact rating. The results of this study are outcomes from a total of a hundred Scottish traditional houses used as case studies and located in one climate with the least variable conditions, so they are more valuable and reliable. Although the selected solution to obtain a nearly-zero energy building renovation depends on the house characteristics and the climatic zone, a direct relation between the U-values of elements, the age of a property and its energy efficiency is observed. The older the homes, the less the improvement/change on the U-values. In this sense, the U-values of elements of the houses built after 1985 are added with a higher slope. The maximum potential growth in energy efficiency is observed in houses built between 1540 and 1814. The same issues are confirmed with regard to the environmental impact rating. Therefore, the priority for renovation process accrues to the traditional houses.

In addition to the existing traditional houses, the energy efficiency standards for new homes are also studied in the thesis. It should be pointed out that all new houses built from the end of 2020 in the member states of the European Union must be nearly-zero energy. The thesis analyzes the U-values and materials of the elements of a typical new house in two European countries (the United Kingdom and Spain) with different building regulations and weather.

Also, the influence of different kinds of materials and U-values on the energy efficiency of new houses according to the standards is studied.

The in-situ measurements permit to calibrate the thermal performance of traditional walls better. However, at present, there are not enough experimental data related to the traditional constructive solutions. The thesis presents the results of experimental U-value measures in a set of twelve traditional Scottish houses and it assesses the suitability of using energy simulation software to estimate the U-values of traditional construction build-up. Except for one case study, the results of the measurements performed in these houses are generally lower than the comparable calculated thermal transmittance. U-value calculations for the brick cavity wall construction with better-defined build-ups are closer to the in-situ measurement results. This acceptable achievement is related to the material with insulation layers because the insulating elements seem to have thermal properties similar to those declared by the manufacturers.

In recent years, buildings have been designed to be better insulated and more tightly sealed in order to enhance their energy efficiency. In energy terms, it is helpful as allows to have enough ventilation, reducing energy losses. Nevertheless, there is a concern that changes made in building fabric to improve energy efficiency can lead to a build-up of pollutants and excessive moisture levels in some circumstances. The thesis presents a complete state-of-the-art of different issues affecting the indoor environmental quality and users' health in buildings, such as the refurbishment works, the indoor air quality, the house services, etc. The study illustrates how it is possible to implement sustainable development practices when upgrading house services in the traditional house stock. A interdisciplinary and holistic method based on an understanding and appreciation of the highly individual nature of many older houses is exposed, reflecting the unique manner in which they have been inhanced over period; the materials and construction methods; the actual and intended performance; and the formal recognition and protection offered by legislation.

Technically the windows, especially traditional ones, are considered as a most targeted building element for the replacement in order to reduce heat loss in houses. Because of their energy saving potential, it is imperative to choose the appropriate windows, because they have a great and long course time influence in the house, with a lifespan between 20 and 50 years, or more. Designing windows properly, enhance not only the indoor thermal environment but also supply natural ventilation and daylight. There are several reasons for studying on the windows energy efficiency; for example, the heat loss and heat gain by windows are around 30% of the energy used for cooling and heating. Also, the windows influence the emissions, thermal comfort and heating/cooling bills. This thesis analyses the state-of-the-art of several parameters related to the energy efficiency of the windows, such as the windows types, the repair or replacement options, glass quality, frames types, windows painting, etc. and briefly studies other factors like heat transfer, ventilation, condensation, noise insulation and ultraviolet protection. Moreover, it shortly discusses future window technologies, for example, zero energy windows, integrated windows, dynamic glazing, phase change materials (PCM), semi-transmitted solar cells and highly insulating windows, such as a vacuum glazing.

Finally, the thesis assesses the influence of the windows on the whole house energy efficiency, considering the same set of twelve traditional Scottish houses previously mentioned. From this analysis, it can be concluded that it is essential to replace the single glazing windows because of their poor thermal condition, dominant carbon emission and its major energy savings in the case of replacement. In the case of double glazing, it is suggested to repair them because of their significant embodied carbon and the higher economic cost associated with their replacement. When comparing the daylighting of these traditional houses with the requirements established for new construction in the Leadership in Energy and Environmental Design (LEED) standard, it is observed that the daylighting in all the case studies is in poor condition. A possible solution could be to use a clear glass without dark colour, as the glass colour does not influence the U-value, but it is a critical factor for daylighting.

RESUMEN

El cambio climático es un tremendo desafío a largo plazo al que se enfrenta el mundo (1). Según la Agencia Internacional de Energía, las viviendas representan alrededor del 40% del consumo mundial de energía (2), y las predicciones actuales muestran que si no se toman medidas definitivas, la tendencia continuará. Según Baetens (3), las emisiones de gases de efecto invernadero de las viviendas en los países desarrollados son responsables de alrededor del 35% de las emisiones. Se están realizando muchos esfuerzos en todo el mundo para reducir el consumo de energía en las viviendas, ayudando a mitigar de este modo el calentamiento global. Mediante la mejora de la eficiencia energética en los edificios, es posible reducir el consumo total de energía de la UE en un 6-7%, y las emisiones de CO_2 en un 6% (4). En la actualidad, las medidas más destacadas se centran en un mayor uso de las tecnologías renovables (5,6).

El Reino Unido alcanzó las 559 millones de toneladas de emisiones anuales de CO_2, de las que el 28% están directamente relacionadas con la energía utilizada en las casas. El gobierno escocés estima que aproximadamente un tercio de la energía podría ahorrarse mediante la implementación de medidas sencillas de ahorro de energía. De este modo, Escocia es uno de los países con unos objetivos de reducción de carbono más ambiciosos del mundo, que incluyen la reducción de las emisiones de gases de efecto invernadero en un 42% para 2020 y en un 80% para 2050, con respecto a los niveles de 1990 (7). Las casas tradicionales representan una cuarta parte de las viviendas existentes en el Reino Unido. Para garantizar que cualquier reforma propuesta sea beneficiosa y efectiva se requiere una cuidadosa planificación y atención, de modo que se pueda preservar el carácter histórico de los edificios. Es esencial comprender el tipo de estructura, los elementos utilizados y los posibles efectos de cualquier modificación propuesta en estas casas. Hay más de 600 zonas de conservación y 46.000 casas listadas de interés arquitectónico o histórico en Escocia. La nación en su conjunto reconoce que es esencial que se preste la debida atención a preservar el carácter de estos edificios y áreas tradicionales. Además, en línea con los objetivos nacionales e internacionales sobre la reducción de CO_2, es esencial que las renovaciones de edificios antiguos aprovechen al máximo las prácticas existentes y emergentes para aumentar la eficiencia energética. Además es fundamental no hacerlo de una manera que comprometa la integridad de las casas, el confort, ni la salud de los ocupantes.

A menudo, las construcciones históricas ofrecen beneficios naturales para el bienestar de los usuarios. Muchas de ellas fueron planeadas cuidadosamente con grandes espacios naturales, altos niveles de luz y otros aspectos que conducen al bienestar. En este sentido, es necesario encontrar un balance entre la disminución de las emisiones de carbono y el mantenimiento de las condiciones de bienestar en las viviendas. Por tanto, el desafío es renovar las casas antiguas a un estándar de eficiencia energética que promueva y mantenga sus beneficios para la salud. La renovación de las viviendas tradicionales hacia viviendas de bajo consumo de energía podría tener consecuencias adversas e involuntarias que implicarían una disminución de la iluminación natural y la calidad del aire interior, junto con otros riesgos, como el

sobrecalentamiento de los espacios habitables. Una combinación de técnicas de ventilación natural y uso de calefacción radiante crearía un ambiente más sostenible y saludable. Otra solución para mejorar la calidad del aire sería evitar determinados productos y materiales que retengan la humedad y emitan sustancias químicas peligrosas. La mayor parte de la literatura señala que una parte significativa del consumo de energía en las viviendas depende de las pérdidas de energía a través de los componentes de la vivienda, como consecuencia del deficiente comportamiento térmico de los componentes actuales, especialmente de las ventanas (8).

Hay una falta de información sobre temas relacionados con la salud y la calidad del aire interior de las viviendas. Las desventajas de las técnicas constructivas que se aplican comúnmente para mejorar la eficiencia energética en viviendas no se han evaluado adecuadamente. No obstante, unos pocos estudios muestran que la renovación de una vivienda puede tener resultados adversos que impliquen una disminución de la iluminación, el sobrecalentamiento y el deterioro de la calidad del aire interior. Con respecto al balance energético de las casas, las pérdidas por transmisión de calor a través de los muros opacos son uno de los términos más importantes del balance (9). La estimación de la eficiencia térmica de los elementos opacos conlleva diversas dificultades, entre las que destacan la falta de datos apropiados para simular el comportamiento energético del edificio con software de tipo dinámico o estático. Además, es esencial el planteamiento de mejoras en las nuevas herramientas de simulación de energía usadas en viviendas tradicionales, agregando bases de datos específicas que incorporen propiedades termofísicas de los elementos de la casa e información más apropiada relacionada con las técnicas de construcción tradicionales.

La integración de las energías renovables y el ahorro de la energía en las viviendas permiten avanzar por una senda que extiende la duración de los combustibles fósiles, a la vez que contribuye a descontaminar el medio ambiente. El reconocimiento de las características particulares de las viviendas tradicionales y la determinación de la mejor manera de satisfacer sus necesidades es un paso fundamental hacia una mejor y más sostenible gestión de los recursos existentes. Por lo tanto, es esencial tener en cuenta las características específicas de estas viviendas y equilibrar todos los problemas asociados para mejorar tanto su calidad ambiental interior como su eficiencia energética.

Los cálculos de la transmitancia térmica (U) son la base para la evaluación energética de las viviendas, siendo una de las bases fundamentales de la legislación y la política energética del sector residencial. La tesis analiza la relación existente entre la antigüedad de la casa, los valores de U de sus componentes y su eficiencia energética. No hay ningún artículo científico que cuantifique la relación exacta que existe entre la edad de la vivienda y los valores de U de sus componentes, calculados mediante software específico. En consecuencia, este estudio pretende evaluar esta relación, ya que este es uno de los factores importantes del comportamiento térmico que guía las evaluaciones de eficiencia energética y la implementación de medidas de eficiencia energética. El estudio no se limita solo a la evaluación de los valores de U, sino que contribuye a un estudio más amplio de evaluación de la sostenibilidad relacionando el efecto del aislamiento en la envolvente térmica, la eficiencia energética y la calificación del impacto ambiental. Los resultados de este estudio proceden de un total de cien casas tradicionales escocesas utilizadas como casos de estudio y ubicadas en climas que presentan mínimas variaciones en sus condiciones, por lo que son más valiosos y fiables. Aunque la solución seleccionada para la renovación de las viviendas hacia el estándar de energía casi nula depende de las características de la vivienda y la zona climática, se observa una relación directa entre los valores de U de los elementos, la antigüedad de una propiedad y su eficiencia energética. Conforme más antiguas son las casas, se observa una menor mejora/cambio en los valores de U. En este sentido, los valores de U de los elementos de las viviendas construidas después de 1985 descienden con una pendiente mayor. El máximo potencial de eficiencia energética se observa en las casas construidas entre 1540 y 1814. Al analizar la calificación de impacto ambiental de las viviendas se observan resultados similares. Por lo tanto, las casas tradicionales deberían ser prioritarias en los procesos de rehabilitación energética.

Además de las viviendas tradicionales existentes, en la tesis también se estudian los estándares de eficiencia energética para las viviendas nuevas. Cabe señalar que todas las nuevas viviendas construidas a partir de finales de 2020 en los estados miembros de la Unión Europea deben ser de energía casi cero. La tesis analiza los valores de U y los materiales utilizados en una vivienda nueva típica ubicada en dos países europeos (Reino Unido y España) con diferentes regulaciones y clima. También se estudia la influencia de los diferentes tipos de materiales y valores de U en la eficiencia energética de las nuevas viviendas de acuerdo con los estándares.

Las mediciones in situ permiten evaluar mejor el comportamiento térmico de los muros tradicionales. Sin embargo, en la actualidad, no hay suficientes datos experimentales relacionados con las soluciones constructivas tradicionales. La tesis presenta los resultados de medidas experimentales del valor de U en un conjunto de doce casas tradicionales escocesas y evalúa la idoneidad de usar software de simulación energética para estimar los valores de U en la construcción tradicional. Excepto en un caso de estudio, los resultados de las mediciones realizadas en estas viviendas son generalmente más bajos que la transmitancia térmica calculada mediante software. Los cálculos del valor de U en paredes construidas de ladrillo, que presentan composiciones mejor definidas están más cerca de los resultados de las mediciones in situ. Esta coincidencia se aprecia especialmente en soluciones que incorporan una capa de aislamiento térmico, ya que los elementos aislantes parecen tener propiedades térmicas similares a las declaradas por los fabricantes.

En los últimos años, los edificios han sido diseñados para estar mejor aislados y más herméticamente sellados con objeto de mejorar su eficiencia energética. En términos energéticos resulta útil, ya que permite tener una suficiente ventilación, reduciendo las pérdidas de energía. Sin embargo, existe la preocupación de que los cambios realizados en la envolvente del edificio para mejorar la eficiencia energética puedan conducir a una acumulación de contaminantes y unos niveles de humedad excesivos en determinadas circunstancias. La tesis presenta un completo estado del arte de diferentes aspectos que afectan a la calidad ambiental interior y a la salud de los usuarios en los edificios, como las obras de rehabilitación, la calidad del aire interior, los servicios de la casa, etc. La tesis ilustra cómo es posible implementar prácticas sostenibles en la renovación de las viviendas tradicionales. Se presenta un enfoque holístico e interdisciplinar basado en una apreciación y comprensión de las características intrínsecas particulares de muchas viviendas antiguas, que es un reflejo de la manera en que se han desarrollado a lo largo del tiempo; analizando los materiales y métodos de construcción utilizados; las diferencias entre el comportamiento real y previsto; y el reconocimiento y protección formal que ofrece la legislación.

Las ventanas, especialmente las tradicionales, se consideran el primer elemento constructivo que debe ser reemplazado con el fin de reducir las pérdidas de calor en las viviendas. Debido a su potencial de ahorro de energía, es imperativo elegir las ventanas más apropiadas, ya que tienen una gran influencia durante el periodo de uso de la vivienda, con una vida útil de entre 20 y 50 años, o más. Diseñar ventanas adecuadamente, no solo mejora el ambiente térmico interior, sino que también permite proporcionar ventilación natural e iluminación natural. Hay varias razones para estudiar la eficiencia energética de las ventanas; por ejemplo, las pérdidas y ganancias de calor a través de las ventanas representan alrededor del 30% de la energía utilizada para la calefacción y refrigeración. Además, las ventanas influyen en las emisiones, el confort térmico y las facturas de calefacción/refrigeración. Esta tesis analiza el estado del arte de varios parámetros relacionados con la eficiencia energética de las ventanas, como los tipos de ventanas, las opciones de reparación o reemplazo, la calidad del vidrio, los tipos de marcos, la pintura de las ventanas, etc. Además se estudian concisamente otros factores como la transferencia de calor, la infiltración, el riesgo de condensación, el aislamiento frente al ruido y la protección ultravioleta. También se analizan brevemente las tecnologías de ventanas futuras, como por ejemplo, las ventanas de cero-energía, las ventanas integradas, el acristalamiento dinámico, los materiales de cambio de fase (PCM, por sus siglas en inglés), las ventanas con células solares semitransparentes y las ventanas altamente aislantes, como el acristalamiento al vacío.

Finalmente, la tesis evalúa la influencia de las ventanas en la eficiencia energética de toda la casa, considerando el mismo conjunto de doce casas tradicionales escocesas mencionadas anteriormente. A partir de este análisis, se puede concluir que es prioritario reemplazar las ventanas de acristalamiento simple debido a su deficiente condición térmica, las emisiones de carbono dominantes asociadas y su mayor potencial de ahorro de energía en caso de ser reemplazadas. En el caso del doble acristalamiento, se sugiere su reparación debido a la mayor cantidad de carbono incorporado y al mayor coste económico asociado a su reemplazo. Al comparar la iluminación diurna de estas casas tradicionales con los requisitos establecidos para nuevas construcciones en el estándar LEED (Leadership in Energy and Environmental Design), se observa que la iluminación diurna en todos los casos de estudios está en mal estado. Una posible solución podría ser usar un vidrio transparente no oscuro, ya que el color del vidrio no influye en el valor de U, pero es un factor importante para la iluminación diurna.

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NOMENCLATURE

Abbreviations

ACS	Air Conditioning System
BIPV	Building Integrated Photovoltaic
BER	Building Energy Rating Certificate
C	Cooling
CG	Cellular Glass
CHP	Combining Heat and Power
CEN	Comité Européen de Normalisation
CESP	Community Energy Saving Programme
CSH	Code for Sustainable Houses
DECADE	Domestic Equipment and Carbon Dioxide Emissions
DUKES	Digest of UK Energy Statistics
ESCos	Energy Service Companies
EPB	Expanded Perlite Board
EPC	Energy Performance Certificate
EPBD	Directive on Energy Performance of Buildings
EPS	Expanded Polystyrene
EU	European Union
FEES	Fabric Energy Efficiency Standard
GBP	Great British pounds
GHG	Green House Gas
GL	Global
H	Heating
HR	Heat Recovery
HEED	Home Energy Efficiency Database
HFC	Hybrid Fibre Coaxial
HVAC	Heating, Ventilation and Air Conditioning

IES-VE	Integrated Environmental Solutions-Virtual Environment
IGZ	Intermediate Geography Zone
LBNL	Lawrence Berkeley National Labs
LC	Low Carbon
LEED-NC	Leadership in Energy and Environmental Design - New construction
LLSOA	Lower Layer Super Output Area
Low-E	Low energy
MDF	Medium Density Fibreboard
MVHR	Mechanical Ventilation with Heat Recovery
MW	Mineral Wool
MIC	Mineral Insulated Cables
MLSOAs	Middle Layer Super Output Areas
NFRC	National Fenestration Rating Council
NZEBs	Nearly-Zero Energy Buildings
PCM	Phase Change Material
PVC-u	Poly Vinyl Chloride un-plasticized
PYL	Laminated Plasterboard
RD	Royal Decree
RITE	Spanish Regulation on Thermal Installations in Buildings
SHCS	Scottish House Condition Survey
SHS	Sick House Syndrome
SHGC	Solar Heat Gain Coefficient
SAP	Standard Assessment Procedure
CTE	Spanish Technical Building Code
IGUs	Insulated Glass Units
UV	Ultra Violet
UK	United Kingdom
UKAS	United Kingdom Accreditation Service
VOCs	Volatile Organic Components
XPS	Extruded Polystyrene
ZCH	Zero Carbon Hub
ZEB	Zero Energy Buildings

Symbols

A	Area (m^2)
$C_{ep, base}$	Base value of the non-renewable energy primary energy consumption (kWh/m^2year)
$C_{ep,lim}$	Limit value of non-renewable primary energy consumption (kWh/m^2year)
$D_{cal,base}$	Base value of the energy demand for heating (kWh/m^2year)
$D_{cal,lim}$	Limit value of the energy demand for heating (kWh/m^2year)
$F_{cal,sup}$	Surface corrector factor of the heating energy demand
$F_{ep, sup}$	Corrective factor per area of energy consumption of non-renewable primary energy
F_{llim}	Modified solar factor skylines limit
R_1, R_2, etc.	Thermal resistance of element 1, 2, etc. (m^2K/W)
R_{si}	Internal convective thermal resistance (m^2K/W)
R_{so}	External convective thermal resistance
S	Sensor-specific sensitivity ($\mu V/ (W/m^2)$).
T_{ij}	Inside surface temperature (K)
T_{oj}	Outside surface temperature (K)
U	Voltage (V)
U_{Clim}	Transmittance limit of roofs (W/m^2K)
U_{Mlim}	Transmittance limit of facade walls and enclosures in contact with the ground (W/m^2K)
U_{Slim}	Transmittance limit of floors (W/m^2K)

Greek

Φ	Heat flux (W/m^2)
ΔT	Temperature difference (K)

CHAPTER 1. INTRODUCTION

1.1 Motivation and context

Climate change is a tremendous long-term challenge facing the world today (1). The EU energy policy introduces an energy efficiency growth target of 20% that is being performed in the legislation of the Member States in various ways (10). The most significant potential for energy savings of almost 40% lies in buildings construction (11). The European Commission published a Directive on Energy Performance of Buildings (EPBD) (2002/91/ EC) improved by Directive 2010/31/UE that came into force in 2010 (12) and by Directive UE 2018/844 (13), which aims to achieve a very low emissions building stock in the EU by 2050.

Alongside the critical impact of houses on energy consumption, also, increasing the importance of their associated environmental impacts is evident (14,15). As declared by Baetens (3), greenhouse gas pollutions brought out via houses in developed countries are responsible for around 35% of the emissions. Many efforts are forced worldwide to reduce energy consumption in houses, to stand out greenhouse gas emissions.

While new constructions need fewer than three to five litters of heating oil per square meter per year, older constructions consume about 25 litters on average (16). Some houses even require up to 60 litters. About 35% of the EU's buildings are over 50 years old (17). By improving the energy efficiency of buildings, it is possible to reduce total EU energy consumption by 6-7% and lower CO_2 emissions by about 6% (4). Recently the most outstanding measures are allocated as more consideration to renewables technologies (5,6). Although now renewable energy resources provide around 15% of whole energy demand in the world as described out of Sumathy and Hasan (18) and Panwar (19), more measures are required, for example, enhancing high-efficient, environmentally friendly and cost-effective house components.

The United Kingdom stood 559 million tons CO_2 emissions per year, with 28% belong to the energy used in houses. Scottish Government estimates a third of it approximately could be preserved by upgrading easy energy-saving methods. Nevertheless, obtaining more diminishes in carbon pollutions from Britain houses to reach the UK Government's purpose for an 80% reduction of CO_2 levels by the year 2050 is a significant challenge. It consigns Scotland to some of the most ambitious carbon reduction targets in the world including the decrease of greenhouse gas emissions 42% by 2020, and 80% by 2050, from 1990 grades (7). With almost 40% of Scotland’s total carbon emissions deriving from domestic energy consumption, and around 20% of all buildings being traditionally constructed, enhancing their energy efficiency is a key to meeting the national carbon reduction commitments (20). To decrease the energy demand of traditional and existing houses in general, active and passive energy efficiency solutions have to be implemented. The optimal solution to any single house will depend on its physical characteristics, the climate and current use, and specific preservation demands.

Scotland has 2.37 million houses, 459,000 of which are pre-1919 construction, typically considered to be poor energy performing houses unable to provide acceptable thermal comfort for occupants. In the UK, fewer than 180,000 new houses are built each year, balanced against a small percentage of houses demolished or upgraded, resulting in an impoverishing housing stock that is thermally inferior (21).

In the published literature, there is an absence of an exact definition for zero carbon homes (22). It is not clear what the term "zero" refers to: to the exergy, or the energy balance, to the energy costs or the direct CO_2 emissions. In general, the primary definition is that a zero carbon home is one with significantly decreased final energy consumption and where it is possible to provide the required energy with renewable technologies. In December 2006 the UK Government published a consultation document setting out plans to move towards zero carbon in the new housing using three main policy levers: the planning system; the Building Regulations and the Code for Sustainable Homes (23). The Code for Sustainable Homes, a voluntary set of standards for assessing new homes, whose highest level (6) requires zero carbon, was published at the same time. Until 2008 houses builders faced a zero carbon definition that effectively required all CO_2 pollution to reduce to zero through on-site means. Both regulated pollution (from heating, cooling, lighting, and ventilation) and unregulated emissions (from household appliances) had to be accounted.

In 2009 the concept of Allowable Solutions was suggested by the UK Government (24). By paying into an Allowable Solutions Fund, a lower on-site pollutions target could set for home builders, whenever preserving the zero carbon policy goal. A significant additional change, in the 2011 budget, was the removal of unregulated emissions from the definition. The Code for Sustainable Houses is the most prominent voluntary sustainability label for building in the UK. The Code is a holistic sustainability ranking tool that rates houses against indicators in nine categories. Houses can be awarded a star rating between levels 1 and 6, with six being the most sustainable. It soon recognised that the cost of the house to achieve level 6, and its impracticality on some sites, meant that delivering zero carbon through an entirely on-site strategy was not the right method for mainstream building production. Since its inception, very few homes have been built to the higher levels of the Code, and of those that have, the vast majority have been public sector housing. The statistics are suggestive of a reticence from the private house building sector to act voluntarily; a view supported by the literature (25–28). Therefore, home builders are failing to deliver zero carbon homes in preparation for the 2016 Regulations.

In line with the above, the European Directive 2010/31/EU establishes that all new buildings constructed in the EU from 2020 onwards should be nearly zero-energy buildings, promoting the thermal envelope improvement, the use of high-efficiency energy equipment and renewable technologies (12,29). This process will involve a higher acceleration of the enhancement of energy performance of the houses, as well as the existing dwelling. In this sense, energy diagnosis of traditional houses is becoming urgent and essential for energy saving. The main ways of heat transfer: conduction, convection, and radiation can be reduced through appropriate construction techniques and materials selection. The increasing attention to energy savings in the building sector has led to more and more performing walls characterised by shallow values of thermal transmittance (30). Evaluation of in-situ measurement of the thermal transmittance becomes essential in high energy performing houses (31).

One further voluntary standard which is growing in the UK is the Passivhaus standard. Established in the early 1990s in Germany (32), to date, over 30,000 buildings have been built according to this voluntary standard. The rule requires houses to be designed and constructed with stringent levels of super insulation, limited thermal bridging, air tightness, and mechanical ventilation with heat recovery (MVHR). These thermal efficiency measures typically reduce the heat demand of a building to such a level as to negate the requirement for a conventional heating system. It suggested that the Passivhaus standard could be the basis for a more robust zero carbon houses policy in the UK. A comparison of potential U–values, the level of specific heat demand and airtightness for zero carbon building with those for the Passivhaus standard is shown in Table 1.1.

Table 1.1. Comparison of fabric energy efficiency requirements: Zero carbon homes and Passivhaus.

	Zero Carbon Homes	**Passivhaus**
Specific heat demand ($kWh/m^2/year$)	≤ 39 (apartment/terraced) ≤ 46 (detached/end terrace)	≤ 15
Walls U-Values (W/m^2K)	0.18	≤ 0.15
Floors U-Values (W/m^2K)	0.18	≤ 0.15
Roofs U-Values (W/m^2K)	0.13	≤ 0.15
Windows U-Values (W/m^2K)	1.4	≤ 0.8
Airtightness (ach @ 50 Pa)	3	≤ 0.6

The UK Government already is committed to a binding target of diminishing carbon dioxide (CO_2) emissions. In 2012, the residential sector accounted for approximately 30% of final energy consumption in the UK, 84% of this energy was used for space heating and domestic hot water (16). Therefore, new housing has the potential to be a leader in meeting the CO_2 pollution reduction target.

Traditional houses account for one-quarter of the UK's existing house stock. Making appropriate and efficient refurbishments will be a positive and worthwhile contribution to reducing carbon dioxide emissions. Many older houses give a particular value and interest to the culture, they are of architectural and historical importance, and their materials and methods of construction are no longer in frequent use. Their characteristics of performance are different from those of modern houses. Their formal recognition by House Regulations and British Standards places an obligation on working with older houses to reflect and take account of these qualities. Each case must be assessed on its own merits. It is recognised as a global priority to use the existing house stock while improving its energy efficiency (33). If the objective is to achieve excellent progress in achieving sustainable development and reducing carbon dioxide emissions, it is necessary to increase the energy efficiency of all the UK's existing houses, not just the 500,000 or so that are listed as of architectural or historical interest.

Traditional house walls are not only of stone and brick, but can be of the earth (cob) or traditional timber frames (often with thin render or weatherboard cladding, or with infill between the structural timbers). Most modern houses are made of hard, durable and impervious materials; to exclude moisture, relying on physical obstacles such as damp-proof methods and membranes, cladding and cavity walls. Traditional houses are entirely different; a lot of them have solid walls, and most have porous fabric that both absorbs and lets the evaporation of moisture readily. Often it is known as the ability of the house fabric to '*breathe*', i.e., having a low vapour resistance. It is often inappropriate to repair such houses with modern materials.

U-value is a typical indicator of thermal efficiency. It can be in-situ measured or calculated by standardised procedures and software tools. U-values are generally calculated with software developed with nontraditional present-day construction in mind. The suitability of such software when used to evaluate traditional houses requires more detailed research and analysis (34). This would help professionals and assessors of energy home performance to make better known and more balanced decisions when assessing and progressing the energy efficiency of old homes. Table 1.2 provides the required U-values in some European countries, it presents the data of April 2007 (35). It shows that the required U-values in Scandinavian countries like Sweden, Norway and Denmark are lower than the rest of the EU countries.

Table 1.2. Required U-values for house components in some European countries.

Required U-value (W/m²K)*							
		Wall		**Roof**		**Floor**	
City	**Country**	**low**	**high**	**low**	**high**	**low**	**high**
Tirana	Albania	0.53	0.53	0.38	0.38	0.5	0.59
Wien	Austria	0.35	0.50	0.20	0.25	0.3	0.40
Bruxelles	Belgium	0.60	0.60	0.40	0.40	0.9	1.20
Sarajevo	Bosnia-	0.80	0.80	0.55	0.55	0.6	0.65
Sofia	Bulgaria	0.50	0.50	0.30	0.30	0.5	0.50
Geneve	Suisse	0.20	0.30	0.20	0.30	0.2	0.30
Zagrep	Croatia	0.90	0.90	0.65	0.65	0.7	0.75
Prag	Czech	0.30	0.38	0.24	0.30	0.3	0.45
München	Germany	0.30	0.30	0.20	0.20	0.4	0.40
Copenhagen	Denmark	0.20	0.40	0.15	0.25	0.1	0.30
Seville	Spain	0.82	0.82	0.45	0.45	0.8	0.82
Valencia	Spain	0.82	0.82	0.45	0.45	0.8	0.82
Barcelona	Spain	0.73	0.73	0.41	0.41	0.7	0.73
Santander	Spain	0.73	0.73	0.41	0.41	0.7	0.73
Madrid	Spain	0.66	0.66	0.38	0.38	0.6	0.66
Salamanca	Spain	0.66	0.66	0.38	0.38	0.6	0.66
Tallinn	Estonia	0.25	0.25	0.16	0.16	0.2	0.25
Helsinki	Finland	0.25	0.25	0.16	0.16	0.2	0.25
Ajaccio	France	0.40	0.40	0.25	0.25	0.3	0.36
Paris	France	0.36	0.36	0.20	0.20	0.2	0.27
Athens	Greece	0.70	0.70	0.50	0.50	1.9	1.90
Budapest	Hungary	0.45	0.45	0.25	0.25	0.5	0.50
Dublin	Ireland	0.27	0.37	0.16	0.25	0.2	0.37
Palermo	Italy	0.64	0.64	0.60	0.60	0.6	0.60

Cagliari	Italy	0.57	0.57	0.55	0.55	0.5	0.55
Firenze	Italy	0.50	0.50	0.46	0.46	0.4	0.46
Milano	Italy	0.46	0.46	0.43	0.43	0.4	0.43
Riga	Latvia	0.25	0.40	0.20	0.20	0.2	0.25
Vilnius	Lithuania	0.20	0.50	0.16	0.40	0.2	0.50
Skopje	Macedonia	0.90	0.90	0.60	0.65	0.7	0.75
Amsterdam	The	0.37	0.37	0.37	0.37	0.3	0.37
Oslo	Norway	0.18	0.22	0.13	0.18	0.1	0.18
Swinonjscie	Poland	0.30	0.50	0.30	0.30	0.6	0.60
Porto	Portugal	0.50	0.70	0.40	0.50	-	-
Constanta	Romania	0.70	0.83	0.33	0.50	0.6	0.91
Stockholm	Sweden	0.18	0.18	0.13	0.13	0.1	0.15
Bratislava	Slovakia	0.32	0.46	0.20	0.30	0.2	0.35
Koper	Slovenia	0.15	0.60	0.15	0.25	0.2	0.45
Novi Sad	Serbia and	0.90	0.90	0.65	0.65	0.7	0.75
London	United	0.25	0.35	0.13	0.20	0.2	0.25
Edinburg	United	0.25	0.35	0.13	0.20	0.2	0.25

*Required U-values are different for various kinds of the house; so just "high" and "low" values of elements (wall, roof and floor) are mentioned covering the extremes of the reported U-values.

Currently, there are several techniques to obtain in-situ U-values (36–39) Some are based on the measurement of the heat flux (40–42) while others are based on the measurement of the thickness of each fabric layer (43). Although the thermal transmittance of opaque walls can be measured by laboratory tests (44), it is also valuable to assess it in real conditions and compare the U-values measured with the U-values calculated using standard tools (45). To realistically achieve an 85% reduction in energy use in buildings by 2050, it is necessary to consider the U-value requirements, which will be in line with the optimum cost level. Such a prerequisite is an essential complement to the whole-house approach taken by the Energy Performance of Buildings Directive (46), and it will assure minimum standards for the house envelope (47). Therefore, first, it is essential to analyse the current U-values of the buildings.

The U-value can be measured according to the conventional technique described in ISO 9869 (42) as the rate of heat flow in the steady state divided by the area and the difference in temperature on each side of a wall. U-values allow regulators to set values that are neither material- nor system-specific but can be attained in different combinations. In addition, U-values are the first guides for a designer or architect in setting the thermal performance of the building envelope (48). Experience has shown that including these specifications at a later stage in the building process is difficult and costly. Therefore, U-values for building components are important factors in the design process.

The parameters that have the greatest relationship with the energy performance of the existing stock are age and dwelling size/type. Modern buildings are much more energy efficient, and smaller properties benefit from less heat loss. Apart from these typical parameters, the quality and amount of insulation and the efficiency of heating systems also influence energy performance (49). Moreover, the authors of the Saxon Study emphasise the dependence of a building's energy demands on shape, size and construction elements as well as the particular conditions of use and location (50). Next chapter deals with the correlation between the U-values of components and the age of a property and its energy efficiency.

Regards to the energy balance of the houses, the heat transmission losses in the opaque walls are one of the most important issues (51). Estimate the thermal efficiency of the opaque elements faces the difficulties of lack of appropriate data for simulating the behaviour of energy building with dynamic or static software. U-value is the most significant factor in determining the thermal efficiency of a house envelope, also subsequently, the overall energy efficiency of a house (52). Typically, the wall also constitutes the most major surface of the opaque element. As shown in Asdrubali et al., 2013a (53), the use phase, involves the higher energy consumption of a building, which strongly depends on the U-values of the thermal envelope. In addition, in the UK, houses are responsible for 48% of national energy consumption (54). An accurate evaluation of the performance of building elements, determined through the heat transmission, is necessary to estimate the annual energy consumption (55,56).

There are some challenges that face those making alterations to buildings of traditional construction. Careful planning and attention are required to ensure that any proposed works will be beneficial and effective while preserving the historical character of the building. It is essential to understand the kind of structure, the elements used and the probable effect of any proposed changes. Moreover, many modern dwelling techniques are incompatible with traditional methods and if applied can have adverse repercussions. In addition, it is essential that any alterations be seeking to enhance energy efficiency, ensure that indoor air quality is maintained or enhanced. It will contain consideration of the ability to regulate internal moisture levels and ensuring that materials do not have a deleterious influence on environmental and human health. Several parameters in the built environment develop and change over time; e.g. the use, the design and layout of settlements and, the design of structures. The care has to be taken in enhancing energy efficiency. Also, a precarious balance needs to be improved in upgrade and retrofit to a higher energy efficiency standard, while the health and well-being of the residences are maintained.

In addition, there is a lack of information on health issues and indoor air quality subject; the disadvantage of packing construction that is applied to enhance the energy saving has not evaluated appropriately. However, little studies show that renovation can have adverse results which imply decreased lighting, overheating and indoor air quality.

There is widespread recognition about which conditions inside the houses are a factor in human health, mainly in breathing related disability. People in developed countries allocate more than 85% of the time indoors the buildings, and as a consequence the influence of inside air on human physiology is significant. There are numerous samples where buildings have been associated with ill-health in individuals or sectors of a population. However, issues concerning health effects of structures and a wide range of genetic and environmental parameters are known to be involved.

A build-up of internal pollution can result from treatments, finishes, and activities within a building. Interior moisture levels are dependent on a wide range of variables including ventilation, external moisture, indoor movement and the ability of a structure to efficiently deal with changes in moisture due to the thermal performance of properties and moisture mass. Studies in the 1970s by Fanger, about air quality source of inside pollution, determined input ventilation tools as a principal source of inside pollution (57). The quality of the air of outside, as well as maintenance structures, determined input ventilation systems as the primary recognised parameters. The studies of Fanger demonstrated that the mechanical ventilation systems which displaced natural ventilation were problematical. In an investigation of 17 offices: 22% of the inside emission came from furnishing and materials, 24% from smoking and 38% from the ventilation system. The method of home design subsequently has given a path to taller spaces and a move back to conventional tools, daylight, views and well-controlled natural ventilation in houses.

Often historical constructions have natural health benefits, many of them were planned carefully with high levels of natural space, light, and other aspects conducive to well-being. The express ‘’ventilate right, built tight’’ approach to renovation as logical for energy efficiency, may nullify the benefits and compromise of environmental quality. The balance requires being stuck between decreasing carbon emissions and keeping residences healthy. Damp, cold building puts a threat to the health, also a building that concentrates pollutants and overheats. The challenge is to renovate old houses to an energy-efficient standard which promotes and maintains their health benefits. Low energy renovation could have adverse and unintended consequences which contain decreased natural lighting and inside air quality together with other hazards and overheating. Rather than renovating traditional houses to upgrade conditions that now needed in new building, a combination of natural ventilation and radiant heating create more sustainable and healthier environment; with them, the rates of air change could be higher than those specified currently; it would decrease the risk of health problems linked to poor inside air quality. Another method to enhance air quality would avoid determining products and materials which prevent the movement of humidity and emit hazardous chemicals.

Most of the literature noticed that a significant portion of the energy consumption in houses depends on the energy losses via house components as a result of the negligible thermal performance of current house components, especially the windows (8). The windows are unique elements of house component that supply passive solar gain, vision, air ventilation, day-lighting, and the option to put the house in extreme conditions. Although, they account for a considerable portion of energy consumption in houses because of their higher U-values in comparison with other elements of the house.

For a typical new house in Scotland, the U-values of the external walls, roof, floor, and windows are respectively around 0.30, 0.16, 0.25 and 2.0 W/m^{2}K as reported by Cuce (8). Moreover, in the rest of the EU countries, the U-values have been improved over the years with the maximum difference of 0.2 W/m^{2}K as shown in Table 1.3.

Table 1.3. Required U-values for windows in residential buildings of various EU countries.

Countries	Source	Typical U-values of windows (W/m^2K)		
		After 2010	2000-2010	Before 1945
Austria	OIB Guideline (58)	1.40	1.8	2.2
Germany	EnEV (59)	1.30	-	-
Hungary	National Building Energy Performance Strategy (60)	1.23	-	-
Ireland	BER (Building Energy Rating) (61)	1.51	-	-
Latvia	PAIC measurements database (Procesu Analīzes un Izpētes Centrs) (62)	1.30	1.8	3

In addition, Table 1.4 shows the required U–values for various European countries in 2005 that prove that they are different in different climates and conditions, depending on several parameters.

Table 1.4. Required U-values for a new building by Building Regulations for various European Countries, in 2005 (63).

Country	Required U-value in 2005 (W/m^2K)	Current Standard practice 2005
Spain, Germany	Volumetric: aggregate heat loss value for whole house component	Double glazing
Poland	2.6	Low-E double glazing
Finland	1.4	Triple (2+1), with Low-E and argon fill
Belgium	3.5 (2.5 in Brussels Region)	Double glazing (Low-E in Brussels region)
Austria	1.9	Low-E double glazing and argon fill.

Windows have an important role in the cooling and heating of houses, especially when the perimeter of windows is considerable. According to the Jelle (64) studies, around 65% of overall energy consumed in the houses belongs to the windows. Because of the importance of windows in decreasing requirement of cooling and heating in the houses, an important consideration at a worldwide scale is specified for enhancing their function. In 2009/10 Changeworks, a sustainable enhancement organisation led research in Edinburgh about single-glazing in traditional houses of Edinburgh. Single glazing was replaced by a kind of slim-profile double-glazing windows, and their thermal performance was measured in situ by Glasgow Caledonian University. The research concluded that this replacement enhances the thermal performance of traditional timber windows significantly (65).

Some people think that traditional houses are more energy inefficient than new houses and it is better to exchange them rather than renovate (66). Although the carbon emissions of modern houses are lower than historical dwellings, it is essential to consider the embodied carbon that refers to the CO_2 produced when destroying them; also, for wastes arrangement, as well as to produce and to transport the new building materials. To enhance the major drawback of windows, the good insulating ability and the work with window coverings which decrease heat loss are the priorities issues of the research (67–71). Nevertheless, heat loss by convection of the covering and near the edges is larger than the conductive heat loss which would decrease greatly the thermal effectiveness of windows treatment even if it has a high conductive resistance to flow the heat.

Historical single glazing window is recognized as the most straightforward choice for exchanging with double glazed. Historical windows are known to be hard to maintain and prone to condensation. Although with good preservation, historic windows outlive more than recent replacement window, also they are recognised as a sustainable resource. On the other hand, the heat lost via a single glazing window are almost double via double glazing windows that meet the Scottish Building Standards. While secondary glazing can be effective as a choice to maintain the existing historic window, there is little data on the performance of more traditional ways of decreasing heat loss, such as curtains, shutters, blinds.

Table 1.5. National House Energy Ratings (NHER) of Scottish building by age as a percentage of overall dwelling NHER band. Source: the Scottish House Condition Survey (SHCS) (72).

Age of houses	**Distribution (%)**	**NHER band**		
		Good (%)	Moderate (%)	Poor (%)
Pre-1919	17	3.9	10.6	2.4
1919-1944	13	4.9	7.5	0.5
1945-1964	25	11.2	13.0	0.7
1965-1982	25	12.1	12.6	0.5
Post 1982	20	15.2	5.1	0.0
Total	100	47.2	48.6	4.1

Table 1.5 demonstrates the portion of houses evaluated as good, moderate and poor for each house age classify as a portion of the whole number of houses regards to the 2005/2006 Scottish House Condition Survey (SHCS) report (72). As shown in Table 5, around 55% of Scottish houses do not have a good energy efficiency rating, and pre-1919 houses are the greatest portion of the poorly rated houses at 2.5% of the overall building.

Houses constructed after 1991 have some minimum comfort conditions as a consequence of standards from that period (73). Thus, energy effective rehabilitation would not obtain a high impact regarding energy performance enhancement. In contrast, during 1945-1991, the industrial revolution led to huge migration to cities as a result of the need for labourers, causing massive construction. This resulted in the rapid construction of houses which were of low quality. Nowadays, houses constructed between 1945 and 1991 are obsolete regarding energy efficiency and living conditions. Also, the majority of the buildings were built between 1945 and 1980 (74). Building Regulations have raised energy efficiency standards for new houses significantly in recent years: for current standards (from April 2006), they are 40% higher than for properties constructed in 2002 and 70% more than those built in 1990 (75). Therefore, most of the existing houses and a significant proportion of those that will still exist in 2050 are built to lower, often much lower, standards than new houses. The existing buildings account for 39% of carbon emissions from residence buildings (76), regarding both their lower energy efficiency and their numbers.

To date, the mostly of policy initiatives have been focused on a new build. It is despite the estimation that the over 70% of the houses that will be standing in 2050 already have been built (77). Therefore, there is a pressing need to enhance consistent guidance on how best to incorporate energy efficiency measures into existing buildings. Historic Scotland organisation is fully aware that older houses have a contribution to make in combating climate change and are actively engaged in determining appropriate solutions that maximise benefits. Also, there is a need to well recognise inside air quality subject in houses and to seek more information about traditional houses.

1.2 The main objective of the thesis and thematic unit

Houses consume a significant part of the overall energy in the world. Apply to renewable energy in houses and energy preservation allows going along a path in extending the fossil fuels life and cleaning the environment. This PhD Thesis aims to make a sustainable approach to houses construction an everyday activity, not the exception. Recognition of the particular characteristics of these houses and how best to reach the needs will be a substantial step towards the more sustainable management of these existing resources. With an overall aim to improve both the internal environment and energy efficiency, it is essential to take account of the specific circumstances of the house and to balance all the issues.

There are over 600 conservation zones and 46,000 listed houses of specific architectural or historical interest in Scotland. The nation as a whole recognises that due care should be given to preserving the character of traditional buildings and areas. Also, in line with national, and international targets on CO_2 reduction, it is essential that renovations of old buildings make the best use of existing and emerging practices to increase energy efficiency, guarantying the integrity of the houses or the comfort or health of occupants. Four principal targets when seeking to enhance the sustainability of the existing house stock are illustrated in Figure 1. Their achievement will help to put right sustainable practice into everyday use, make a significant contribution to the appropriate and sympathetic preservation and the beneficial use of existing houses, obtaining significant reductions in carbon dioxide emissions as well.

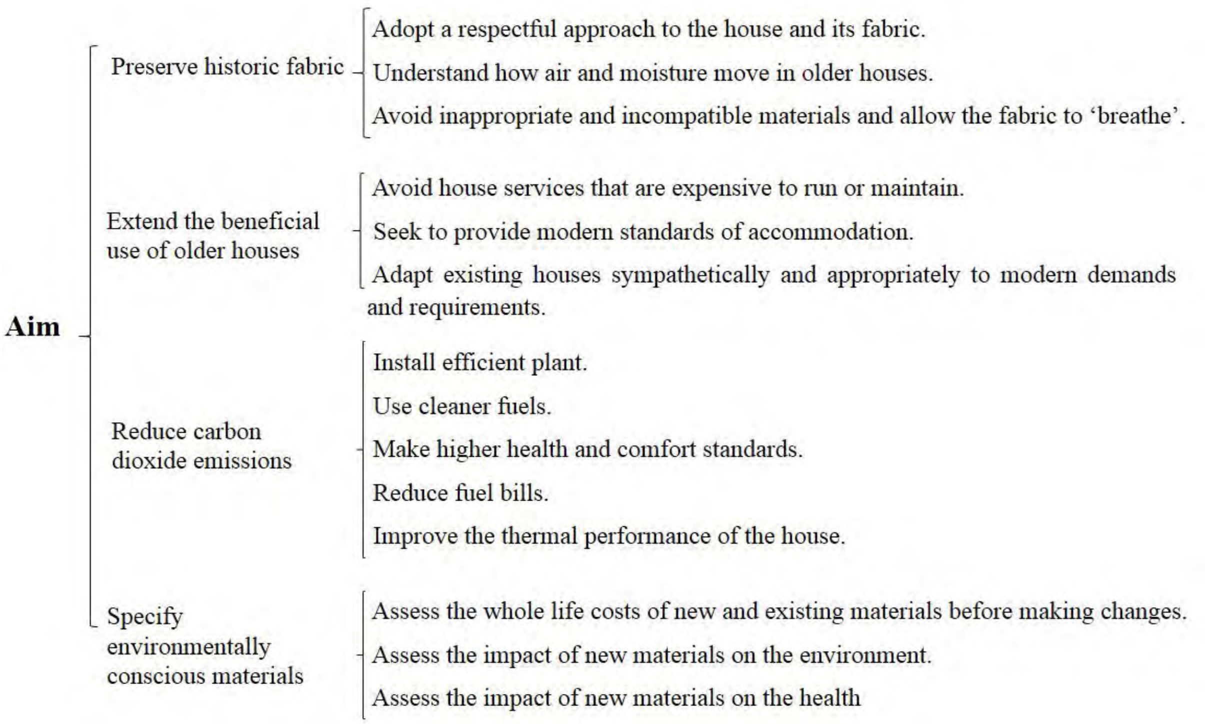


Figure 1.1. The principal objective of enhancing the sustainability of the existing house. Source: Own elaboration.

1.2.1 Aim and objectives

The aim of this PhD Thesis is to assess the parameters influence on the U-values of house components; first work on the relationship between the age of the building, the material/thickness of house components and the U-value, as a consequence the effect of insulation on the U-values on the energy efficiency and environmental impact rating is assessed. The thesis makes this analysis for traditional, existing and new houses using energy simulation software and suggesting some methods to meet energy efficient houses. In addition, for evaluating the suitability of energy simulation software in traditional houses, work on the in situ U-value measurement, and a comparative analysis of energy performance based on two different energy simulation tools is made for new houses. Moreover, the issues affecting the indoor environmental quality and users' health in the house are evaluated. Also, the thesis analyses the relative parameters related to the energy efficiency of windows as a most targeted building element to reduce heat loss. For improving the result, it analyses the parameters in twelve houses as case studies in the UK.

Objective 1. Assess the relevance between the age of the building and the U-value since this is one of the important factors of thermal performance which guides energy efficiency assessments and implementing energy efficiency measures. This is not limited to U-value measurement alone, but it will contribute to a wider study on sustainability together with the effect of insulation on envelopes, energy efficiency and environmental impact rating.

Furthermore, discussion about the relationship between the U-value and the material/thickness is included.

Objective 2. Identify the influence of different kinds of materials on the U-values and energy efficiency according to the standards and building regulation by a comparative analysis of energy performance based on two different energy simulation tools considering three kinds of construction in a typical new house located in six different cities of two countries with different kinds of weather. In addition, the appropriate materials for each group for moving toward energy efficient houses are suggested. These recommended materials can be applied to other EU countries as the lowest U-values are considered.

Objective 3. Evaluate the suitability of energy simulation software to estimate the U-values of traditional construction build-up. The relevance of this objective stems from the fact that the knowledge of energy performance of traditional houses has not yet been improved in an appropriate way. Also, there are not enough experimental data related to the traditional constructive solutions. Therefore it is essential to enhance the new energy simulation tools dedicated to traditional houses adding specific databases related to the thermophysical properties of house elements and more appropriate information referred to traditional construction techniques.

Objective 4. Appraise the issues affecting the indoor environmental quality and users' health in buildings to illustrate how it is possible to put sustainable development into practice when upgrading house services in the traditional house. There is a lack of information on health issues and indoor air quality subject. So, a holistic and interdisciplinary approach based on an appreciation and understanding of the highly individual nature of many older houses is needed.

Objective 5. Analyse some parameters (such as the kind of windows, repair or replacement options, glass quality, kind of frames, etc) related to the energy efficiency of the windows and shortly discuss future window technologies (e.g. zero energy windows, integrate surface for arranging, dynamic glazing, phase change materials, semi-transmitted solar cell and highly insulating windows such as a vacuum glazing).

1.2.2 Structure of the thesis

After the introduction presented in this chapter, the PhD Thesis has been structured as follows. In Chapter 2, the study consists of 50 houses built during1915-2015, and 50 pre-1915 properties identified as traditional construction. All the houses are used as case studies chosen from Scotland's Lothian zone, and most of them are located in Edinburgh. This led to a better and more secure result because the weather and local materials reduced the errors. It attempts to provide an assessment considering a range of parameters that may impact the energy performance and environmental behaviour of traditionally built houses by using the DesignBuilder software.

In Chapter 3, a simple 100m^2 one-floor house is considered as a case study for three different kinds of construction in six different cities of the United Kingdom and Spain with different kinds of weather. Also, two kinds of software tools are used for comparing the results. One of them is Lider-Calener (HULC) for cities in Spain; another one is DesignBuilder which is suitable for the UK. Finally, appropriate kind of construction solutions is suggested for each city.

In Chapter 4, a study of twelve properties located in Scotland, which were visited for making some experimental U-value measurements, is undertaken. They are houses with different kinds of materials, all of them constructed pre-1919 with traditional construction techniques. Eight of them are located in Edinburgh, one in Dalkeith, one in Lauder, one in Bonnyrigg and one in Duns. The primary focus of the studies is on walls constructed with a range of materials and techniques; thirteen walls are measured, and just two walls are insulated. The measurement is conducted during a 90 hour period. All the U-value measurements are based on the heat flux method, which uses data of a heat flux sensor and two temperature sensors.

In Chapter 5, first, some subject regards to the healthy building, such as the contaminations materials, thermal mass, ventilation, orientation, lighting and heating are discussed and then these subjects are assessed in a total of twelve Scottish houses used as case studies. All the case studies are similar to chapter 4. They are analysed and several improvement recommendations for improving indoor air quality, reducing the movement of moisture, etc. are suggested.

In Chapter 6, first work on the windows energy efficiency and its relationship with the windows U-values; also, some subjects about thermal optimisation of windows and the new windows solutions are discussed. Then by using the Lawrence Berkeley National Laboratory software, all parameters that have an influence on the windows energy efficiency are analysed. Moreover, the structure of the windows and the influence of each parameter on the whole U-values of the windows are studied. Finally, the windows defined in chapters 4 and 5 are chosen and modelled by the software to obtain the U-values and SHGC analysing all the conditions and alternatives of the windows in order to suggest the appropriate method for improving the windows in the houses (repairing or replacement).

CHAPTER 2. CALCULATION AND COMPARATIVE ANALYSIS OF THERMAL TRANSMITTANCE (U-VALUE) OF SCOTTISH HOUSES FROM RECENT CENTURIES

This chapter is conducted on the steady-state heat loss of dwellings, as quantified by U-value assessment, to provide an appraisal with a range of factors that may impact energy performance and environmental behaviour. The study consisted of 50 houses built between 1915 and 2015 and 50 houses previous to1915 identified as traditional construction. All were Scottish homes, and some were in poor condition. First, the methodology followed, focused on the data sources and the building stock selection, is presented. Then, the results of the study and the relationships between U-value, age, wall thickness, materials types, insulation layers, energy efficiency and environmental impact rating are shown and discussed. Finally, the most relevant conclusions of the study are drawn.

2.1 Methodology

Traditional buildings are considered to be those built before 1919 (in this PhD thesis, the study period for existing houses is 100 years from 1915 to 2015), employing load-bearing mass masonry walls, with pitched roofs of slate or other natural roofing materials. Windows are single-glazed with timber frames, often in the sliding sash and case shape, and the houses have internal timber and lime plaster finishes and passive ventilation systems (20). With the government’s commitment to increase housing supply, around two-thirds of houses standing in 2050 are likely to have been built before 2005, and new buildings represent only approximately 1% of the total stock each year (78).

First, it is essential to develop a method for assessing U-values in both historical and modern houses. This comprises a comprehensive analysis and diagnosis of the houses, their history, and cultural heritage as well as the material, thickness, all characteristics of elements, energy efficiency, heat demand and so forth. The chapter focuses on fabric heat loss through the U-value measurement of the wall, two kinds of roofs, floor, and the internal wall. Two periods have been selected: traditional houses from pre-1915 and newer houses from 1915-2015. Also, six construction date ranges have been selected: pre-1815 (more than 200 years of age), 1815-1865 (age of 150-200 years), 1865-1915 (age of 100-150 years), 1915-1945 (age of 70-100 years), 1945-1985 (post-war houses with the age of 30-70 years), 1985-2015 (age of 2-30 years which include newer and lightweight structures with insulation). These ages were derived from householder knowledge plus at least one other source such as house style; an age plate or plaque indicating dwelling/development year of manufacturing; the age of electricity meter and glazing age stamp (79).

Broadly, U-values are being calculated with readily available software programs developed with current non-traditional construction in mind rather than measured in-situ. Such calculations are typically carried out to show compliance with building standard requirements. DesignBuilder (80) was the selected software for the U-value comparison calculations (81). The calculations are based on the standards set out in the document BR 443 Conventions for U-value calculations (82) which underpin house regulation energy conservation legislation and are also the basis of different energy assessment methods. Figure 2.1 summarises the procedure followed for the information compilation and the working process with the DesignBuilder tool.

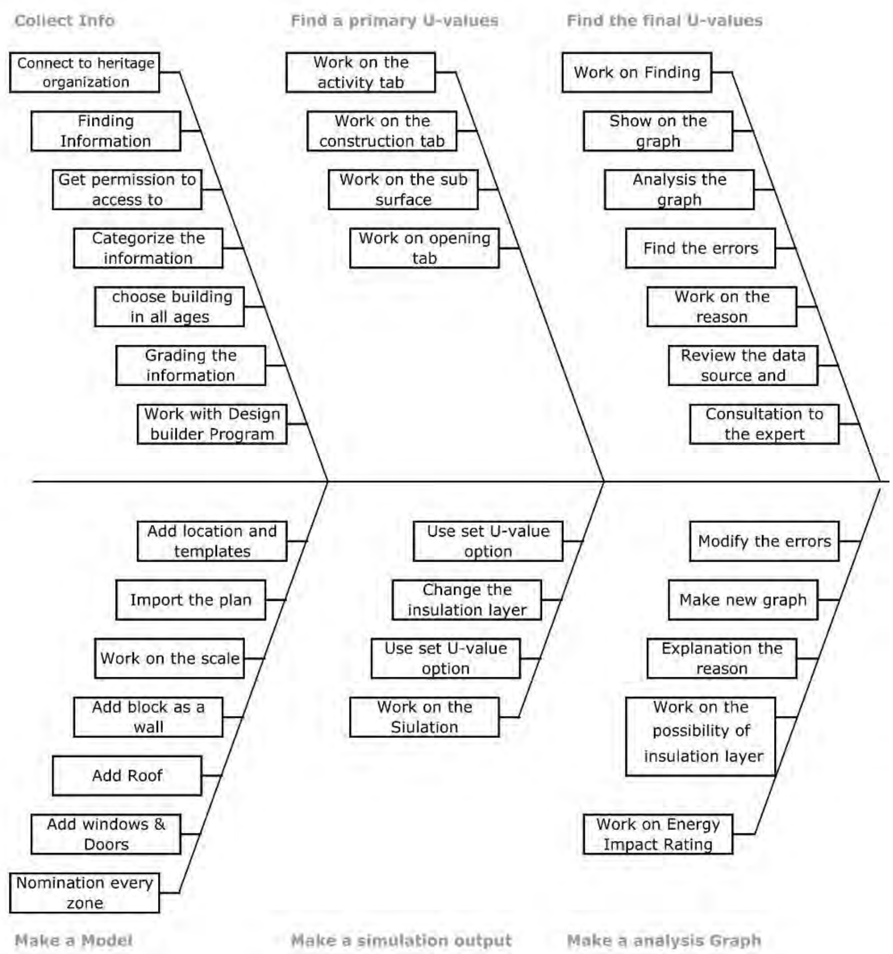


Figure 2.1. The process of modelling by software.

2.1.1 Data sources

Figures 2.2 and 2.3 illustrate the number of houses studied in different age ranges, all of which have been chosen from Scotland, Lothian zone. Half are existing homes built during 1915-2015, with 13 of these are modern houses under ten years old and 17 with insulation materials and 10-30 years old. The remaining half are traditional houses built more than 100 years ago, with 37 aged 100 to 200 years old, 12 aged 200 and 305 years, and one house 475 years old.

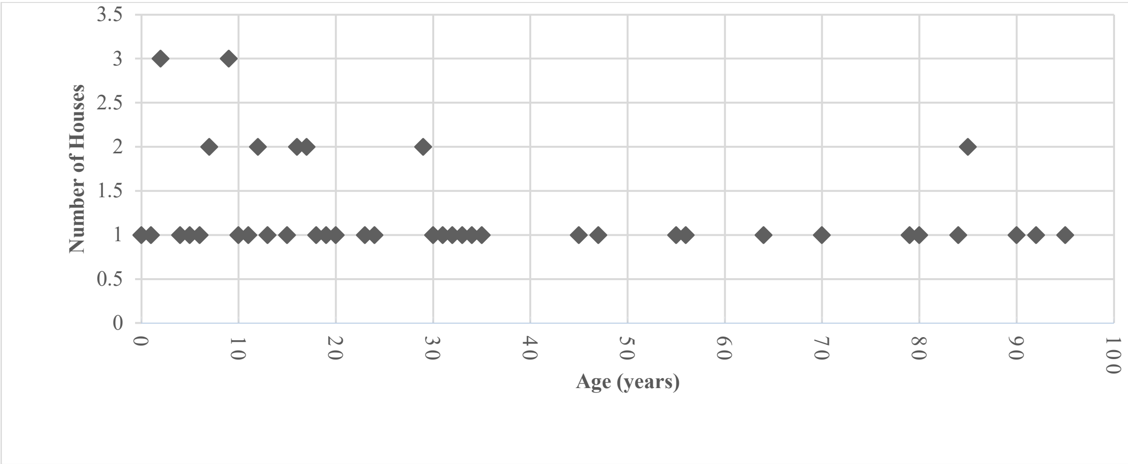


Figure 2.2. The number of existing houses studied in different age ranges.

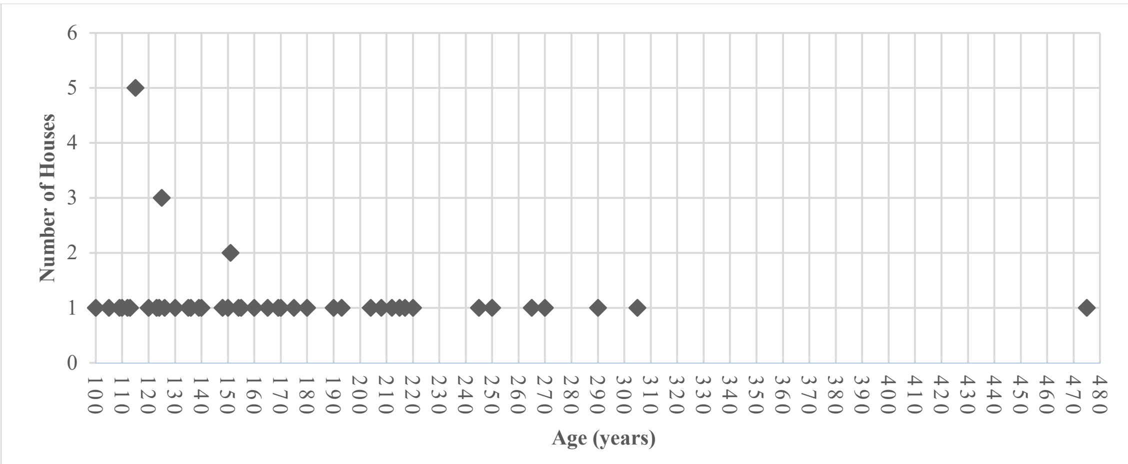


Figure 2.3. The number of traditional houses studied in the different age ranges.

As shown in Table 2.1, 98% of the dwellings have pitched roofs known for a long lifespan and were designed to maximise usable space in a house's loft area. These dwellings will benefit from added insulation, and will not experience the extreme temperatures associated with a flat roof installation. However, pitched roof also comes with a high price tag; the intricate design and significant labour and material costs mean that they are far more expensive than a flat roof. Moreover, installing a pitched roof may result in issues with the depths of the footings of the home as it places a greater burden on the house's foundations, and so it may not be possible to restore old flat roofs with pitched roofs.

Fifty-three per cent of the buildings have both pitched, and flat roofs and two houses had only a flat roof. Flat roofing is both economical and efficient, and its replacement can take just a day.

Table 2.1. Characteristics of the buildings analysed in different age ranges.

Year	Age	Number of houses			Condition
		With the just Pitched roof	With just Flat roof	With both Pitched and Flat roof	
1540-1814	201-475	4	0	9	Traditional*
1815-1865	150-200	5	0	8	Traditional
1866-1895	120-149	8	0	5	Traditional
1896-1915	100-119	4	0	7	Traditional
1916-1935	80-99	5	0	2	Existing**
1936-1985	30-79	2	1	10	Existing
1986-2005	10-29	10	0	7	Existing
2006-2015	0-9	7	1	5	Modern***

* Traditional houses refer to buildings built more than 100 years ago without any insulation and having a historical architectural style. Most of them are valuable but in poor condition and may need refurbishment.

** Existing houses refer to buildings between 30 and 99 years old. There are two kinds of existing houses. The first are 10-30 years old and are in better condition than older ones as they have insulation and are built according to the regulations and standards from their period. The second is 31-99 years old and were built during the World Wars without insulation making them poorly energy efficient. In addition, they are less valuable than traditional houses and need more refurbishment.

*** Modern houses are new buildings, built with new methods in the last ten years according to the new regulations and standards. Energy efficiency and CO_2 emissions were important factors in the construction of these houses.

Data were collected on a wide variety of parameters. Data sources on building stock including information on whether properties were habitable or not, the age of buildings, type of buildings, construction type, heritage protection and architectural type.

2.1.1.1 Building stock

The details of data sources are shown in Table 2.2.

Table 2.2. The details of building components sources.

Data Source	Summary of data provided
Listed building data (83)	Identification of listed buildings.
Conservation area data	Conservation area boundaries.
Home Energy Efficiency Database (HEED) (84)	Supplying a unique record of energy efficient installations that have been implemented in houses. Data have been collected from a variety of sources.
Home analytics (86)	Property characteristics and the capability for energy efficiency measures. Based on probabilities, accuracy at small scale is limited (85).
House condition surveys (87)	Overview of housing in each nation includes age, type, energy efficiency measures. The data were taken from a small sample so is limited in accuracy.
UK housing review 2012 (88)	Housing stock and finances.
National statistics websites statistics (89)	A variety of statistics including some on housing and fuel poverty.
The building at risk registers (90)	Historic buildings deemed to be in a state of disrepair.
Registry sources (91)	Data on ownership and selling of properties.
TABULA (92)	EU project has created a data structure, which can class buildings into typologies. It provides information on residential properties such as size, age, energy consumption and potential impact on energy saving improvement. In addition, it takes into account national climatic data.
Google street view	Photographic images of properties, allowing the identification of specific features such as building height and construction.

The other data sources were DECADE (Domestic Equipment and Carbon Dioxide Emissions) (93), Digest of UK Energy Statistics (DUKES) (94), EPC Register (Energy Performance Certificate) (95), Housing Energy Fact File (21), MLSOAs (Middle Layer Super Output Areas), IGZ (Intermediate Geography Zone) , and LLSOA (Lower Layer Super Output Area) (96,97), Scotland’s 2011 Census (data on the type of house, house size and central heating systems, but not energy efficiency of buildings) (98), Historic Scotland Data Services (99) (provides an online database of listed buildings which can be downloaded as a GIS dataset (100)).

2.1.1.2 Pre-1945 properties

For pre-1945 housing, Household Condition Surveys (87) may be useful. The main limitation faced is to determine which homes are likely to be in the correct age range (101,102). There are a few ways to infer where clusters of older properties exist. For example, where central heating is absent; where there are listed buildings in the area or the presence of a conservation area; where individual housing types (e.g., terraced houses) are prevalent and using the pre-1945 maps available at the National Library of Scotland. Also, information can be gathered from data sources for energy efficiency such as Home Analytics and HEED (Home Energy Efficiency Database). However, none of these indicators is going to be completely reliable, and any data would probably indicate where to investigate initially.

2.1.2. Collection of information

Information collected during searching was classified into two categories: Category A, research and guidance, relevant to existing building, and Category B, the performance and characteristics of traditional houses without additional energy-saving refurbishment measures. In total, around 600 documents were sourced for traditional houses with 80% concerned with retrofitted houses, and only 20% pertained to the nature of traditional houses. The performance housing stock and whole building performance comprised the largest proportion of references with 20% concerned with the production of construction elements. Twenty-four per cent of the latter involved the evaluation of existing house stocks, while 76% focused on the appraisal of elements for the energy efficiency of the traditional building. The second largest proportion of all research references, 14%, was also concerned with performance assessments but focused on an individual house or building performance (103).

Walls studies constituted a high proportion of references, 14%. There was a lack of investigation into traditional roofs and unventilated construction. Only 3% of references considered floors. Timber windows in traditional houses were well considered by both guidance literature and research (6% of references). Thermal bridging is an important consideration for heat loss (leading to increased energy use) and potential health and fabric risks. There is a growing understanding of this matter for new construction in policy, practice, and regulation, although research often shows a gap between the designed and as-built work in the energy savings (103). In many situations, the data commonly used by specifiers and contractors do not come directly from investigation or even from formal guidance, but from building regulations, certifications, trade literature, and other industrial documents.

Information was sourced via internet searches, and by contacting those involved in the retrofit industry (including membership organisations participating in construction), representative bodies of installers and fabrication of products used in retrofitting, and United Kingdom Accreditation Service- (UKAS) authorised organisations. Also included was a significant UK study by the Energy Saving Trust, which included internal/external temperatures, gas/electricity use, airtightness testing, wall U-value measurements, Standard Assessment Procedure (SAP) assessments, internal/external thermography, internal humidity, and measurements of wall surface temperature (104).

2.2 Results

Figures 2.4 to 2.8 present the U-values of the main elements of the thermal envelope in the analysed buildings. They illustrate a direct correlation between the age of the houses and thermal performance, but also that the U-values of the walls and roofs of the houses built after 1985 increased with a higher slope. It has been determined that the older the building, the less the growth/change on U-values. In addition, this demonstrates the effect of recent national regulations on zero carbon houses and insulation requirements.

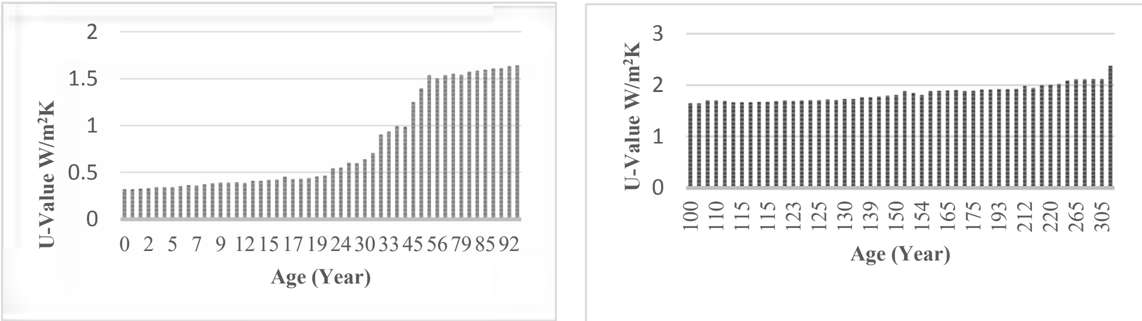


Figure 2.4. The U-values of existing houses' main walls (left) and the U-values of traditional houses' main walls (right).

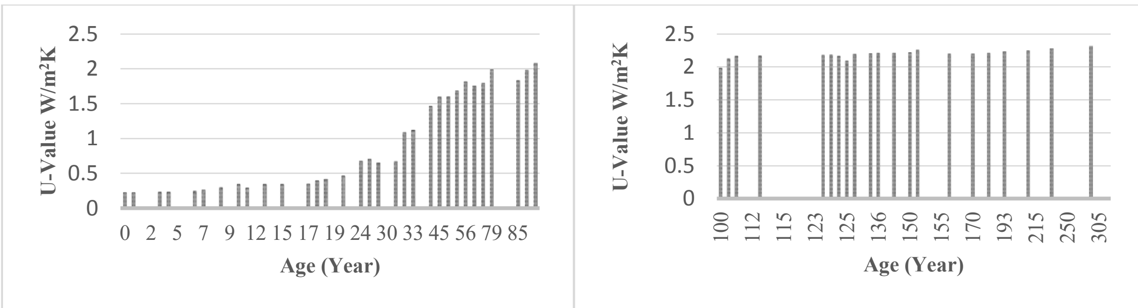


Figure 2.5. The U-values of existing houses' flat roofs (left) and the U-values of traditional houses' flat roofs (right).

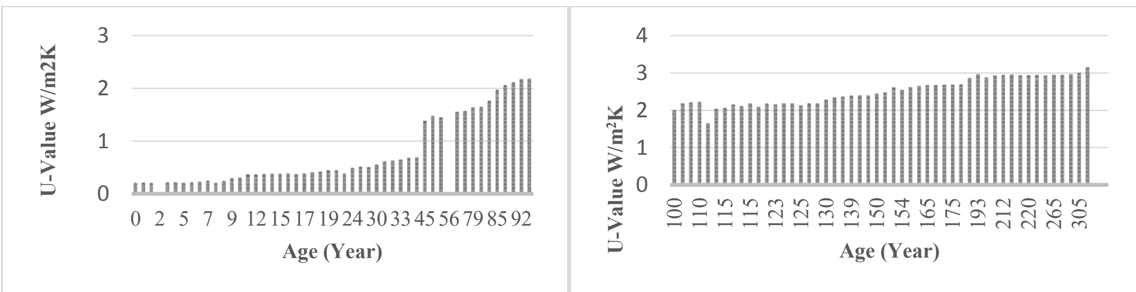


Figure 2.6. The U-values of existing houses' pitched roofs (left) and the U-values of traditional houses' pitched roofs (right).

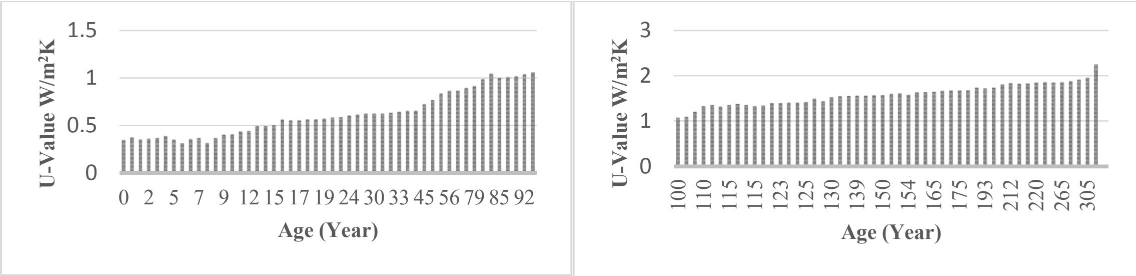


Figure 2.7. The U-values of existing houses' floors (left) and the U-values of traditional houses' floors (right).

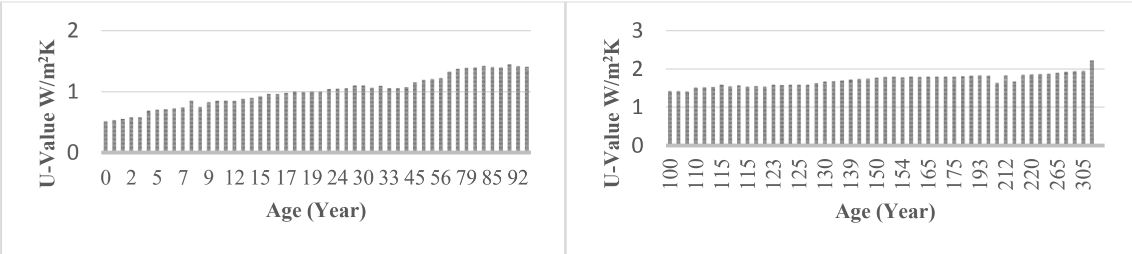


Figure 2.8. The U-values of existing houses' internal walls (left) and the U-values of traditional houses' internal walls (right).

2.2.1 U-value and age

Tables 2.3 and 2.4 show that there is a direct relationship between the age of homes and U-values and that the U-values from band G (1986-2005) changed markedly compared to the older houses where there is less change of U-values. This demonstrates the effect of national regulations with regard to zero carbon houses and the corresponding higher insulation requirements.

Table 2.3. Average U-values (in W/m^{2}K).

Year	**Band**	**Walls**	**Flat Roofs**	**Pitched Roofs**	**Floors**	**Internal Walls**
1540-1814	A	2.05 ± 0.1	2.27 ± 0.03	2.96 ± 0.09	1.87 ± 0.05	1.86 ± 0.07
1815-1865	B	1.87 ± 0.06	2.24 ± 0.04	2.65 ± 0.20	1.64 ± 0.08	1.80 ± 0.02
1866-1895	C	1.73 ± 0.04	2.18 ± 0.02	2.26 ± 0.10	1.48 ± 0.07	1.63 ± 0.10
1896-1915	D	1.67 ± 0.02	2.11 ± 0.09	2.13 ± 0.08	1.29 ± 0.09	1.50 ± 0.08
1916-1935	E	1.60 ± 0.03	1.93 ± 0.10	1.99 ± 0.17	1.00 ± 0.04	1.40 ± 0.01
1936-1985	F	1.19 ± 0.45	1.29 ± 0.50	1.17 ± 0.45	0.74 ± 0.15	1.175 ± 0.17
1986-2005	G	0.46 ± 0.10	0.40 ± 0.19	0.39 ± 0.10	0.53 ± 0.10	0.90 ± 0.13
2006-2015	H	0.35 ± 0.03	0.24 ± 0.018	0.23 ± 0.04	0.35 ± 0.03	0.66 ± 0.15

Table 2.4. Minimum and Maximum U-values (in W/m^{2}K).

Year	Walls		Flat roofs		Pitched roofs		Floors		Internal walls	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1540-1814	1.913	2.375	2.236	2.319	2.877	3.153	1.735	2.238	1.816	2.216
1815-1865	1.803	1.918	2.2	2.359	2.441	2.962	1.571	1.733	1.765	1.82
1866-1895	1.694	1.79	2.094	2.21	2.126	2.402	1.391	1.561	1.533	1.737
1896-1915	1.641	1.673	1.985	2.173	2.002	2.223	1.071	1.377	1.402	1.579
1916-1935	1.573	1.644	1.797	2.082	1.652	2.184	0.983	1.054	1.393	1.403
1936-1985	0.64	1.54	0.708	1.756	0.551	1.636	0.621	0.907	1.096	1.388
1986-2005	0.391	0.601	0.304	0.68	0.314	0.507	0.406	0.622	0.848	1.099
2006-2015	0.319	0.392	0.232	0.266	0.208	0.301	0.345	0.401	0.51	0.826

2.2.2 U-value and wall thickness

Table 2.5 presents the thickness of housing walls according to age. This shows that the assertion of a direct correlation between U-values and thickness is not a certainty. In general, a trend of U-values reducing with wall thickness has been observed. However, it is possible to divide the data into groups; for example, the walls of 80-year-old houses are thicker than those of 30 years, but it is not seen that 30 years old houses have thinner walls than 40 or 50 years old houses.

The most important finding regarding thickness is that in newer buildings, the U-values increase with wall thickness, but in traditional houses the U-values decrease with wall thickness. Also, for the newer buildings with timber frame construction, the insulation layer has more effect on U-value than the thickness; and for traditional houses, this shows that the kind of materials has more influence on thermal performance than wall thickness. Furthermore, the thermal performance of non-traditional timber walls in modern homes is better than brick/block cavity walls, and these both act better than traditional sandstone walls. In the traditional houses, inversely, the thermal performance of traditional sandstone walls is better than brick/block walls, as there is no insulation layer in these kinds of buildings.

Commonly, in homogenous walls built of heavyweight materials, e.g., stone/brick/cob, U-values seem to decline as the wall thickness decreases. The U-values for brick walls show the relationship between increased wall thickness and declining U-values. In general, materials that are less dense incorporate more trapped air and therefore have an insulating effect. Hence, the relationship between increased wall thickness and decreased U-values, found amongst heavyweight walls, is not replicated with the lightweight walls (81).

The variations in the thicknesses of the air gaps and insulation layer found for newer walls, and crucially the air present within them, have a significant influence on the thermal conductivity of the wall as a whole. While thickness is an important factor for U-value and thermal performance, there are other matters such as the kind of material that affect U-value more.

Both conductivity and resistivity are independent of the size and thickness of the house elements. However, the heat flow across the element (wall or roof) depends not only on the thermal conductivity of the material but also on its thickness. The greater the thickness, the lower the rate of heat flow. Overall, the concept of the thermal inertia of a wall or the building structure is closely related to its weight, i.e., the combination of density and thickness of the material as pointed out by Givoni (1976)(105) although this effect has not been assessed in this chapter because it is focused on the U-values.

Table 2.5. The thickness of walls with regard to age.

Age	Approximate thickness (cm)
0-9	22
10-29	22 ± 5
30-79	30 ± 5
80-99	30 ± 7
100-119	40 ± 5
120-149	45 ± 5
150-200	45 ± 15
201-475	60 ± 30

2.2.3 U-value and materials

Table 2.6 demonstrates that in newer buildings, the thermal performance of non-traditional timber walls is better than that in brick/block cavity walls, and these two act better than traditional sandstone walls. This is because most newer buildings 0-30 years old were built with non-traditional timber construction and insulation layers and therefore have lower U-values.

Table 2.6. U-Values of walls (in W/m^2K) with regard to materials.

Age	Year	Traditional sandstone walls	Brick/block cavity walls	Non-traditional timber walls	Non-traditional concrete walls	Non-traditional metal-frame walls
Between 0-100	1914-2015	1.12	0.887	0.42	0.377*	0.45*
More than 100	1540-1915	1.413	1.856			

*These are from less than three elements, and so, it is not possible to get an accurate result.

In a traditional building, the thermal performance of traditional sandstone walls is better than that in brick/block walls, as there is no insulation layer in these kinds of buildings; for these buildings, thickness and material are relevant. To clarify this factor, the age of the buildings is divided into several ranges, as in Table 2.7.

Table 2.7. U-values (in W/m^2K) according to the materials.

Age	Year	Traditional sandstone walls	Brick/block cavity walls	Non-traditional timber walls	Non-traditional concrete walls	Non-traditional metal-frame walls
0-29	1986-2015		0.43	0.4	0.377*	0.375*
30-79	1936-1985	1.3	1.175	0.706*		
80-119	1896-1935	1.63	1.65			
120-200	1815-1895	1.7	1.855			
201-475	1540-1814	2.07	2.011			

* These are from less than three elements, and so, it is not possible to get an accurate result.

In the houses from 1986 to 2015, known as lightweight constructions with insulation layers, the thermal performance of non-traditional timber walls is better than that in brick/block cavity walls, but the difference is minimal. For other types of walls, it is difficult to discriminate differences because they are fewer. For the houses from 1936 to 1985, the thermal performance of brick/block cavity walls is better than that in solid stone walls. For the houses from 1815 to 1895, the thermal performance of solid stone walls is better than that of brick/block cavity walls. These illustrate the effects of the type of material and the thickness. For the houses with ages of 80-119 years and 201-475 years, the U-values of two types of constructions are almost the same, but in both cases, the thermal performance of solid stone walls is a little better.

The proportions of stone, mortar, and voids are unknown to the houses in this study. A sandstone test wall in Baker (2007) had a ratio of 60/40 stone to mortar, and would most likely represent the correct proportions of these walls (106). A 60/40 stone to mortar split results in a U-value of 1.7 W/m^2K while adding 30mm plaster decreases it to 1.6 W/m^2K. The addition of a slightly ventilated air layer behind a lath and plaster lining to a 60/40 stone/mortar wall will change the calculated U-value to 1.2 W/m^2K.

Traditional houses present particular difficulties because while it may be possible to determine the overall width of a wall, its exact build-up can be difficult to determine. For example, traditional walls can be composites of materials in varying proportions to create a homogeneous whole, e.g., clay and straw to create a cob wall. In other instances, the materials and their quantity remain unknown, such as with the proportion of mortar, voids, and stone tangled in the core of a rock wall.

Old houses are often referred to as being of 'breathable' construction, meaning that the materials of their construction have the ability to absorb and release moisture. Most of the walls studied had an interior finish of gypsum plaster and lime. Specific wall types consisted of masonry walls of granite, limestone, slate, grit stone, flint, and milestone (both as ashlar block and rubble constructions). In addition, there are unfired soil-based materials such as cob walls (chalk and earth) or as part of infilling material for a timber-frame as straw/clay and wattle and daub (81).

2.2.4 Applying insulation materials to traditional building

Improvement of the building fabric of traditional buildings is an option to decarbonise their energy usage. Selecting the appropriate location, materials and their application as insulation in older houses will depend on several factors, including building condition, the resistivity of materials, repair constraints or historical significance, the available budget, and the level of disruption to the occupant. The required U-values to meet Level 6 of the code for sustainable homes (Level 6 is the level to achieve zero carbon homes) are 0.15 W/m^2K for walls and 0.1 W/m^2K for roofs and floors (107). In this study, the material considered for the insulation is Extruded Polystyrene (XPS)-CO_2 Blowing insulation with a thermal conductivity of 0.025 W/mK. The minimum, maximum and average quantity of the required insulation layer to reach Level 6 is shown in Tables 2.8 and 2.9.

The quantities of insulation required for buildings older than 70 years (built before 1936) were generally similar, with a difference in thickness of about 3 centimetres. However, it is seen that most of the walls need more than 20 centimetres of insulation and other elements more than 30 centimetres. It is considered too difficult to justify such insulation (108), and that it is impossible to meet Level 6 for sustainable homes just by renovating them with an insulation layer. It is necessary to use other new sustainable technologies to reach Level 6 with current houses' conditions.

Table 2.8. Minimum and maximum quantity of the required insulation layer (in cm) with regard to building age.

Age	**Walls**		**Flat roofs**		**Pitched roofs**		**Floors**	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1540-1814	21	23.5	32.4	32.5	33	33.3	32	32.4
1815-1865	21	21.33	32	32.5	33	33.2	31.8	32
1866-1895	19.9	21	31	32.4	32.7	33.2	31	31.8
1896-1915	18.9	19.8	32	32	32.8	33	30	32
1916-1935	18.5	19	32	33.3	32	33	30	31
1936-1985	18	19	28	32	32	33	28	32
1986-2005	14	19	23	28	26	32	26	28
2006-2015	11	14	19	21	18	26	23	25

Table 2.9. The average quantity of the required insulation layer (in cm) according to age.

Age	Walls	Flat roofs	Pitched roofs	Floors
1540-1814	22.15	32.445	33.07	32.12
1815-1865	21.12	32.37	33.09	31.09
1866-1895	20.3	33.12	32.95	31.6
1896-1915	19.19	32	32.67	31.09
1916-1935	18.52	32	32.14	30.14
1936-1985	18.38	30.45	32.35	29.46
1986-2005	15.2	24.2	29.47	26.8
2006-2015	12.45	20.1	22	25

In addition, many properties have solid walls and no loft or are high-rise and mid-floor flats with little chance for refurbishment other than with the cheapest and simplest insulation measures. These would need more expensive and difficult measures such as changing old and non-gas heating systems, insulating solid walls, installing micro-generation systems or installing double glazing (109). Overall, it is considered difficult or impossible to achieve Level 6 (23) just by adding an insulation layer to the elements of such houses, unless accompanied by other technologies.

2.2.5 Energy efficiency rating and environmental impact rating

Tables 2.10 and 2.11 present aggregated statistical information based on the Energy Performance Certificates (EPCs) of the analysed houses. These certificates include current energy consumption and CO_2 emissions of these houses and propose energy efficiency measures assessing the economic costs and the typical savings over three years. EPCs are considered to be an adequate tool to analyse the current energy efficiency of the houses as well as their improvement potential.

Table 2.10 shows that the maximum potential growth in energy efficiency occurs for the houses built between 1540 and 1814 then, those built between 1815 and 1915, and as a whole, all homes more than 100 years old. The same factors occur for the environmental impact rating. The costs of energy for heating, hot water, lighting, and ventilation have been increasing over the years, but the energy costs of D band houses are higher than their older homes, and that of B band is lower than expected. If typical saving costs (e.g., adopting sustainable technology for existing houses, or adding insulation layers/ low energy lighting/condensing boilers and so forth for traditional buildings) are considered, it is found that the best regular saving is related to D band homes. Therefore, the priority for renovation is dwellings with ages between 80 to 99 years. According to energy cost and typical savings cost, the houses of bands C and A, and then B, take precedence over others. For the renovation of newer houses, the buildings in bands E and F have priority.

Table 2.10. Average maximum growth in energy efficiency, environmental impact and investment cost*.

Year	Band	Number of houses	Average of maximum growth in energy efficiency	Average of maximum growth in environmental impact	Average of current energy cost (£) for three years	Average of typical saving cost over a three-year period (£)	Average investment the cost to obtain typical saving cost (£)
1540-1814	A	13	28.1 ± 13	27 ± 12	11,300	4,300	25,000
1815-1865	B	13	24.8 ± 12	25.7 ± 12	8,260	3,635	23,000
1866-1895	C	13	24.75 ± 11	23.25 ± 10	11,000	5,036	21,000
1896-1915	D	11	25 ± 8	26.1 ± 9	12,500	5,571	22,800
1916-1935	E	7	20.5 ± 10	17.8 ± 8	7,500	2,192	17,700
1936-1985	F	13	15.8 ± 7	17 ± 8	7,000	2,010	12,700
1986-2005	G	17	12.6 ± 6	13 ± 6	7,700	1,109	14,600
2006-2015	H	13	7.8 ± 3	6.5 ± 3	5,500	380	13,600

Table 2.11. Recommendations on the percentage of renewable energy systems and average investment*.

Year	Band	Number of houses	Recommendations the percentage of renewable energy systems			Average investment for renewable energy systems (£)	Average investment for other actions (£)
			Solar photovoltaic panels, 2.5 kWp (%)	Solar water heating (%)	Wind turbine (%)		
1540-1814	A	13	85	46	15	10,100	14,900
1815-1865	B	13	77	31	7.7	8,100	14,900
1866-1895	C	13	62	8	7.7	6,000	15,000
1896-1915	D	11	72	27	18	9,800	13,000
1916-1935	E	7	100	43	14	11,500	6,200
1936-1985	F	13	85	46	7.7	9,400	3,300
1986-2005	G	17	100	53	17	12,700	1,900
2006-2015	H	13	92	62	15	12,100	1,500

* Assessors accredited by Elmhurst have offered all the data regarding just these two tables, an Approved Organization Appointed by Scottish Ministers. The information has been produced under the Energy Performance of Buildings (Scotland) Regulations 2008 from data lodged to the Scottish EPC register (110).

By combining the above result (priority for improvement belongs to traditional buildings with the age of more than 100 years) with the result for the quantity of insulation required (which shows that the houses with the age of more than 100 years need around 20 centimetres for walls and 30 centimetres for other elements), it is concluded that the use of renewable energy systems and sustainable technologies is necessary for old houses.

Table 2.11 illustrates that in order to enhance the energy and environmental performance of the houses, renewable energy systems are recommended for older houses less than those for newer houses, except for buildings with the age of more than 200 years. However, the differences are small. Solar photovoltaic panels are suggested more than other renewable energy systems. The reason is that the typical yearly saving costs of solar photovoltaic panels are almost twice as much as those of solar water heating systems, and they have more influence on the energy and environment rating. In addition, the indicative cost of solar photovoltaic panels is lower than that of a wind turbine for these houses.

It can be concluded from the economic data in Tables 2.10 and 2.11 that for newer houses most of the investment is in the installation of renewable energy systems, while for traditional houses it is for other solutions, such as internal or external thermal insulation, upgrade to heating controls and replacement of boilers. Lastly, it is noted from Table 2.10 that in using new sustainable technologies for traditional houses to meet Level 6 of the code for sustainable homes, this will require almost twice as much investment as other houses.

2.3 Discussion

U-value calculations are the basis for house energy assessment and house energy legislation and policy. Working with DesignBuilder program illustrated that the current models used to assess the energy performance of house elements, and the whole building stocks are particularly problematic when applied to traditional houses. Rye (2010, 2011a) and Baker (2011) both provide evidence for the shortcomings of heat loss models for traditionally built walls leading to misunderstanding of the thermal performance of these elements (and thus contributing to the degree of error embedded in whole house energy models) (34,81,106).

Traditional houses are very diverse (a function of their age and the highly localised house form and materials used in construction). However, they are commonly treated as a single generic type pre-1915 within stock databases. Consequently, there is a lack of typological analysis and distinction of traditional houses in economic modelling and a lack of base-case working data for a traditional structure with which to calibrate and appraise energy assessment models (103). There are numerous other reasons for the modelling gap including a lack of accurate base case data about, and understanding of, the construction forms of traditional houses and their materials. In general, grouping all houses built before 1915 under a single set of performance assumptions is not appropriate for what is a diverse range of dwellings.

To achieve energy efficient rehabilitation of housings, massive dissemination and awareness, as well as social management, are needed. During the renovation process, buildings constructed between 1866 and 1915 should be boosted due to their huge stock, explicability potential, need for restoration and lack of energy efficiency measures. It is also evident that both modelling and monitoring in traditional houses still require further enhancement to use as standardised tools for appraisement. In addition, in specific zones, operator errors can be remarkable, and this portends a need for precaution in using outputs from both modelling and proctoring, and the requirement for stricter protocols, training, and oversight.

To obtain a Near Zero Energy Building renovation, renewable technologies must be implemented. The selected solution will depend on the house characteristics and the climatic zone. Also, it is challenging to meet level 6 of the code for sustainable homes just by renovating houses with insulation layers; preferably, it is necessary to use new sustainable technologies. In addition, traditional houses require more investment, almost twice as much as newer homes. Nevertheless, there are still barriers including information and upfront costs which many of the developing policies are designed to address. In the longer term, it is essential to look at new, emerging technologies and a more extensive range of measures to meet the requirements of the 2050 timetable.

2.4 Conclusions

The motivation of the present chapter was to analyse the main factors that affect the energy performance of traditional and modern Scottish houses. To this end, a methodology was developed with which to collect the information needed to assess and analyse the U-values of a sample of 50 Scottish houses. The results showed that there is a strong relationship between the U-values of elements and the age of a property and its energy efficiency: the older the homes, the less the improvement on U-values. Also, the U-values of elements of the houses built after 1985 were added with a higher slope; which demonstrates the effect of installing insulation layers.

Furthermore, it is observed that the U-values are reduced with wall thickness, except for newer buildings, where the U-values are increased. This shows that the insulation layer, typically found in new buildings, has more influence on the U-value rather than the wall thickness. Moreover, in traditional houses, the kind of material has more influence on thermal performance than the thickness.

Concerning the wall type, the thermal performance of non-traditional timber walls is better than that of brick/block cavity walls, but the difference is minimal. For the buildings with the age of 30 to 79 years, the thermal performance of brick/block cavity walls is better than that of solid stone walls. For the buildings of the age of 120 to 200 years, the thermal performance of solid stone walls is better than that of brick/block cavity walls. It just illustrates the effect of the kinds of materials and the thickness. Finally, the maximum potential growth in energy efficiency is found for houses built between 1540 and 1814. The same issues were confirmed with regard to the environmental impact rating. A way onward, according to energy cost and average saving cost, the priority for the renovation process is found in the traditional houses.

CHAPTER 3. NEW HOUSES AND RECOMMENDATION OF PROPER MATERIALS FOR THREE KINDS OF CONSTRUCTIONS IN TWO DIFFERENT COUNTRIES

This chapter aims to identify the influence of different kinds of materials on the U-values and energy efficiency in new houses according to the current standards and building regulation of two European countries: UK and Spain.

After a brief introduction, the methodology followed is presented. Then, the main targets proposed for zero carbon homes in the UK and the energy efficiency regulation and standards in Spain are analysed. After that, a typical new one-floor house of 100 m^2 adapted to six different cities of these countries and considering three kinds of construction (brick/block, metal and timber) is used as case study. A comparative analysis of energy performance based on two different energy simulation tools: DesignBuilder and Lider-Calener are carried out, and the appropriate materials for moving toward energy efficient houses are suggested.

3.1 Introduction

Globally, buildings represent around 40% of primary energy consumption. The construction part has been identified as the industry with the most significant potential to reduce waste. The UK Government committed to a binding target of diminishing carbon dioxide (CO_2) emissions. In 2012, the private section accounted for approximately 30% of final energy consumption in the UK, 84% of this energy used for space heating and domestic hot water (16). Therefore, new housing has the potential to be a leader in meeting the CO_2 pollution reduction target.

In December 2006 the Labour Government published a consultation document setting out plans to move towards zero carbon in the new housing using three main policy levers: the planning system; the building regulations and the Code for Sustainable Homes. The Code for Sustainable Homes, a voluntary set of standards for assessing new homes, whose highest level 6 requires zero carbon, was published at the same time. Until 2008 houses builders faced a zero carbon definition that effectively required all CO_2 pollution to reduce to zero through on-site means. Both regulated pollution (from heating, cooling, lighting, and ventilation) and unregulated emissions (from household appliances) had to be accounted. It soon recognised that the cost of the house to this definition (Code for Sustainable Houses, Level 6), and its impracticality on sites, meant that delivering zero carbon through an entirely on-site strategy was not the right method for mainstream building production.

In 2007, the UK Government proclaimed the intention to move towards the demand for all new building to be zero carbon from 2016 ahead of the Europe-wide requirement for all new buildings to be nearly zero-energy by 2020. After announcing, the zero carbon defined over a year, the net carbon pollution from all energy used in the building would be zero. As a means of encouraging the house construction sector to improve the energy efficiency of new homes voluntarily, the Code for Sustainable Homes was introduced in 2007.

In 2009 the concept of Allowable Solutions was suggested by the UK Government. By paying into an Allowable Solutions Fund, a lower on-site pollutions target could set for home builders, whenever preserving the zero carbon policy goal. A significant additional change, in the 2011 budget, was the removal of unregulated emissions from the definition. The Code for Sustainable Houses is the most prominent voluntary sustainability label for building in the UK. The Code is a holistic sustainability ranking tool in which houses are rated against indicators in nine categories. Houses can be awarded a star rating between levels 1 and 6, with six being the most sustainable.

From the inception of the Code, very few homes have been built to the higher levels of the Code, and of those that have, the vast majority have been public sector housing. The statistics are suggestive of a reticence from the private house building sector to act voluntarily; a view supported by the literature (25–28). Therefore, home builders are failing to deliver zero carbon homes in preparation for the 2016 Regulations.

3.2 Methodology

The methodology of the chapter is categorised in five steps as shown in Figure 3.1:

First Step: Study on the energy efficiency regulation, standards in the UK.

Second step: Study on the energy efficiency regulation, standards in Spain.

Third step: Work on the DesignBuilder program and suggest appropriate materials for wall, two kinds of roof, floor and the internal wall of new houses for three types of construction (brick/block, metal and timber construction) which meet the requirement regulation standards with U-value consideration in Edinburgh, Leeds, Pembrokeshire and Zaragoza.

Fourth step: Work on the Lider-Calener (Hulc) program and suggest appropriate materials for wall, two kinds of roof, floor and the internal wall of new houses for three types of construction (brick/block, metal and timber construction) which meet the requirement regulation standards with U-value consideration in Zaragoza, Almeria, and Avila.

Fifth Step: Results discussion and conclusions.

Sixth step (Appendix B): Analysing the required information including:

- Energy efficiency/policy package in Spain and UK.
- Energy efficiency in Zaragoza and Edinburgh.
- Energy efficiency in Almeria and Avila.
- Energy efficiency in Leeds and Pembrokeshire.
- The energy simulation software tools.
- The weather of Zaragoza, Edinburgh, Almeria, and Avila.

Figure 3.1 Methodology followed for the study of energy efficiency regulation and U-values of new homes in Spain and the UK.

In this chapter, work on the U-values and materials of the elements of a sample house in two European countries with different kinds of conditions as building regulations and weather is presented. Also, the influence of different kinds of materials and U-values on the energy efficiency of new houses according to the standards is studied. The United Kingdom and Spain have been chosen as the author live in both countries and is familiar with the condition and standards of each country, also required information is available and it is possible to visit the houses, agencies, site and so forth. In addition, these two countries have different kinds of condition, rules, regulation and these differences is more challenging. A simple 100 m^2 one-floor house 3 meters in height has been considered as a case study as shown in Figure 3.2. It causes focus more on the materials and U-values and reduces the effects of other factors. In addition, today a 100 m^2 flat in a multi-family building in Europe is prevalence (111).

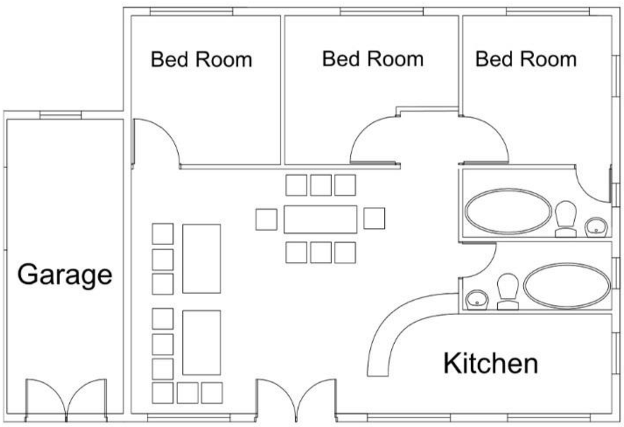


Figure 3.2. Geometrical definition of the individual house used as a case study.

Two kinds of software tools have been used for obtaining the results. One of them is Lider-Calener (Hulc) (112) for Spain; another one is DesignBuilder which is suitable for the UK, Spain and any country in the world. DesignBuilder U-value Calculator tool was selected to calculate the U-values of the house components measured. It was deemed an appropriate tool for the U-value comparison calculations since its calculations are based on the standards set out in the document BR 443 (82). Also, DesignBuilder is a thermal simulation program that enables the energy modelling and analysis of any building. The program can simulate different models for heating, cooling, heating, ventilation, lighting, and other energy flows (113). DesignBuilder has been used for Edinburgh (UK) and Zaragoza (Spain), but Lider-Calener (Hulc) program just handle the cities of Spain as it works for the regulation in Spain so, three different cities have been chosen for study, as the highest altitude, Ávila (Spain) with altitude of 1054 m and climate zone E1, Almería (Spain) with altitude of 0 m and climate zone A4 as lowest altitude, finally Zaragoza (Spain) with height 207 m and climate zone D3.

3.3 Study on the targets for zero carbon homes proposed in the UK

The definition of zero carbon buildings in the UK has been discussed in the context of changes made since the standard first proposed. Heffernan et al. (2013) suggest that the definition for zero carbon buildings is limited and present energy balance choices for consideration in the development of a holistic description (114). Zero carbon homes is a standard announced to the UK building industry in 2007; the UK Government declared that all new houses should be zero carbon from 2016. The standard was initially ambitious, requiring not only the emissions from regulated energy (for hot water, cooling, heating, lighting, ventilation and auxiliary services) to be accounted for but also those from unlimited energy (for cooking and plug-in appliances). The Zero Carbon Hub is a private/public partnership that continues to be central to the development of the definition of zero carbon houses in the UK (115). The 2014 proposals suggest the zero carbon houses standard will comprise three elements for compliance: a Fabric Energy Efficiency Standard (116,117); on-site energy generation using zero or low-carbon technologies (Carbon Compliance) (118) and allowable solutions (24) for local, near and off-site carbon offsetting, such as a community renewable energy scheme.

The UK Government initially criticised for the ambitious speed, and scale of the zero carbon policy and recommendations had to limit the targeted reduction of CO_2 emissions. However, more recently, concerns have been expressed that the standard may be further ‘watered down’ before coming into force. There has been criticism within the academic literature (119–122) that the proposed energy efficiency requirements of the zero carbon buildings standard are weak because the requirement is too generous about the allowance for the purchase of energy from offsite sources as opposed to conserving energy.

3.3.1 On-site performance targets proposed for zero carbon homes

The Fabric Energy Efficiency Standard (FEES) is the proposed maximum space cooling and heating energy demand for zero carbon houses. FEES is expressed regarding primary energy requirement (kWh/m^2/year), that provides a stable target for construction and design of the house fabric. It ensures that a minimum standard for envelope (the longest-lasting part of a house) will become embedded in every fabric's housing portfolio. FEES can achieve a variety of house specifications including traditional masonry cavity wall.

The Carbon Compliance limit is the maximum amount permitted of CO_2 arising from heating, cooling, hot water use, lighting, and ventilation. It is expressed in carbon terms (kgCO_2/m^2/year) to provide a clear link with the UK Government's carbon reduction strategy. The Carbon Compliance standard can meet a broad range of heating/fuel types. The limits of heating and cooling energy demand for zero carbon houses and the maximum CO_2 emissions is shown in Table 3.1, while a comparison between the main requirements of FEES and the Passivhaus standard is presented in Table 3.2.

Table 3.1. On-site performance targets proposed for zero carbon homes.

Built Form	**Fabric Standard (FEES) (maximum energy requirement for space heating & cooling) kWh/m^2/year**	**Carbon Compliance (maximum on-site carbon pollution from the house's construction & design) kgCO_2/m^2/year**
Apartment blocks	39	13
Mid terrace houses	39	11
End of terrace houses	46	11
Semi-detached houses	46	11
Detached houses	46	10

Table 3.2. The Passivhaus and FEES standards.

	FEES	**Passivhaus**
Average U-value, W/m^2/K	0.13 - 0.18	0.10 – 0.15
Air permeability rate m^3/h/m^2 @50Pa	5.0	1.0
Thermal bridge (y-value), W/m^2/K	0.05	0.02
Space heating/cooling demand, kWh/m^2/year	46	25-30 (approx)

3.3.2 The fundamental ways of achieving zero carbon

Three strategic design methods for complying with the zero carbon definition have been introduced: first method A.-Balanced, then method B-Extreme Fabric and finally, method C-Extreme LC (Low Carbon) Technologies. For allowable solutions contribution, the primary solution is to take into account the carbon pollution and then consider the heating extension district.

3.3.2.1 Method A - Balanced

It consists of houses with fabric function at the level of Fabric Standard and those that with technology of low carbon method. The design reaches two of the requirements for zero carbon homes and will be compliant with the remaining pollution, with using Allowable Solutions, 11 kgCO_2/m^2/year are eliminated. Allowable tackles are based on the diminish the rest of carbon pollution (11 kgCO_2/m^2/year) to zero. By applying this alternative, it is expected that the house builder would select an eligible tackle, for example, to pay totally into a carbon fund at a specified rate per ton of CO_2 for the program. The benefits are the equivalent method will become familiar to many home builders.

3.3.2.2 Method B - Extreme Fabric

It consists of houses with physical performance especially in advance of fabric standard (at the same range of the Passivhaus), also with little, low carbon on-site technologies. They must have total pollutions below the range of Carbon Compliance (e.g. a home pollution rate of 11 $kgCO_2/m^2/year$ for the semi-detached example). The diminution of total pollution is obtained via measurement of fabric energy efficiency. Via the method A, allowable tackles will be applied to decrease the rest of carbon pollution to zero. It expected that house builders who select method B would want eligible tackles Type 1, for example, to pay in a fund of energy at a specified range per ton of carbon. The regular Passivhaus way is a sample of this method which suggests architects a standard with an associated certification scheme and old UK support network. The Passivhaus standard is an established Extreme Fabric method. The benefit is that the Extreme Fabric method is a durable and robust method of diminishing carbon pollution. Also, it allows obtaining a considerable decrease in primary energy consumption. The rules contain precise consideration on airtightness, removing thermal bridges, high ranges of insulation, also support the MVHR for thermal comfort and indoor air quality.

3.3.2.3 Method C - Extreme Low Carbon Technologies

The aim of this method is the attainment of a zero carbon house just applying via low carbon on-site technology and component. It depends on comprehensive apply of energy technology and high functional structure. The function of the component in this method is considerably better than Passivhaus ranges and FFES which operate the technology of zero/low energy on-site carbon energy to the maximum, to decrease total pollution significantly rather than the recommended standard of Carbon Compliance, also aiming reach to the zero pollution.

Plans that meet zero pollution in these two methods will reach all the zero carbon conditions. There is no commitment for eligible tackles designs which are in accordance of justification some alternative; for instance, on the solar design (consider south facing roof for panels), high functional of the component, efficient biomass boilers. The benefits of this method is a highly aspirational for clients who see themselves at the leading edge of sustainability. This method can be scaled; for example, it is possible to develop the equipment when the infrastructure site is in place. Nevertheless, technically and costly, it is almost more difficult rather than methods A and B.

3.3.2.4 Permissible tackle sort 1, pay in a carbon fund

When the permissible tackle program is later completed, for resolving the problems of times, or geography, when the permissible tackle applied in the various locality, the carbon fund is useful. In the future, house builders welcome to paying into a carbon fund that delivers carbon saving, also they wish to create private carbon funds.

3.3.2.5 Permissible tackle sort 2, investment in an extension of district heating.

District heating supply hot water and heating with adding size contain cogeneration plant, for example, central boilers in parallel with combined heat and power. It uses a limited number of houses (e.g. from 22 to 50). It contains biomass-fuelled boilers and communal electric ground-source heat pumps where main gases are unavailable that qualify as a renewable heat source. District heating or combined heat and power tools have justified the 'Extreme Fabric' or 'Balanced' methods, and need a permissible tackle to remove the total carbon. Supplied the CHP/DH programs have the potential to increase the size to have excess capacity which supports extensions of heat network pipework. It is improbable that homebuilder applies the extra pipework, as it caused extra payment to the Energy Services Companies (ESCOs) (123) for extending. The contents of the carbon accounting methods and the financials are under conversation by industry and government. The extension of district heating method has a considerable effect on saving financial because of their potential for absorbing extra investment. Moreover, the permissible tackle can be more financial rather than method A, and B regards to the values of the saved carbon via an extension of the infrastructure.

The obstacles (124) have been collected into five categories: economic, legislative and cultural, skills and knowledge, legislative, cultural and industry. The delay of Government to prepare a precise description of zero carbon is known as an obstacle. Nevertheless, the advantage determined are helpful, the obstacles and resolutions are essential for meeting the Zero Carbon Homes (ZCH). The obstacles determined first are economic, then they are lack of knowledge in residence, designing and planning. More obstacles are comprised: enhanced capital costs; the nature of the volume construction industry, lack of payback for speculative housebuilders and the need to promote economic growth; resulting in the absence of drive from volume housebuilders; and the demand for more context-specific solutions.

3.3.3 Protective methods for zero carbon home building

The protective methods (124) have been classified into four subjects: financial, industry, training and awareness; legislation and education. Via supporting the subject of education, training, and awareness can meet zero carbon house easily. The most important subjects were improving occupant education and outreach; it caused the most significant obstacles determined regards to the knowledge theme and skills. The introduction of zero carbon programs is one method to develop awareness.

Regards to the subject of legislation, the description for zero carbon houses; stricter building regulations and a robust planning policy framework as methods are the obstacles which formerly determined. In the UK, the need for the Government to approving its obligation to zero carbon houses and supply the precise detail of the regulations so all involved in the reaching of zero carbon home will be provided and programmed. The motivations contain diminution in council tax; motivation via planning tool; subsidies and tax motivations. It is recommended that when residences have recognised the advantage of ZCH then, request for the product will begin to enhance.

Some subject determined regards to the industry subject protect mechanisms such as context-specific design, collaborative working, and off-site construction and self-build. The sector requires a more significant change than merely perpetuating traditional methods of construction but making it more energy efficient. The demand for a move towards off-site manufacture more for improved attention to detail and quality; also, the need to reduce waste as a driver even guiding construction in the direction of off-site fabrication. An increase in self-build ways of procurement which tend to complement off-site production, the proposal to encourage more self-build process is made not only as a means of tackling the barriers identified within the volume home industry but also as a way of engaging occupants in the course of delivering new houses as a long-term solution.

3.3.4 Benefits of zero carbon home building

The benefits are divided into four groups; individual, economic, environmental and industry. The sub-subjects of the individual are quality of living environment, lower fuel bills, sustainable behaviour, comfort, healthier homes and health & wellbeing. The sub-themes of economic include: quicker sales/rental, cheaper running costs, tenants afford rent, energy security, quality housing stock, long-term investment and inward investment. The environment ones comprise: mitigate climate change, reduced CO_2 pollutions, and lower environmental influence. Finally, the subjects of industry contain knowledge, expertise, prestige, and marketing.

3.3.4.1 Standard features of Zero Carbon Houses

Zero carbon house not only apply to energy efficient and features of the passive solar design but also apply to the technology of renewable energy. The most effective method to decrease the energy bills and the emissions is to diminish the energy demand. It is possible via making houses more energy efficient, either applied at the renovation or design phases. Some examples are high levels of insulation, thick air-tight walls and large south-facing windows with sun louvres. Lots of beneficial tips are available in the Energy Saving Trust. Other technologies such as hydropower or wind turbines hardly ever are used domestically, but potentially could be appropriate for substantial rural houses. Passivhaus, a stricter type of zero-carbon building, usually do not have any renewable technologies because they are so incredibly energy efficient that they do not need any cooling or heating. In contrast, some buildings that cannot reasonably install renewables (such as inner-city flats) will be able to achieve the zero carbon standard if the house builder offsets the emissions off-site with allowable solutions by investing in renewable energy elsewhere or retrofitting other homes.

3.3.4.2 Policy changes and progress

The UK public policy statement proclaimed that all new houses would be zero carbon by 2016 to combat climate change. Later, the Zero Carbon Hub arranged to handle this ambitious policy. Nevertheless, the plan was discarded in 2015; the Zero Carbon Hub stopped performances in March 2016, even though now still the website is online.

By replacing the Code for Sustainable House, the new House Quality Mark is a comprehensive and optional standard for new builds that support environmental, economic parameters and health/wellbeing. A house does require to be net-zero carbon to obtain full marks in the environmental part. Also, the Home Quality Mark contains the embodied pollutions in materials, construction and local ecology. Nevertheless high-quality standard and competition are the only matters forced house buyers and builders for using zero carbon. Therefore, the distribution and implementation of innovation for energy efficiency have been slow. Also, the private house-building part is failing to answer the non-mandatory motivation for reaching zero carbon houses. The drivers determine as being legislative, such as the Climate Change Act and the Building Regulations. The fundamental obstacles determined were knowledge, skills and financial which contained the knowledge of residences, improved the capital cost, public awareness and viability program. The obstacle of industry subject contained the resistance that changes the nature of the house-building industry. Moreover, require motivating more considerable demand as a method to protect the reaching of zero carbon houses. Uncertainty in the future legislation was determined as an obstacle, which must be tackled by the government.

There are 4.6 million households in fuel poverty in the UK, meaning it is essential to spend more than 10% of the income on keeping the house at a comfortable temperature (defined as 18-22ºC) (125). There are three relevant parameters: energy efficiency of the house, household income, and energy costs. As a whopping 95% of fuel poor houses poorly insulated, energy efficiency is an area which can make a big difference. The climate change and energy costs/fuel poverty are the primary drivers; the second point is that zero carbon gives us a common goal which is clear and ambitious. In contrast, a term like the eco house is vague and can be used to describe an off-grid Earthship and also a traditional flat with wall insulation and LED lights.

The mechanisms for the delivery of zero carbon homes, ranging from establishing a robust planning policy framework to encouraging the financial sector to support the delivery of zero carbon homes through mortgage lending which acknowledges the reduced operational costs of a zero carbon home. The government and industry should work together to support transportation, as no single solution will independently suffice to increase the distribution of zero carbon homes. Therefore, it is necessary for the government and industry companies to prioritise enhancing public awareness in regards to the advantages of zero carbon houses. It is essential that the zero carbon house standard definition allow the industry to help decrease the influence of new buildings on climate change.

Table 3.3. Examples of proposed NZEBs (Nearly zero energy buildings) targets reported across EU. (126)

Country	**Building type**	**Metric**	**Energy uses included**	**Energy performance ($kWh/m^2/year$)**	**Renewable energy share**	**National Legislation providing the definition** (127)
Denmark	Residential	Primary energy	Regulated energy	20	51-56%	BR10
France	Residential	Primary energy	Regulated energy	50	-	RT2012
Belgium (Brussels)	Residential	Primary energy	Heating, DHW, appliances	45	-	Brussels Air, Climate and Energy Code
Cyprus	Residential	Primary energy	Regulated energy	180	25%	NZEB Action Plan
Latvia	Residential	Primary energy	Regulated energy	95	-	-

As shown in Table 3.3, European countries have proposed different targets for nearly zero energy buildings. In all of them, primary energy is selected as the main indicator, ranging from 20 to 180 kWh/m^2/year.

The types of construction and building materials were used vary throughout Europe. In Germany in the residential sector, the pre-fabrication with 25% share is prevalence rather than office buildings. The share of masonry construction is 48%, concrete 35%, timber construction 6% and metal construction is 9%. In addition, the share of masonry construction is 13% in single-family house and 2% in multifamily dwellings, timber construction has 81% and 88%, and the rest are concrete buildings. In France, the share of timber construction is around 36% in agricultural, 24% in sports halls, 5% in industrial, 4% for single family and 1% for multifamily houses (128). Figure 3.2 illustrates the market share for the concrete and steel construction in the UK.

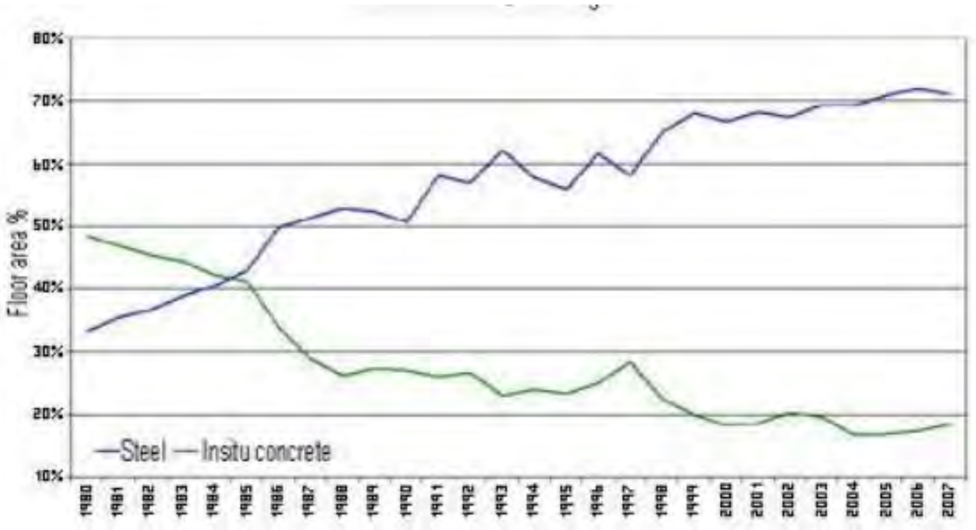


Figure 3.3. Market share for concrete and steel construction in the UK. Source: UK report (129).

3.4 Study on the energy efficiency regulation and building standards in Spain

3.4.1 Introduction

The Spanish construction sector has developed several instruments in order to obtain considerable savings. In Spain, energy efficiency in houses is improving more slowly than in the other EU Member States, but the new regulation opens a unique chance to recover the lost years.

In Spain a series of development have been made in the relevant legislation transposing the EPBD Directive 2002/91/CE (139), such as the approval of the Technical Building Code (CTE), the Royal Decree on the main procedure for Energy Performance Certification of New Construction (RD 47/2007) (140), authorized by the Council of Ministers on January 16, 2007, and the revision of the Regulations on Heating Installations in Building (RITE) (141). An energy certification procedure for existing buildings has been considerably delayed until the transposing of the 2010 revision of the EPBD (Directive 2010/31/EU) (12). The leading European regulations are Directive 2002/91/CE, Directive 2010/31/UE and Regulation 244/2012 (142). At present, the Spanish regulation for buildings is mainly based on three Royal Decrees: RD 314/2006 (143), partially modified by Ministerial Decree FOM/1635/2013, RD 1027/2007, partially modified by RD 238/2013, and RD 235/2013 (144).

Royal Decree 314/2006, partially modified by Ministerial Decree FOM/1635/2013, approves the Technical Building Code (CTE) and transposes directly the EPBD in its Article 15 on Energy Savings (HE). It contains six HE guidelines on the limitation of energy demand, solar thermal contribution, lighting efficiency, solar photovoltaic contribution and thermal efficiency. The instructions contain procedures, examples of solutions and technical rules for identifying whether a construction matches with the stipulated performance steps. The Principal Energy Saving Requirements (HE) cover the following subjects:

- HE0. Energy consumption limitation.
- HE1. Energy demand limitation.
- HE2. The efficiency of thermal installations.
- HE3. Energy efficiency of the lighting installation.
- HE4. Minimum solar contribution to the buildings hot water supply.
- HE5. Minimum photovoltaic contribution to the electric powers.

Royal Decree 235/2013 establishes the necessary process for the energy certification of new and some existing constructions and supplies the legal framework for energy performance certification of these constructions. It assesses the houses annual non-renewable primary energy consumption, and apart from the energy rating given it, its global CO_2 emissions. The standard energy scale in Spain ranges from A (very high performance, involving a substantial contribution of renewable energies to construction consumption) to G (very low performance). These regulations depend on the total emissions of construction, regarding demand, primary and final energy consumption, and emissions. In addition, it supplies a new official program for calculating the EPC (Energy Performance Certificate) by either of two possible ways: a simplified method and a general method, both containing all validated processes approved by the Certification Commission. The latter requires the use of the official program called Lider-Calener (Hulc) that has two different versions, Calener_VYP for houses and small tertiary constructions and Calener_GT for massive tertiary constructions.

The regulations promote initiatives for enhancing penetration and efficiency of renewable energies in the construction sector by Energy Service Companies and IDAE's Financing Line to Stimulate Renewable Energies in constructions through BIOMCASA-GEOTCASA-ESCOs-SOLCASA; 330 ESCO Plan (Activation Plan in State General Administration constructions through ESCOs).

Energy consumption in average Spanish buildings is 40% lower than in the EU (145), partially due to its mild climate that decreases heating requirements (45% of the house energy demand). Another reason is the lower appliance rate, but it underwent a noticeable enhancement throughout the 90s, and present rates are similar to the EU average. The percentage of final energy consumption for dwelling space heating went down in 2000-2010 by more than 10% (146). In Spain, final energy consumption in the buildings sector is distributed in the average household for use in heating (42%), hot water (26%), lighting (8.8%) and air-conditioning (0.5%). The remaining consumption of electrical appliances (12%) and stoves (10.7%) are analysed in the Household Appliances document (16).

3.4.2 Energy efficiency problem and opportunities in Spain

40% of EU energy consumption is in constructions which is in continuous expansion as energy consumption increases. So, two necessary measures in the building sector are needed to decrease the European Union's energy dependency and (Green House Gas) GHG emissions: diminution of energy consumption and use of renewable energy resources. Full administration of existing European measures would make European industry more competitive; decrease energy dependence; contribute to economic growth and job creation; contribute to the reduction of GHG emissions and of the harmful impact of energy generation on the environment; save up to €1000 per household per year; and improve the living conditions and comfort of its citizens (147). Spain has the chance to achieve those goals, but there are some problems which must be solved, for example, monitor compliance with Royal Decree 235/2013 (144); promote citizen awareness; meet legislation deadlines; regulate and penalize noncompliant regions and refurbish the large stock of houses for sale constructed under older less efficient regulations so more efficient houses will be available.

Building constructions have an influence on long-term energy consumption; given the long renovation cycle for new buildings and existing constructions that are subject to significant renovation should reach minimum energy efficiency requirements adapted to the local climate. As the performance of alternative energy provides systems which are not explored to its full potential, alternative energy providers methods should be considered for new houses. One of the main problems in Spain is the large stock of buildings for sale built under the old legislation (before RD 235/2013 and RD 47/2007). Improvement of the built-up area in 2005 multiplied almost 2.6 times compared to 1990; in this course, the majority of the city was covered by residential buildings. For instance, in 2005 it represented 98% compared to tertiary sector houses, in which excessive construction led to low-quality buildings and low energy efficiency (143).

Spain has the essential energy performance certification, the official program that takes most methods of construction, cooling, heating, hot water systems and lighting into account. The obstacle with current Spanish legislation applicable to new houses is regulation without enforcement leads to lack of compliance, and it makes no provision for enforcement. This is because regional governments are not involved due to lack of motivation and enough knowledge. A solution is complicated due to the big difference with other European countries, demotivation of the residences on the subject, decentralisation of attention in energy subjects, and the vast stock of unsold building based on older less efficient regulations so no new dwellings are being built.

3.4.3 Energy efficiency regulation: the Spanish Technical Building Code

3.4.3.1 Section HE0: limitation of energy consumption

The section applies to new buildings and extensions to existing properties. The energy consumption of the buildings is limited according to the climate zone of their location.
In the case of permanently open buildings due to their characteristics of use, the energy consumption for their conditioning will be supplied exclusively with energy from renewable sources.

In the case of new buildings or extensions of existing buildings for private residential, the non-renewable primary energy consumption of the building (or the enlarged part, if any), must not exceed the limit value $C_{ep,lim}$, obtained by the equation 3.1.

$C_{ep,lim} = C_{ep,\ base} + F_{ep,\ sup} / S$ (eq. 3.1)

where:

- $C_{ep,lim}$ is the limit value of non-renewable primary energy consumption for heating, cooling and DHW services, expressed in kWh/m^2·year, considering the useful area of the living spaces.
- $C_{ep,\ base}$ is the base value of the non-renewable primary energy consumption, depending on the winter climate zone corresponding to the location of the building, which takes the values of Table 3.4.
- $F_{ep,\ sup}$ is a corrective factor per useful area, whose values are shown in Table 3.4.
- S is the useful surface of the living spaces of the building (or the enlarged part), in m^2.

Table 3.4. The base value of non-renewable primary energy consumption and corrective factor per area.

	Climate zone in winter					
	α	A*	B*	C*	D	E
$C_{ep,base}$ (kWh/m^{2}year)	40	40	45	50	60	70
$F_{ep,sup}$	1,000	1,000	1,000	1,500	3,000	4,000

* The values of $C_{ep,\ base}$ for winter climate zones A, B and C of Canary Islands, Balearic Islands, Ceuta, and Melilla will be obtained by multiplying the values of $C_{ep,\ base}$ of this Table by 1.2.

Table 3.5 shows the limit values obtained by considering various building useful surfaces in equation 3.1.

Table 3.5. Non-renewable primary energy consumption limit values.

Climate severity in winter	**Non-renewable primary energy consumption limit (kWh/m^{2}year)**					
	α	A	B	C	D	E
Useful surface = 100 m^2	50	50	55	65	90	110
Useful surface = 500 m^2	42	42	47	53	66	78
Useful surface = 1,000 m^2	41	41	46	52	63	74
Useful surface = 5,000 m^2	40	40	45	50	60	71

Since a new single house with a useful surface of 90 m^2 and located in three different locations (Zaragoza, Ávila and Almería) will be considered as a case study in the next subsection, here the limit values of non-renewable primary energy consumption for heating, cooling and DHW are calculated:

- For Zaragoza (climate zone D3): $C_{ep,lim} = 60 + 3{,}000 / 90 = 93.3$ kWh/m^{2}year.
- For Ávila (climate zone E1): $C_{ep,lim} = 70 + 4{,}000 / 90 = 114.4$ kWh/m^{2}year.
- For Almería (climate zone A4): $C_{ep,lim} = 40 + 1{,}000 / 90 = 51.1$ kWh/m^{2}year.

3.4.3.2 Section HE1: limitation of energy demand

This section applies to new buildings and, interventions in existing buildings. The energy demand of the buildings is limited according to the climate zone. In buildings of private residential use, the characteristics of the elements of the thermal envelope must be such that they avoid decompensation in the thermal quality of the different spaces, the transfer of heat between various units of use and common areas of the building. Risks due to processes that result in a significant loss of temperature or the useful life of the elements such as condensation are prevented.

3.5.3.2.1 Limitation of the building's energy demand.

The heating demand of the building (or the enlarged part, if any), must not exceed the limit value $D_{cal,lim}$, obtained by equation 3.2:

$D_{cal,lim} = D_{cal,base} + F_{cal,sup} / S$ (eq. 3.2)

where:

- $D_{cal,lim}$ is the limit value of the energy demand for heating, expressed in kWh/m^2·year, considering the useful area of the living spaces.
- $D_{cal,\ base}$ is the base value of the energy demand for heating, for each climate zone in winter corresponding to the building location. The values are shown in Table 3.6.
- $F_{cal,\ base}$ is a surface corrector factor, whose values are shown in Table 3.6.
- S is the useful surface of the living spaces of the building, in m^2.

Table 3.6. Base value of heating demand and corrective factor per area.

	Climate zone in winter					
	α	A*	B*	C*	D	E
$D_{cal,base}$ (kWh/m^{2}year)	15	15	15	20	27	40
$F_{cal,sup}$	0	0	0	1,000	2,000	3,000

Table 3.7 shows the limit values resulting from considering various building useful surfaces in equation 3.2.

Table 3.7. Heating demand limit values.

Climate severity in winter	Heating demand limit (kWh/m^{2}year)					
	α	A	B	C	D	E
Useful Surface = 100 m^2	15	15	15	30	50	70
Useful Surface = 500 m^2	15	15	15	22	34	46
Useful Surface = 1,000 m^2	15	15	15	21	32	43
Useful Surface = 5,000 m^2	15	15	15	20	30	41

Considering again a new house located in three different locations (Zaragoza, Ávila and Almería), which will be presented as a case study in the next subsection, the limit values of heating demand are calculated below:

- For Zaragoza (climate zone D3): $D_{cal,lim}$ = 27+2,000 / 90 = 49.2 kWh/m^{2}year.
- For Ávila (climate zone E1): $D_{cal,lim}$ = 40 + 3,000 / 90 = 73.3 kWh/m^{2}year.
- For Almería (climate zone A4): $D_{cal,lim}$ = 15 + 0 / 90 = 15 kWh/m^{2}year.

Moreover, there is also limit demand for cooling in new residential buildings. The limit value is 15 kWh/m^2·year in summer climate zones 1, 2 and 3 (Zaragoza and Ávila); while it is 20 kWh/m^2·year in summer climate zone 4 (Almería).

These two differentiated energy demands for heating and cooling for residential buildings are intended to achieve adequate strategies for limiting energy demand, as these methods are different depending on whether the request for heating or cooling demand reduced.

3.4.3.2.2 Limitation of thermal decompensations in private residential buildings.

The thermal transmittance and air permeability of the openings and the thermal transmittance of the opaque walls, roofs, and floors, which compose the thermal envelope of the building must not exceed the values set out in Table 3.8 excluding thermal bridges. The exclusion of thermal bridges includes doors and other linear or point elements that modify the transmittance of the thermal envelope at the local level.

Table 3.8. Maximum thermal transmittance and air permeability of the items of the thermal envelope.

Parameter	Climate zone in winter					
	α	A	B	C	D	E
Thermal transmittance of walls and elements in contact with the ground(1) (W/m^{2}K)	1.35	1.25	1.00	0.75	0.60	0.55
Thermal transmittance of roofs and floors in contact with air (W/m^{2}K)	1.20	0.80	0.65	0.50	0.40	0.35
Thermal transmittance of openings(2) (W/m^{2}K)	5.70	5.70	4.20	3.10	2.70	2.50
Air permeability of openings(3) (m^3/hm^2)	≤ 50	≤ 50	≤ 50	≤ 27	≤ 27	≤ 27

(1) For elements in contact with the ground, the indicated value is only required to the first meter of the buried wall, or the first meter of the ground perimeter supported on the ground to a depth of 0.50m.

(2) The typical behaviour of glass and frame is considered, Includes skylights and windows.

(3) The permeability of the indicated carpentries corresponds to a measure with an overpressure of 100 Pa.

The thermal transmittance of party walls and interior partitions that delimit units of residential use and other uses or common areas of the building cannot exceed the values of Table 3.9. When the interior partitions only delimit units of residential use, the values of Table 3.10 must be considered.

Table 3.9. Thermal transmittance limit of internal partitions, when delimiting units of different use, common areas, and party walls, U in W/m^2K.

Element type	**Climate zone in winter**					
	α	A	B	C	D	E
Horizontal and vertical partitions	1.35	1.25	1.10	0.95	0.85	0.70

Table 3.10 Thermal transmittance limit of internal partitions, when delimiting units of the same use, U in W/m^2K.

Element type	**Climate zone in winter**					
	α	A	B	C	D	E
Horizontal partitions	1.90	1.80	1.55	1.35	1.20	1.00
Vertical partitions	1.40	1.40	1.20	1.20	1.20	1.00

3.4.3.3 Reference building

The reference building is defined by the same shape, size, orientation, interior zoning, use of each space, and the same obstacles as the object building. Reference values considered for the reference building in Almería, Zaragoza and Ávila are shown in Tables 3.11, 3.12 and 3.13 respectively.

Table 3.11. Reference building values in Almería (climate zone A4).

Transmittance limit of facade walls and enclosures in contact with the ground: U_{Mlim}	**0.94 W/m²K**			
Transmittance limit of soils: U_{Slim}	0.53 W/m^2K			
Transmittance limit of covers: U_{Clim}	0.50 W/m^2K			
Modified solar factor limit of skylines: F_{llim}	0.29			
	Transmittance limit of openings: U_{Hlim} (W/m^2K)			
% of openings	N/NE/NO	E/O	S	SE/SO
From 0 to 10	5.7	5.7	5.7	5.7
From 11 to 20	4.7	5.7	5.7	5.7
From 21 to 30	4.1	5.5	5.7	5.7
From 31 to 40	3.8	5.2	5.7	5.7
From 41 to 50	3.5	5.0	5.7	5.7
From 51 to 60	3.4	4.8	5.7	5.7

Table 3.12. Reference building values in Zaragoza (climate zone D3).

Transmittance limit of facade walls and enclosures in contact with the ground: U_{Mlim}	0.66 W/m^{2}K			
Transmittance limit of soils: U_{Slim}	0.49 W/m^{2}K			
Transmittance limit of covers: U_{Clim}	0.38 W/m^{2}K			
Modified solar factor limit of skylines: F_{Ilim}	0.28			
	Transmittance limit of openings: U_{Hlim} (W/m^{2}K)			
% of openings	N/NE/NO	E/O	S	SE/SO
From 0 to 10	3.5	3.5	3.5	3.5
From 11 to 20	3.0	3.5	3.5	3.5
From 21 to 30	2.5	2.9	3.5	3.5
From 31 to 40	2.2	2.6	3.4	3.4
From 41 to 50	2.1	2.5	3.2	3.2
From 51 to 60	1.9	2.3	3.0	3.0

Table 3.13. Reference building values in Ávila (climate zone E1).

Transmittance limit of facade walls and enclosures in contact with the ground: U_{Mlim}	0.57 W/m^{2}K			
Transmittance limit of soils: U_{Slim}	0.48 W/m^{2}K			
Transmittance limit of covers: U_{Clim}	0.38 W/m^{2}K			
Modified solar factor limit of skylines: F_{Ilim}	0.36			
	Transmittance limit of openings: U_{Hlim} (W/m^{2}K)			
% of openings	N/NE/NO	E/O	S	SE/SO
From 0 to 10	3.1	3.1	3.1	3.1
From 11 to 20	3.1	3.1	3.1	3.1
From 21 to 30	2.6	3.0	3.1	3.1
From 31 to 40	2.2	2.7	3.1	3.1
From 41 to 50	2.0	2.4	3.1	3.1
From 51 to 60	1.9	2.3	3.0	3.0

3.4.3.4 Guidance values for parameters, Characteristic of the thermal envelope

The values have been obtained considering thermal bridges equivalent to those of the reference building and a building of average compactness. To simplify the use of Table 3.14, a total area of openings not exceeding 15% of the useful surface has been considered. The thermal transmittance of openings and the modified solar factor should be reduced compared to those indicated in case of the greater surface of openings in comparison with the useful surface. For each level of solar gain and climate zone, a range of transmittances provided corresponds to a total percentage of openings compared to the useful area between 15% (lower level) and 10% (upper level).

Table 3.14. Recommended values of thermal transmittance of the building elements, in W/m^2K.

	Climate Zone					
The transmittance of the element (W/m^2K)	α	A	B	C	D	E
U_M	0.94	0.50	0.38	0.29	0.27	0.25
U_S	0.53	0.53	0.46	0.36	0.34	0.31
U_C	0.50	0.47	0.33	0.23	0.22	0.19

U_M: Thermal transmittance of facade walls and enclosures in contact with the ground.

U_S: Thermal transmittance of floors (forged in touch with outside air).

U_C: Thermal transmittance of covers.

Table 3.15. Thermal transmittance of openings, in W/m^2K.

Thermal transmittance of openings (W/m^2K)		**α**	**A**	**B**	**C**	**D**	**E**
Solar gain	High	5.5 – 5.7	2.6 – 3.5	2.1 – 2.7	1.9 – 2.1	1.8 – 2.1	1.9 – 2.0
	Medium	5.1 – 5.7	2.3 – 3.1	1.8 – 2.3	1.6 – 2.0	1.6 – 1.8	1.6 – 1.7
	Low	4.7 – 5.7	1.8 – 2.6	1.4 – 2.0	1.2 – 1.6	1.2 – 1.4	1.2 – 1.3

For the modified solar factor, for climate zones with a summer type 4, a value less than 0.57 in south/southeast/southwest orientation, and less than 0.55 in east/west direction can be considered.

3.5 Case studies (the UK and Spain) modelled with the Design-Builder Software

In this part, as mentioned before, work on three prevalence kinds of construction (brick/block, metal and timber construction) for four cities with a different kind of weather, their weather characteristics are presented in Appendix B, three of them located in the UK, Edinburgh (Scotland), Leeds (England) and Pembrokeshire (Wales), and another one placed in Spain, Zaragoza. Another city in a different country has been chosen in regards to the work on different kinds of weather with different kinds of building regulations and standards to analyse the differences. For this reason, first, made the models using Design-Builder software, and then, appropriate materials for walls, two kinds of roof, floor and the internal wall of new houses for three kinds of construction are suggested. One feature of suggested materials is that they had to meet the required regulatory standards and required U-values. In addition, the heating, cooling, simulation, cost of construction, and embodied and equivalent carbon is studied. The information related to the second part has been set in Appendix C. The results of DesignBuilder software for three cities in the UK are similar, for avoiding repetition, just the results of Edinburgh are presented. Table 3.16 illustrates the required U-value for each city.

Table 3.16. Required U-values for three different cities in the UK.

	Edinburgh (Scotland) [W/m²K]	**Leeds (England) [W/m²K]**	**Pembrokeshire (Wales) [W/m²K]**	**Zaragoza (Spain) [W/m²K]**
Wall	0.2	0.22	0.22	0.6
Floor	0.19	0.18	0.18	0.4
Pitched Roof	0.17	0.18	0.18	0.4
Flat Roof	0.17	0.18	0.18	0.4
Internal Wall	0.28	0.3	0.3	0.85-1.2

As shown in the above table, the required U-values for Edinburgh, Leeds and Pembrokeshire are almost similar, so the kind of construction, materials and other analysis are the same.

Table 3.17. U-value of external walls in residential buildings built after 2010. (130)

	Source	**2012**	**2014**	**2015**
Austria	OIB (131)	-	-	0.35
Bulgaria	NEEAP (132)	-	0.35	-
Croatia	Building code	-	1.47	-
Denmark	EMO (The Danish energy labelling scheme database)	0.16	0.13	-
France	Tabula (133)	-	0.28	-
Germany	EnEV (134)	0.28	0.28	0.28
Hungary	National Building Energy Performance Strategy	-	0.45	0.24
Italy	EEAP 2014 (135)	-	0.41	-
Latvia	PAIC measurements database (136)	-	-	0.18
Romania	C107 (137)	-	0.56	-
Slovenia	Long-term strategy (138)	-	0.28	-

For choosing these materials and these solutions, the *''trial and error''* method was used. It is based on the repeat all the possibilities until the best options are found. As working with DesignBuilder program and besides knowing the required U-values; then test all the options and combine all the alternatives to find the best way and obtain the minimum required U-values. The other reasons for selecting the materials are their low CO_2 emissions. Also it is important to take into account to using local materials as much as possible, it is very efficient as an environmentally and economically. This method has been used for the three kinds of construction.

3.5.1 Brick/block construction

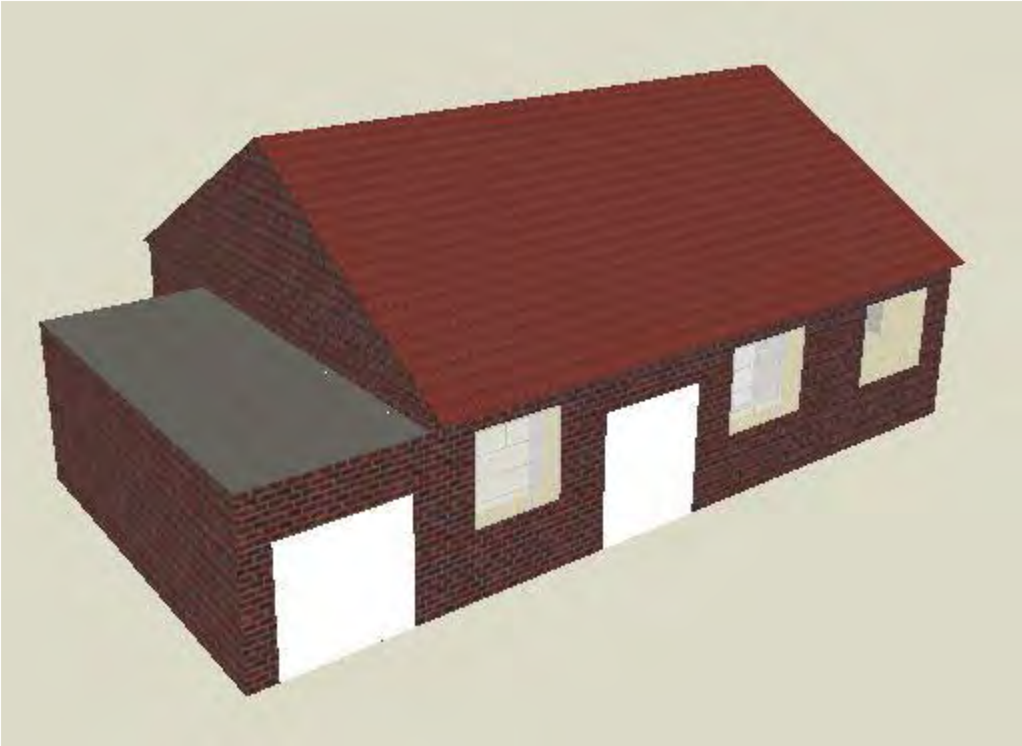
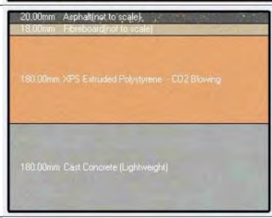
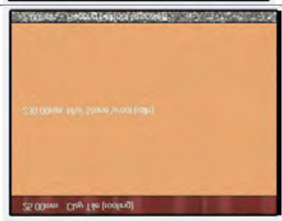
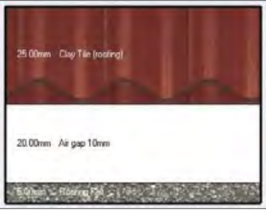
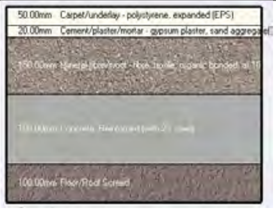


Figure 3.4. Visualisation image of brick construction in DesignBuilder program.

Table 3.18. Suggested materials for brick/block construction.

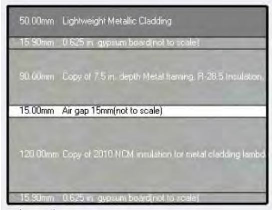
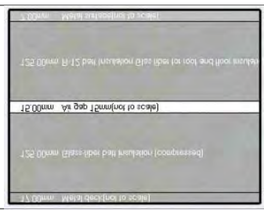
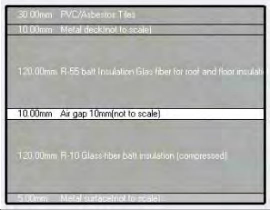
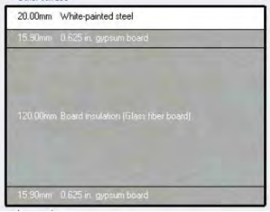
Material and Thickness (mm)							**Image**	**Thickness (mm)**	**R-Value (m^2K/W)**	**U-value (W/m^2K)**
External Walls & Below Grade Walls	Brick, Outer Leaf	115	XPS Extruded Polystyrene- CO_2 Blowing	150	Concrete Block + Gypsum Plastering	11 + 205		400	4.994	0.2
Flat Roof	Asphalt + Fibreboard	20+ 18	XPS Extruded Polystyrene – CO_2 Blowing	180	Cast concrete (Lightweight)	180		398	6.236	0.16
Pitched Roof (Occupied)	Clay Tile	10	MW Stone Wool (rolls)	230	Roofing Felt	7		262	5.952	0.168

Pitched Roof (Un occupied)	Clay Tile	25	Air Gap	20	Roofing Felt	5		50	0.341	2.930
Internal Walls	Gypsum Plasterboard	25	MW Glass Wool (Standard board) + Brickwork, Inner Leaf	120 + 125	Gypsum Plasterboar d	20		285	3.399	0.28
Ground Floor & Internal Floor	Carpet/underl ay – Polystyrene, expanded (EPS)	50	Cement gypsum plaster + Mineral fibre/wool at 100 degree	20+ 150	Concrete, Reinforced (with 2% steel) + Floor Screed	180 + 100		500	5.468	0.18

3.5.2 Metal construction

Figure 3.5. Visualization image of metal construction in DesignBuilder program.

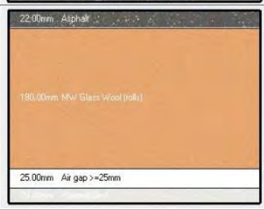
Table 3.19. Suggested materials for metal construction.

Material and Thickness (mm)							**Image**	**Thickness (mm)**	**R-Value (m^2K/W)**	**U-value (W/m^2K)**
External Walls & Below Grade Walls	Lightweight Metallic Cladding + 0.625 in. gypsum board	50+ 159	Insulation, expanded polystyrene, molded board, depth metal framing +Air Gap	90+ 15	Insulation for metal cladding lambd, 0.0432 + 0.625 in. gypsum board	120 +15 9		307	5.268	0.19
Flat Roof	Metal deck + Glass-fibre batt insulation + Air Gap	17 + 125 + 15	R-12 Glass fibre batt insulation for roof insulation between metal framing	125	Metal surface	7		289	6.124	0.163
Pitched Roof (Occupied)	PVC/Asbestos Tiles + Metal deck	30 + 10	R-55 Batt insulation glass fiber for roof between metal framing + Air Gap	120 + 10	R-10 Glass-fibre bath insulation + Metal surface	120 +5		295	5.907	0.169
Pitched Roof (Un occupied)	PVC/Asbestos Tiles + Metal deck	30 + 10	Air Gap	25	Metal surface	5		70	0.366	2.735
Internal Walls	White-painted steel + 0.625 in. gypsum board	20 + 15. 9	Board insulation (Glass fibre board)	120	0.625 in. gypsum board	15.9		172	3.702	0.270
Ground Floor & Internal Floor	Cast concrete (Light weight) + cement gypsum plaster	50 + 20	Glass fibre/wool resin bonded	180	Concrete, Reinforced (with 2% steel) + floor Screed	180 + 50		480	5.560	0.18

3.5.3 Timber construction

Figure 3.6. Visualization image of timber construction in DesignBuilder program.

Table 3.20. Suggested materials for timber construction.

Material and Thickness (mm)							**Image**	**Thickness (mm)**	**R-Value (m^2K/W)**	**U-value (W/m^2K)**
External Walls & Below Grade Walls	Hardboard (High density) + 0.625 in. gypsum board	20 + 158	R-21 Fiberglass batt 2*6 in. (5.5 in. cavity) (Weighting factor is 75% insulated cavity)	180	4 in. Wood 2*4 at R-1.25/in. + 0.625 in. gypsum board	102 + 158		334	5.492	0.182
Flat Roof	Asphalt	22	MW Glass Wool (rolls)	220	Air Gap + Plasterboard	25 + 13		287	4.931	0.18
Pitched Roof (Occupied)	Ceramic/clay tiles-clay tile, burnt	25	Board insulation (Glass fiber borad)	200	Wooden battons + 0.625 in. gypsum board	110 + 20		355	6.686	0.15
Pitched Roof (Un occupied)	Ceramic/clay tiles-clay tile, burnt	25	Air Gap	17	Wooden battons + 0.625 in. gypsum board	130 + 20		192	1.464	0.683

Internal Walls	Plywood	25	XPS Extruded Polystyrene-CO_2 Blowing	120	Plywood	25		170	4.123	0.243
Ground Floor & Internal Floor	Timber Flooring	40	Air layer unventilated-floor + Floor/Roof Screed	10 + 80	Concrete, Reinforced (with 2% steel) + Urea Formaldehyde Foam	180 +200		500	5.969	0.168

According to the Regulation, all the suggested materials for three kinds of construction meet the required U-values in Edinburgh, and these kinds of materials are perfect for new brick/block, metal and timber construction. The only point is that for brick/block construction and timber construction, respectively the external wall thickness of 400 mm and 335 mm, are mass rather than existing kind of wall, it's because of reaching to the U-value of around 0.2 W/m^2K, it's just possible when using a 150-180 mm insulation. Hopefully in the future by using a better kind of insulations with better R-value, these issues will be solved.

3.6 Case studies (Spain) modelled with Lider-Calener (HULC) Software

In this part, a study on the three Spanish cities with a different type of weather using Lider-Calener (Hulc) software was performed, applying the same three kinds of construction which were considered for construction in the UK (brick, timber and metal construction). The cities that have been chosen are Ávila as the highest altitude, with an altitude of 1054 m and climate zone E1, Almería with an altitude of 0 m and climate zone A4 as lowest altitude, finally Zaragoza with height 207 m and climate zone D3. A model in Lider-Calener (Hulc) software is made, and appropriate materials are recommended for walls, two kinds of roofs, floors and the internal walls of new houses for three types of construction that meet the required U-values established in the building regulation and standards. In addition, the heating and cooling demand of the buildings and the energy certification of the houses is studied. The information related to this second part has been set in Appendix D.

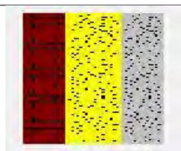
The Unified Lider-Calener (Hulc) Tool (112) includes the unification in a single platform which is used for the evaluation of energy demand and energy consumption. This tool is the General Procedure for Energy Certification of Buildings, and it includes the essential changes for the convergence of energy certification with the Basic Energy Saving Document (DB-HE) of the Technical Building Code (CTE) and the Regulation of Thermal Installations of Buildings (RITE) (141). This computer tool allows the verification of the requirements 2.2.1 of section HE0, 2.2.1.1 and points 2 of section 2.2.2.1 of section HE1 of the DB-HE Basic Energy Saving Document (148). It also allows the verification of section 2.2.2 of chapter HE0 to be verified, as established by the DB-HE, according to the necessary procedure for the energy certification of buildings.

For choosing these materials and these solutions, similarly as in the UK analysis, the *''trial and error''* method was used. Although the same kind of materials and the same initial thickness of the materials which were used for the UK was considered here, they were adapted to the required demand and energy consumption established in the Spanish regulation. Also, the local materials and their low CO_2 emissions as much were considered as possible. This method has been used for the three kinds of construction.

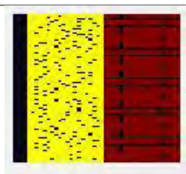
3.6.1 The elements of brick construction

Table 3.21. Suggested materials for brick/block construction in Spain.

A1. External Wall

Material	**Thickness [m]**	**Conductivity [W/mK]**	**Density [kg/m^3]**	**C_p [J/kg·K]**	**U-value [W/m^{2}K]**
½ foot LP metric or Catalan 40 mm<G<60	0.115	0.667	1,140	1,000	0.13
XPS expanded with HFC [0.025 W/mK]	0.150	0.025	38	1,000	
Cellular concrete cured in autoclave	0.115	0.090	300	1,000	
Gypsum plaster	0.020	0.400	900	1,000	

A2. Flat Roof

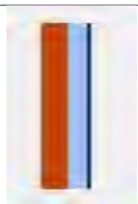
Material	**Thickness [m]**	**Conductivity [W/mK]**	**Density [kg/m^3]**	**C_p [J/kg·K]**	**U-value [W/m^{2}K]**
Sandy asphalt	0.020	0.150	2,100	1,000	0.17
Polyvinyl chloride, PVC + 40% plasticizer	0.180	0.140	1,200	1,000	
XPS expanded with CO_2 [0.034 W/mK]	0.180	0.034	38	1,000	
FR of lightweight concrete	0.180	1.786	1,238	1,000	

A3. Pitched Roof Insulated

Material	**Thickness [m]**	**Conductivity [W/mK]**	**Density [kg/m^3]**	**C_p [J/kg·K]**	**U-value [W/m^{2}K]**
Ceramic tile	0.025	1.300	2,300	840	0.11
XPS expanded with HFC [0.025 W/mK]	0.230	0.025	38	1,000	
Bitumen felt or foil	0.007	0.230	1,100	1,000	

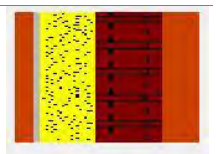
A4. Pitched Roof Uninsulated

Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m³]	C_p [J/kg·K]	U-value [W/m²K]
Ceramic tile	0.025	1.300	2,300	840	3.50
Camera and air slightly ventilated horizontal	0.01	Thermal resistance [m²K/W] 0.075			
Bitumen felt or foil	0.005	0.230	1,100	1,000	



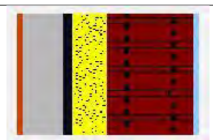
A5. Ground Floor

Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m³]	C_p [J/kg·K]	U-value [W/m²K]
Plate or ceramic tile	0.050	1.000	2,000	800	0.19
Mortar cement or lime for masonry and for plaster / plaster	0.020	0.550	1,125	1,000	
MW mineral wool	0.150	0.031	40	1,000	
Lightweight concrete	0.180	1.786	1,238	1,000	
Sand and gravel [1,700<d<2,200]	0.100	2.000	1,450	1,050	



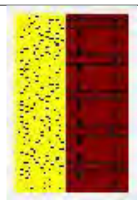
A6. Ceiling

Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m³]	C_p [J/kg·K]	U-value [W/m²K]
Platelet or stoneware tile	0.020	2300	2,500	800	0.20
Mortar cement or lime for masonry and for plaster / plaster	0.020	0.550	1,125	1,000	
Mortar of light aggregates [vermiculite, pearlite]	0.100	0.410	900		
Bitumen felt or foil	0.030	0.230	1,100	1,000	
PUR iron with HFC or pentane and coating	0.100	0.025	45	1,000	
FR of lightweight concrete	0.250	1.323	1,330	1,000	
Camera and air slightly ventilated horizontal	0.02	Thermal resistance [m²K/W] 0.080			
Plasterboard laminated PYL	0.020	0.250	825	1,000	



A7. Internal wall for Brick Construction.

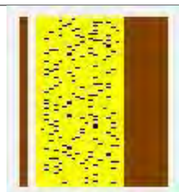
Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m³]	C_p [J/kg·K]	U-value [W/m²K]
Gypsum plaster	0.025	0.400	900	1,000	0.27
MW mineral wool	0.100	0.031	40	1,000	
½ foot LP metric or Catalan 40 mm<G<60	0.125	0.667	1,140	1,000	

Gypsum plaster	0.020	0.400	900	1000	

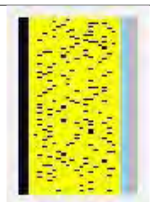
3.6.2. The elements of metal construction

Table 3.22. Suggested materials for metal construction in Spain.

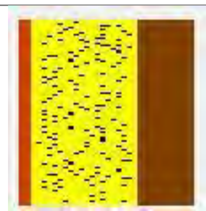
B1. External Wall

Material	**Thickness [m]**	**Conductivity [W/mK]**	**Density [kg/m^3]**	**C_p [J/kg·K]**	**U-value [W/m^{2}K]**
Fiberboard, including MDF	0.020	0.070	180	1,700	0.11
Insulating gypsum plaster	0.020	0.180	550	1,000	
XPS expanded with HFC [0.025 W/mK]	0.165	0.025	38	1,000	
Expanded cork with synthetic resins	0.102	0.049	125	1,560	
Insulating gypsum plaster	0.020	0.180	550	1,000	

B2. Flat Roof

Material	**Thickness [m]**	**Conductivity [W/mK]**	**Density [kg/m^3]**	**C_p [J/kg·K]**	**U-value [W/m^{2}K]**
Sandy asphalt	0.022	0.150	2,100	1,000	0.16
MW mineral wool	0.180	0.031	40	1,000	
Camera and air slightly ventilated horizontal	0.01	Thermal resistance [m^{2}K/W]			
		0.075			
Mortar cement or lime for masonry and for plaster / plaster	0.020	0.550	1,125	1,000	

B3. Pitched Roof Insulated.

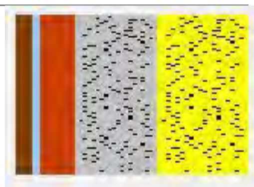
Material	**Thickness [m]**	**Conductivity [W/mK]**	**Density [kg/m^3]**	**C_p [J/kg·K]**	**U-value [W/m^{2}K]**
Ceramic tile-porcelain	0.025	1.300	2,300	840	0.12
XPS expanded with CO_2 [0.034 W/mK]	0.180	0.034	38	1,000	
Expanded cork with synthetic resins	0.130	0.049	125	1,560	
Insulating gypsum plaster	0.020	0.180	550	1,000	

B4. Pitched Roof Uninsulated.

Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m^3]	C_p [J/kg·K]	U-value [W/m^2K]
Ceramic tile-porcelain	0.025	1.300	2,300	840	0.32
Camera and air slightly ventilated horizontal	0.01	Thermal resistance [m^2K/W]			
		0.075			
Expanded cork with synthetic resins	0.130	0.049	125	1,560	
Plasterboard laminated PYL	0.020	0.250	825	1,000	

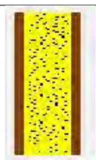
B5. Ground Floor

Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m^3]	C_p [J/kg·K]	U-value [W/m^2K]
Fiberboard, including MDF	0.040	0.070	180	1,700	0.23
Camera and air slightly ventilated horizontal	0.01	Thermal resistance [m^2K/W]			
		0.075			
Sand and gravel [1,700<d<2,200]	0.08	2.000	1,450	1,050	
Cellular concrete cured in autoclave	0.200	0.090	300	1,000	
Expanded clay, loose aggregate	0.180	0.148	538	1,050	



B6. Internal wall

Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m^3]	C_p [J/kg·K]	U-value [W/m^2K]
Fiberboard, including MDF	0.025	0.070	180	1,700	0.20
XPS expanded with HFC [0.025 W/mK]	0.100	0.025	38	1,000	
Fiberboard, including MDF	0.025	0.070	180	1,700	



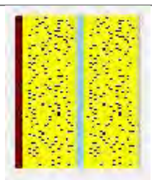
3.6.3 The elements of timber construction

Table 3.23 Suggested materials for timber construction in Spain.

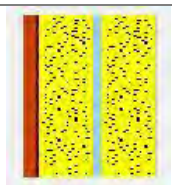
C1. External Wall

Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m^3]	C_p [J/kg·K]	U-value [W/m^{2}K]
Stainless steel	0.050	17.000	7,900	460	0.19
Mortar cement or lime for masonry and for plaster / plaster	0.016	0.300	625	1,000	
EPS Expanded Polystyrene	0.090	0.029	30	1,000	
EPB expanded perlite panel> 80%	0.110	0.062	190	1,000	
Mortar cement or lime for masonry and for plaster / plaster	0.016	0.300	625	1,000	

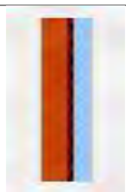
C2. Flat Roof

Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m^3]	C_p [J/kg·K]	U-value [W/m^{2}K]
Concrete slab	0.017	1.667	2,000	1,000	0.19
CG cellular glass panel	0.125	0.050	125	1,000	
The camera of slightly air ventilated horizontal	0.02	Thermal resistance [m^{2}K/W]			
		0.08			
CG cellular glass panel	0.125	0.050	125	1,000	
Alloys of aluminum	0.007	160.000	2,800	880	

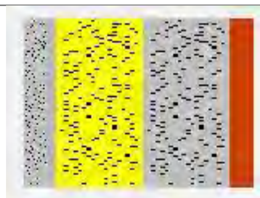
C3. Pitched Roof Insulated.

Material	Thickness [m]	Conductivity [W/mK]	Density [kg/m^3]	C_p [J/kg·K]	U-value [W/m^{2}K]
Ceramic tile	0.030	1.300	2,300	840	0.22
Concrete slab	0.010	2.500	2,500	1,000	
EPB expanded perlite panel,> 80%	0.120	0.062	190	1,000	
The camera of slightly air ventilated horizontal	0.01	Thermal resistance [m^{2}K/W]			
		0.075			
CG cellular glass panel	0.120	0.050	125	1,000	
Iron, casting	0.005	50.000	7,500	450	

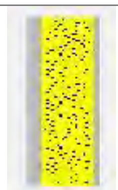
C4. Pitched Roof Uninsulated.

Material	**Thickness [m]**	**Conductivity [W/mK]**	**Density [kg/m³]**	**C_p [J/kg·K]**	**U-value [W/m²K]**
Ceramic tile	0.030	1.300	2,300	840	3.67
Concrete slab	0.010	2.500	2,500	1,000	
The camera of slightly air ventilated horizontal	0.01	Thermal resistance [m²K/W] 0.075			
Iron, casting	0.005	50.000	7,500	450	

C5. Ground Floor

Material	**Thickness [m]**	**Conductivity [W/mK]**	**Density [kg/m³]**	**C_p [J/kg·K]**	**U-value [W/m²K]**
Cellular concrete cured in autoclave	0.050	0.090	300	1,000	0.22
Mortar cement or lime for masonry and for plaster / plaster	0.020	0.550	1,125	1,000	
CG cellular glass panel	0.180	0.050	125	1,000	
Reinforced concrete	0.180	2.500	2,600	1,000	
Sand and gravel [1,700<d<2,200]	0.050	2.000	1,450	1,050	

C6. Internal wall

Material	**Thickness [m]**	**Conductivity [W/mK]**	**Density [kg/m³]**	**C_p [J/kg·K]**	**U-value [W/m²K]**
Alloys of aluminum	0.020	160	2,800	880	0.40
Mortar cement or lime for masonry and for plaster / plaster	0.016	0.300	625	1,000	
CG cellular glass panel	0.110	0.050	125	1,000	
Mortar cement or lime for masonry and for plaster / plaster	0.016	0.300	625	1,000	

All of the mentioned elements meet the required U-values according to the Regulation in Spain, so they are acceptable.

3.7 Results and discussion

3.7.1 Results of the HULC program (Spanish case studies: Zaragoza, Almería, Ávila)

3.7.1.1 Construction in Zaragoza

Table 3.24. Results of three kinds of construction in Zaragoza.

Construction	**Demand (kWh/ m^{2}year)**		**Final Consumption (kWh/m^{2}year)**				**Primary Consumption (kWh/m^{2}year)**				**CO_2 Emissions (kgCO_2/m^2/year)**				**Grade (kgCO_2/ m^2/year)**
	H[1]	C[2]	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	
Brick Zaragoza	40	9.7	47	4.9	7.2	59	56	9.5	8.6	74	12	1.6	1.8	15.2	B 15.2
Brick Zaragoza Uninstall P.R[5]	43	14	58	5.7	7.2	71	61	14	8.6	84	13	2.4	1.8	17.1	B 17.1
Brick Zaragoza Flat Roof	56	12	66	6.1	7.2	79	78	12	8.6	99	16	2.0	1.8	20.4	C 20.4
Metal Zaragoza	43	14	47	7.1	7.2	61	55	14	8.6	78	12	2.4	1.8	16	B 16.0
Metal Zaragoza Uninstall P.R[5]	50	15	60	7.9	7.2	73	62	15	8.6	86	13	2.5	1.8	17.5	B 17.5
Metal Zaragoza Flat Roof	69	14	79	7.0	7.2	98	94	13	8.6	116	20	2.3	1.8	24	C 24.0
Timber Zaragoza	38	13	45	6.5	7.2	59	54	13	8.6	75	11	2.2	1.8	15.3	B 15.3
Timber Zaragoza Uninstall P.R[5]	49	15	56	7.3	7.2	71	67	15	8.6	90	14	2.4	1.8	18.5	B 18.5
Timber ZaragozaF.R[6]	60	18	69	9.0	7.2	85	82	17	8.6	108	17.4	3.0	1.8	22.2	C 22.2

[1]H: Heating [2]C: Cooling [3]ACS: Air condition system [4]GL: Global [5]P.R: Pitched roof [6]F.R: Flat roof

According to Table 3.24, the brick and timber construction are good options for building in Zaragoza. There are no significant differences between these two kinds of construction, but the brick construction is a little more suitable rather than others, especially when triple glazed windows are used. The metal construction with that kind of elements is acceptable, but it has a lower grade.

The flat roof is not acceptable for any kinds of construction. If the building design involves using a flat roof, it is essential to use more insulation layers or using materials with lower thermal conductivity. As the space below the pitched roof is unoccupied, it is possible not to install the roof elements, but just for brick and timber construction, the uninsulated pitched roof is not acceptable for metal construction. Also, the uninsulated brick pitched roof construction is more suitable than timber construction.

3.7.1.2 Construction in Almería

Table 3.25. Results of three kinds of construction in Almería.

Construction	Demand (kWh/m^{2}year)		Final Consumption (kWh/m^{2}year)				Primary Consumption (kWh/m^{2}year)				CO_2 Emissions ($kgCO_2/m^2/year$)				Grade ($kgCO_2/m^2/year$)
	H[1]	C[2]	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	
Brick Almería	4.3	16	5.7	8.2	7.2	21	6.7	16	8.6	31	1.4	2.7	1.8	6.0	B 6.0
Metal Almería	5.8	17	7.2	8.4	7.2	23	8.6	16	8.6	34	1.8	2.8	1.8	6.4	B 6.4
Timber Almería	5.3	19	6.6	9.6	7.2	23	7.9	19	8.6	35	1.7	3.2	1.8	6.7	B 6.7
Timber Almería Flat roof	12	20	15	9.9	7.2	32	18	19	8.6	46	3.8	3.3	1.8	8.9	B 8.9

[1]H: Heating [2]C: Cooling [3]ACS: Air condition system [4]GL: Global

According to Table 3.25, the brick construction is the best option for building in Almería, after that the metal construction and the last option is the timber construction. Also, the flat roof timber construction is acceptable in Almería with a good grade. Almería is the warmest city in Spain. It demonstrates that the brick construction is the best option for warmer places and the timber construction is the worst option.

3.7.1.3 Construction in Ávila

Table 3.26. Results of three kinds of construction in Ávila.

Construction	Demand (kWh/m^{2}year)		Final Consumption (kWh/m^{2}year)				Primary Consumption (kWh/m^{2}year)				CO_2 Emissions ($kgCO_2/m^2/year$)				Grade ($kgCO_2/m^2/year$)
	H[1]	C[2]	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	
Brick Ávila	53	0.6	61	0.3	7.2	70	73	0.6	8.6	82	16	0.1	1.8	17.5	B 17.5
Metal Ávila	57	1.0	66	0.5	7.2	74	79	0.9	8.6	88	17	0.2	1.8	18.7	B 18.7
Timber Ávila	50	2.8	58.4	1.4	7.2	67	70	2.8	8.6	81	15	0.5	1.8	17	B 17
Timber Ávila Flat roof	72	3.8	82	1.9	7.2	92	98	3.7	8.6	110	21	0.6	1.8	23.3	C 23.3

[1]H: Heating [2]C: Cooling [3]ACS: Air condition system [4]GL: Global

According to Table 3.26, the timber construction is the best option for building in Ávila, after that the brick construction and the last option is the metal construction. Also, the flat roof timber construction is acceptable in Ávila, but with an unfavourable grade. Ávila is the coldest city in Spain. It demonstrates that timber construction is the best option for cooler places and metal construction is the worst option.

3.7.1.4 Brick/Block Construction in three Spanish cities

Table 3.27. Results of brick/block construction in three cities in Spain.

Construction	**Demand (kWh/m²year)**		**Final Consumption (kWh/m²year)**				**Primary Consumption (kWh/m²year)**				**CO_2 Emissions ($kgCO_2/m^2$/year)**				**Grade ($kgCO_2/m^2$/ year)**
	H[1]	C[2]	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	
Brick Zaragoza	40	9.7	47	4.9	7.2	59	56	9.5	8.6	74	12	1.6	1.8	15.2	B 15.2
Brick Zaragoza Uninstall P.R[5]	43	14	58	5.7	7.2	71	61	14	8.6	84	13	2.4	1.8	17.1	B 17.1
Brick Zaragoza F.R[6]	56	12	66	6.1	7.2	79	78	12	8.6	99	16	2.0	1.8	20.4	C 20.4
Brick Zaragoza Triple Glazed	34	8.2	40	4.1	7.2	47	47	8.0	4.3	60	10	1.4	1.8	12.2	B 12.2
Brick Zaragoza Simple Glazed	43	8.3	49	4.2	7.2	57	58	8.1	4.3	70	12	1.4	1.8	14.6	B 14.6
Brick Almería	4.3	16	5.7	8.2	7.2	21	6.7	16	8.6	31	1.4	2.7	1.8	6.0	B 6.0
Brick Ávila	53	0.6	61	0.3	7.2	70	73	0.6	8.6	82	16	0.1	1.8	17.5	B 17.5

[1]H: Heating [2]C: Cooling [3]ACS: Air condition system [4]GL: Global [5]P.R: Pitched roof [6]F.R: Flat roof

The brick construction is acceptable for Zaragoza with an insulated or uninsulated pitched roof but not with a flat roof. If it triple glazed windows are used, the grade goes three level up. Also double glazed is acceptable; but with simple glazed, the heating demand exceeds the limitation and do not pass the regulation. As shown in Table 3.27, between three cities, brick construction with that element is the best option for Almería, then Zaragoza and finally for Ávila.

3.7.1.5 Metal Construction in three Spanish cities

Table 3.28. Results of metal construction in three cities in Spain.

Construction	**Demand (kWh/m²year)**		**Final Consumption (kWh/m²year)**				**Primary Consumption (kWh/m²year)**				**CO_2 Emissions ($kgCO_2/m^2$/year)**				**Grade ($kgCO_2/m^2$/ year)**
	H[1]	C[2]	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	
Metal Zaragoza	43	14	47	7.1	7.2	61	55	14	8.6	78	12	2.4	1.8	16	B 16.0
Metal Zaragoza less Window	49	12	54	8.6	7.2	65	62	12	8.6	82	13	2.0	1.8	16.9	B 16.9

Metal Zaragoza Uninstall P.R[5]	50	15	60	7.9	7.2	73	62	15	8.6	86	13	2.5	1.8	17.5	B 17.5
Metal Zaragoza F.R[6]	69	14	79	7.0	7.2	98	94	13	8.6	116	20	2.3	1.8	24	C 24.0
Metal Almería	5.8	17	7.2	8.4	7.2	23	8.6	16	8.6	34	1.8	2.8	1.8	6.4	B 6.4
Metal Ávila	57	1.0	66	0.5	7.2	74	79	0.9	8.6	88	17	0.2	1.8	18.7	B 18.7

[1]H: Heating [2]C: Cooling [3]ACS: Air condition system [4]GL: Global [5]P.R: Pitched roof [6]F.R: Flat roof

The metal construction is acceptable for Zaragoza just with an insulated Pitched roof, the uninsulated pitched roof and flat roof are not allowed. For better condition especially for the cooling part, it is better to use fewer windows or reduce the size of the windows. If it has happened, the grades will go one level up. As shown in Table 3.28, between three cities, metal construction with that element is the best option for Almería, then Zaragoza and finally for Ávila.

3.7.1.6 Timber Construction in three Spanish cities

Table 3.29. Results of timber construction in three cities in Spain.

Construction	**Demand (kWh/m²year)**		**Final Consumption (kWh/m²year)**				**Primary Consumption (kWh/m²year)**				**CO₂ Emissions (kgCO₂/m²/year)**				**Grade (kgCO₂/ m²/year)**
	H[1]	C[2]	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	H[1]	C[2]	ACS	GL	
Timber Zaragoza	38	13	45	6.5	7.2	59	54	13	8.6	75	11	2.2	1.8	15.3	B 15.3
Timber Zaragoza Uninstall P.R[5]	49	15	56	7.3	7.2	71	67	15	8.6	90	14	2.4	1.8	18.5	B 18.5
Timber Almería	5.3	19	6.6	9.6	7.2	23	7.9	19	8.6	35	1.7	3.2	1.8	6.7	B 6.7
Timber Ávila	50	2.8	58.4	1.4	7.2	67	70	2.8	8.6	81	15	0.5	1.8	17	B 17
Timber Zaragoza F.R[6]	60	18	69	9.0	7.2	85	82	17	8.6	108	17.4	3.0	1.8	22.2	C 22.2
Timber Almería F.R[6]	12	20	15	9.9	7.2	32	18	19	8.6	46	3.8	3.3	1.8	8.9	B 8.9
Timber Ávila F.R[6]	72	3.8	82	1.9	7.2	92	98	3.7	8.6	110	21	0.6	1.8	23.3	C 23.3

[1]H: Heating [2]C: Cooling [3]ACS: Air condition system [4]GL: Global [5]P.R: Pitched roof [6]F.R: Flat roof

The timber construction is acceptable for Zaragoza with an insulated or uninsulated pitched roof. Between three cities, Timber construction with that element is the best option for Almería, then Zaragoza and finally for Ávila. Similar to Metal construction. As shown in Table 3.29, if the building design involved using a flat roof with the mentioned material, it would only be possible for Almería. Also, it would be possible for Ávila, but with an unfavourable emission grade.

3.7.2 Results of the DesignBuilder program (case studies: Edinburgh and Zaragoza).

Table 3.30. Results of U-values for three different kinds of construction in Edinburgh using DesignBuilder Program.

Construction	U-value (W/m²K)	Thickness (mm)
External Wall Brick	0.200	400 (150 XPS Insulation)
External Wall Metal	0.190	307 (210 Polystyrene Insulation)
External Wall Timber	0.182	334 (180 Fiberglass Insulation)
Flat Roof Brick	0.160	398 (180 XPS Insulation)
Flat Roof Metal	0.163	289 (250 Fiberglass Insulation)
Flat Roof Timber	0.200	247 (180 MW Insulation)
Pitched Roof (Insulated) Brick	0.168	262
Pitched Roof (Insulated) Metal	0.169	295
Pitched Roof (Insulated) Timber	0.150	355
Pitched Roof (UN-insulated) Brick	2.930	50
Pitched Roof (UN-insulated Metal	2.735	70
Pitched Roof (UN-insulated Timber	0.683	192
Internal Wall Brick	0.294	263 (100 MW Insulation)
Internal Wall Metal	0.270	172 (120 Fiberglass Insulation)
Internal Wall Timber	0.243	170 (120 XPS Insulation)
Ground Floor Brick	0.183	500 (150 Wool Insulation)
Ground Floor Metal	0.180	480 (180 Wool Insulation)
Ground Floor Timber	0.168	500 (200 Urea Insulation)

According to Table 3.30, all the fabric components meet the required U-value. Usually, the timber materials with a conductivity of around 0.07 W/mK have better U-value rather than a brick with a conductivity of about 0.7 W/mK and metal with a conductivity of approximately 17 W/mK for steel and 50 W/mK for iron. Regards to the external wall, it is expected that brick walls have a better U-value rather than metal ones, although the metal walls have a thicker insulation layer; also, timber walls have a better U-value although they have a thinner insulation layer.

Regards to the flat roof the U-value of brick material is better than the timber roof, although both of them have the same quantity of insulation material. It illustrates the effect of the insulation material, the conductivity of XPS insulation is around 0.025 W/mK, but the conductivity of mineral wool (MW) is approximately 0.05 W/mK, which shows that using a different insulation material has a significant effect on the U-value.

About the Pitched roof, there is a limitation to use different kinds of insulation layers with different thickness for roofs of this sort so, generally simple insulation with a typical thickness is used, and the last U-value is agreeing with the kind of another material. Regards to uninsulated pitched roofs, as the resistance of timber materials, are less than another primarily when used as an oblique, it is essential to use more thickness so, increasing the thickness results in better U-value.

For the internal walls, the metal and timber walls have the same thickness as a whole and insulation layer but because of having a better conductivity of both timber and insulation materials owns lower U-values. On the ground floors, it expected that the U-value of the brick floor is lower than metal ones, but it is not observed. This demonstrates the influence of some insulation layers on U-values: the brick and metal materials have the same U-values and the same kinds of insulation, but they have a different amount of insulation materials that effect on U-values.

Table 3.31. Results of U-values for three kinds of construction in Zaragoza, using two different software tools.

Construction	U-value (W/m^2K)	Thickness (mm)
External Wall Brick (DesignBuilder)	0.200	400 (150 XPS Insulation)
External Wall Metal (DesignBuilder)	0.190	307 (210 Polystyrene Insulation)
External Wall Timber (DesignBuilder)	0.182	334 (180 Fiberglass Insulation)
External Wall Brick (HULC)	0.130	400 (150 XPS Insulation)
External Wall Metal (HULC)	0.190	307 (210 Polystyrene Insulation)
External Wall Timber (HULC)	0.110	334 (180 Glass Insulation)
Flat Roof Brick (DesignBuilder)	0.160	398 (180 XPS Insulation)
Flat Roof Metal (DesignBuilder)	0.163	289 (250 Fiberglass Insulation)
Flat Roof Timber (DesignBuilder)	0.200	247 (180 MW Insulation)
Flat Roof Brick (HULC)	0.170	398 (180 XPS Insulation)
Flat Roof Metal (HULC)	0.190	289 (250 Glass Insulation)
Flat Roof Timber (HULC)	0.160	247 (180 MW Insulation)
Pitched Roof (Insulated) Brick (DesignBuilder)	0.168	262
Pitched Roof (Insulated) Metal (DesignBuilder)	0.169	295
Pitched Roof (Insulated) Timber (DesignBuilder)	0.150	355
Pitched Roof (Insulated) Brick (HULC)	0.110	262
Pitched Roof (Insulated) Metal (HULC)	0.130	295
Pitched Roof (Insulated) Timber (HULC)	0.120	355
Pitched Roof UN-insulated Brick (DesignBuilder)	2.930	50
Pitched Roof UN-insulated Metal (DesignBuilder)	2.735	70
Pitched Roof UN-insulated Timber (DesignBuilder)	0.683	192
Pitched Roof UN-insulated Brick (HULC)	3.500	50
Pitched Roof UN-insulated Metal (HULC)	3.670	70
Pitched Roof UN-insulated Timber (HULC)	0.320	192
Internal Wall Brick (DesignBuilder)	0.294	263 (100 MW Insulation)
Internal Wall Metal (DesignBuilder)	0.270	172 (120 Fiberglass Insulation)
Internal Wall Timber (DesignBuilder)	0.243	170 (120 XPS Insulation)
Internal Wall Brick (HULC)	0.27	263 (100 MW Insulation)
Internal Wall Metal (HULC)	0.40	172 (120 Glass Insulation)
Internal Wall Timber (HULC)	0.20	170 (120 XPS Insulation)
Ground Floor Brick (DesignBuilder)	0.183	500 (150 Wool Insulation)
Ground Floor Metal (DesignBuilder)	0.180	480 (180 Wool Insulation)
Ground Floor Timber (DesignBuilder)	0.168	500 (200 Urea Insulation)
Ground Floor Brick (HULC)	0.190	500 (150 Wool Insulation)
Ground Floor Metal (HULC)	0.220	480 (180 Wool Insulation)
Ground Floor Timber (HULC)	0.230	500 (200 Urea Insulation)

Table 3.31 demonstrates that in most of the materials there is a difference between the U-values. It is observed that the same materials in the HULC software have better conductivities. For example, in the DesignBuilder program there are two kinds of XPS insulation with a conductivity of 0.04 W/mK, but in the HULC software there are seven kinds of XPS insulation with different conductivity from 0.025 W/mK, it exactly happened for fibreglass insulation which it has a conductivity of 0.05 W/mK in HULC software and between 0.043 W/mK and 0.085 W/mK in DesignBuilder that for the slabs it is essential to use a fibreglass insulation with 0.085 W/mK. As a whole, the library of DesignBuilder program has more materials rather than HULC, and the kinds of materials are further.

For two kinds of software, the same materials with the same thickness were used that caused to reach the different U-values. In two different software, it is impossible to work on the same materials with the same thickness and reach the same U-values. Firstly, tried to reach the same U-values in two software that it caused different materials or thickness; however, with that kinds of materials and thickness, it was not possible to meet the building regulations of Spain. According to the HULC program, the houses with that materials are not acceptable for Spain because they exceeded the consumption and demand limitation for heating or cooling. Therefore it was necessary to change the methodology and work on the same materials and thickness to meet the U-values which are acceptable for both building regulations of Spain and the UK.

Table 3.32. Results of the site and source energy for three kinds of construction in two different cities using DesignBuilder Program.

	Edinburgh			**Zaragoza**		
	Brick. Energy per total Building Area (kWh/m^2year)	Metal. Energy per total Building Area (kWh/m^2 year)	Timber. Energy per total Building Area (kWh/m^2 year)	Brick. Energy per total Building Area (kWh/m^2 year)	Metal. Energy per total Building Area (kWh/m^2 year)	Timer. Energy per total Building Area (kWh/m^2 year)
Total Site Energy	47.24	44.36	44.03	26.50	24.62	24.97
Total Source Energy	168.98	158.56	157.31	78.80	73.98	73.71

Table 3.32 illustrates that the energy consumption of houses in Edinburgh is around double time more than Zaragoza. The energy of timber construction is lower than another after that metal construction and brick construction involves the highest energy consumption. The site and source energy respectively refer to final and primary energy.

Table 3.33. Results of the costs of construction for three kinds of construction in Edinburgh using DesignBuilder Program.

Structure	**Brick/Block Construction (GBP)**	**Metal Construction (GBP)**	**Timber Construction (GBP)**
Structure costs	43,400	46,600	45,000
HVAC costs	16,700	18,000	17,800
Lighting costs	10,000	10,800	10,600
Surface finish costs	11,000	12,000	11,500
Building total cost	294,197	314,210	298,681

As shown in Table 3.33, the construction cost of metal is more than two another kinds, and the brick/block construction is the cheapest. The prices depend on many factors and can be very different in every country or city, but the DesignBuilder program considers the same unit costs per kg for each country.

Table 3.34. Results of the CO_2 emissions for three kinds of construction in Edinburgh using DesignBuilder Program.

	Brick Construction	**Metal Construction**	**Timber Construction**
Embodied carbon ($kgCO_2$)	61,811	215,803	70,145
Equivalent CO_2 ($kgCO_2$-eq)	71,051	231,758	79,249

Regards to Table 3.34, as expected the emissions of metal construction are high, around triple of another kind of construction. The emissions of brick and timber construction are similar, but the brick construction is a little better.

According to the literate and studies (149,150), the timber construction emits less CO_2 rather than brick and metal construction. However, in this study, as shown in the above table, the CO_2 emissions of timber construction is more than brick construction. One of the reason is that the kind of insulation used in walls and roof in brick/block construction is XPS Extruded Polystyrene-CO_2 Blowing, that is one of the best insulation layers with the lowest CO_2 emissions especially between insulation materials and with the lower CO_2 emissions rather than fibreglass insulations which is applied in the timber construction. As a whole, the timber is a favourable environmentally building material that offers the best choice in energy consumption and CO_2 emissions. In addition, the timber should persuade developers to the compilation of more timber in the construction to enhance the environmental aspect and economically options. Table 3.35 summarises the main advantages and disadvantages of using timber, brick/block and metal materials in new constructions.

Table 3.35. Advantages and disadvantages of three different kinds of materials.*

	Timber	Brick/Block	Metal
Advantages	The most green & Eco-friendly material. Pre-manufactured possibility. Lightweight.	The most durable material. Need the lowest maintenance. The most fire resistant material.	The most recycled material. Long span construction possibility. Pre-manufactured possibility. Lightweight.
Disadvantages	Insect infestations. Need the highest maintenance.	Time. Heavyweight.	Rust. Unsafe in heated conditions.

*This information can change depending on the climate conditions.

Table 3.36 outlines the recommended kinds of construction for three different cities in Spain with different kinds of weather.

Table 3.36. Recommended kinds of constructions for three different locations.

	★★★[1]	★★☆[2]	★☆☆[3]
Ávila (cold weather)	Timber	Brick	Metal
Zaragoza (intermediate weather)	Brick	Timber	Metal
Almería (hot weather)	Brick	Metal	Timber

[1] This kind of construction is the best alternative and strongly suggested.
[2] This kind of construction is an appropriate alternative.
[3] This kind of construction is the worst alternative and not suggested.

Metal construction has better performance in hot weather locations rather than timber, because of the ability of flam and fungal attack of timber and, moisture movement; the moisture in wooden elements could diminish the durability of the structure.

3.8 Conclusions

Nowadays in the EU, the trend of construction moves toward green and energy efficient buildings. Timber has the greenest features and is known as an eco-friendly material. However, it also depends on the climate condition. The most durable material is masonry material that needs lower maintenance rather than timber and metal materials. The most recycled material is metal, so, by applying the metal frame, some money can be saved.

From the analysis of the energy performance of new houses in Spain and the UK, it can be concluded that timber construction is the best option for places with cold weather, the brick construction is the best alternative for places with hot weather, and both these kinds of construction are the better options for locations with more moderate weather rather than metal construction. In addition, uninstalled pitched roofs are not accepted for the houses that are placed in hot weather.

Reaching the lower U-values by using the existed materials is very difficult. The only way is increasing the thickness of elements, which reduces the useful surface for the building users.

If the national governments set low U-values, a new generation of technology and materials especially insulation material will be needed. It is possible to reach the lower U-values with new construction generation such as intelligent and prefabricated buildings. The suggested materials in this chapter could be applied to other EU countries, as the lowest U-values have been considered. However, it should be checked according to the building regulations and standards of each country.

CHAPTER 4. IN-SITU THERMAL TRANSMITTANCE MEASUREMENT FOR EVALUATING DIFFERENCES BETWEEN ACTUAL AND MODELLED HOUSE THERMAL PERFORMANCE

Energy diagnosis and check of energy performance of traditional houses are becoming urgent and essential to achieving energy saving in the residential sector. This chapter presents the results of some experimental studies focused on the enhancement of the methods to assess the energy efficiency in traditional houses. It is focused on U-value as an indicator of thermal energy efficiency of traditional houses and involves in-situ measurement and the subsequent comparison with U-values calculated by an energy simulation software tool to check its suitability to estimate the U-values of traditional construction build-up.

The primary objective of the study is to assess the actual thermal performance of traditional house components to guide energy efficiency assessments and to aid in the selection of refurbishment choices. Also, it aims to present the measurement and analysis procedures used to determine the in-situ U-values.

The chapter firstly describes the methodology followed for the in-situ U-value measurements and calculations. All the U-value measurements were based on the heat flux method, which uses data of a heat flux sensor and two temperature sensors. Then, it presents the main characteristics of the twelve case studies (houses), where measurements were taken, and the detailed building components. Next, the U-values measured are compared to the calculated U-values, analysing the causes of the differences between these values. The primary focus of the studies is on walls constructed with a range of materials and techniques.

4.1 Methodology

This section describes the work on measuring the thermal transmittance (U-value), through components of traditionally constructed properties. The properties featured in the chapter are typical examples of pre-1919 construction in Scotland. All of the houses are of traditional construction (solid walls), and most are constructed from lime-bonded rubble or ashlar stonework, typically 300 to 600mm thick, with natural slate or tile roofs, doors and timber windows (151).

The heat flow was directly measured through the house components using heat flux sensors mounted on an internal surface and using temperature sensors inside and outside the dwelling. All measurements were taken in occupied properties and therefore included external, and interior wall finishes.

The measurements had to be performed in the selected wall where heat flow is one-dimensional. One-dimensional heat flow demonstrates the flowing of heat in one plane of the wall and out the other face; where the cross-sectional zone of the wall in the heat flow direction is stable. Those walls were selected by an infra-red camera that generally is used to locate places with much difference temperature and inhomogeneous components; moreover, it assists to not locate the sensors on the cold bridges.

Where possible a North face or protective wall was selected to avoid direct solar radiation (151), so solar radiation could not affect. It is better to avoid measuring in the south wall of a dwelling since the thermal storage capacity of the wall should not be underestimated. Moreover, it is better to cover the temperature sensor to block any direct sunlight (e.g., with aluminium foil) (152).

Measurements had no impact on the daily routines of building occupants because the measurement setup was rather small. If the sensors are located correctly, they will not bother any house resident. To increment the accuracy of the obtained data dwelling occupants, the indoor temperature was kept as stable as possible (e.g., by limit the opening of the window or not switching the radiator off during the night).

4.1.1 In-situ measurement equipment and process

Each of the measurement setups included:

- 1 x Heat flux sensor.
- 2 x Temperature sensors.
- 1 x Data logger with an adjustable calculating frequency that facilitates automatic recording of heat flux through the house component, indoor, and outdoor temperatures.

For each configuration, a heat flux sensor was mounted on the inside of the wall using regular adhesive tapes. One of the temperature sensors was mounted near the heat flux sensor. The second temperature sensor was installed in correspondence of the other surface temperature positioned inside.

During in-situ calculations, the boundary conditions (solar radiation, temperature and wind speed) changed with time (34). Therefore the heat flux sensor was covered with aluminium foil to minimise the impact of the solar radiation on the measurement outcomes. The whole setup was connected to the data logger, who recorded the heat flux (φ_j) and inside surface temperature (T_{ij}) and outside surface temperature (T_{oj}) simultaneously in each j instant at a sampling rate of 1 sample per 10 minutes. Sensors place were chosen to avoid the probable thermal bridge, locations nearby to corners and windows. The heat flow sensor was ideally placed about halfway between the edges and window, and ceiling and floor. Figure 4.1 illustrates the in-situ measurement graphically.

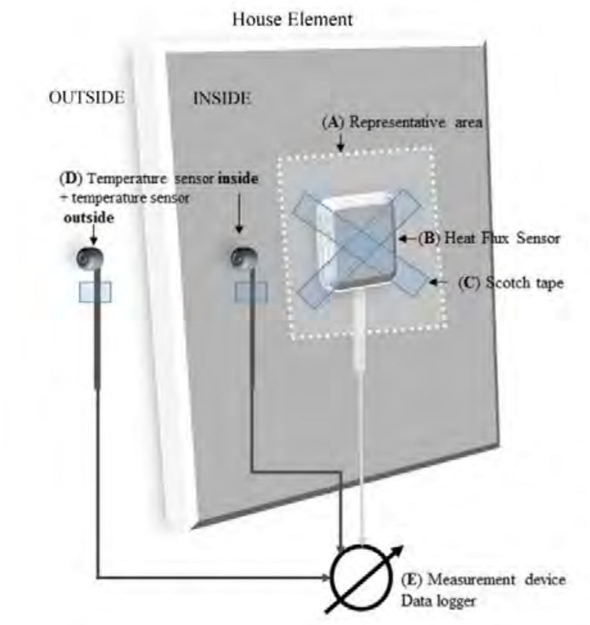


Figure 4.1. Schematic graphic of the in-situ measurement.

The following process was used to arrange a measurement:

- A representative area (A) of the surface to be studied was chosen, ensuring that the housing element was dry, flat and free of dust.
- Heat flux sensor placement: The heat flux sensor (B) was mounted on the indoor surface and was protected from direct heating, convection, and solar radiation. It was capped with the same material as its surrounding material (C).
- Temperature sensor placement: Two sensors (D) were placed on roughly opposite sides of the house component where the heat flux sensor is positioned. To ensure accurate calculations, the surface of the sensor was exposed to the air mimicking the surrounding wall surface or window. For example, if the surface to be determined was covered with black paint, maximum accuracy was obtained by covering the sensors with the same colour.
- Data acquisition (according to the Standard ISO 9869 (42)): The minimum calculation duration considered was 72 hours. The measurement was ended when the U-value did not deviate by more than ±5% of the value achieved 24h earlier (automatically calculated). Typical recording frequency of the data logger (E) is one data point per 5 minutes. The U-value calculation by means of experimental data was performed using the progressive average method.
- Use the data logger (E) to obtain results of the heat flux.
- Connect the heat flux sensor to the measurement tool and record the output voltage U, and calculate the heat flux φ using the sensor-specific sensitivity S.

The equation 4.1 is used for calculating the heat flux (W/m^2):

$\varphi = \frac{U}{S}$ (eq. 4.1)

Where φ is the heat flux in W/m^2, U is the measured voltage in V and S is the sensor-specific sensitivity in μV/ (W/m^2).
Then equation 4.2 is used for calculating the U-Value (W/m^{2}K) from the measurements:

$$U - value \ = \frac{\sum_{j=1}^{n} \varphi_j}{\sum_{j=1}^{n} (T_{ij} - T_{oj})} \ \text{(eq. 4.2)}$$

Where T_{oj} is the outside surface temperature (K), T_{ij} is the inside surface temperature (K), and φ_j is the heat flux (W/m^2) in each j instant, from j=1 to n.

4.1.2 U-value calculations

The U-values of the house components measured were also calculated by using a software tool. Energy simulation software tools for buildings have had developments over the years (153). Currently, there are different tools with different levels of complexity and response to different variables. Some examples are DesignBuilder (EnergyPlus), ESP-r (Energy Simulation Software tool), IES-VE (Integrated Environmental Solutions-Virtual Environment) and TRNSYS. For this study, Design-Builder U-value Calculator tool was selected to calculate the U-values of the house components measured. It was deemed an appropriate tool for the U-value comparison calculations since its calculations are based on the standards set out in the document BR 443 (82). Also, Design-Builder is a thermal simulation program that enables the energy modelling and analysis of any building. The program can simulate different models for heating, cooling, heating, ventilation, lighting, and other energy flows (113).
In order to calculate the U-value, a wall stratigraphy of the house and the materials thermal conductivity values are required. In this study, the building materials database of Design-Builder, which includes default thermal conductivity values, was considered. The Standard ISO 9869 (42) provides thermal conductivity values of the primary construction materials when it is not possible to get direct information from a database or a product data sheet. Starting from this information, it is possible to choose among many categories for each material, characterised by different thermal properties.
Then equation 4.3 is used for calculating the U-Value (W/m^{2}K) of a house component from the Design-Builder U-value Calculator tool:

$$U - value \ = \frac{1}{R_t} = \frac{1}{R_{si} + R_{layers} + R_{se}} \ \text{(eq. 4.3)}$$

Where R_t is the total thermal resistance of the house component considered (m^{2}K/W), R_{layers} is the total thermal resistance of the component (m^{2}K/W), whereas R_{si} and R_{se} are the convective thermal resistance of the inside and outside surfaces of the component (m^{2}K/W).

In this study, a value of 0.09 m^{2}K/W and 0.03 m^{2}K/W was taken for R_{si} and R_{se} respectively.
Moreover, the equation 4.4 allows to calculate R_{layers} (m^{2}K/W):

$R_{layers} = \sum_{k=1}^{m} R_k$ (eq. 4.4)

Where R_k is the thermal resistance of the layer k of the component (m^2K/W), from k=1 to m layers.
Finally, R_k (m^2K/W) can be calculated using equation 4.5 if the layer is solid, or using equation 4.6 if the layer is a fluid (e.g. air gap):

$R_k = \frac{e_k}{\lambda_k}$ (eq. 4.5)
$R_k = \frac{1}{h_k}$ (eq. 4.6)

Where e_k is the thickness of the layer k (m), λ_k is the thermal conductivity of the layer k (W/mK), and h_k is the convective heat transfer coefficient of the layer k (W/m^2K) of the component, from k=1 to m layers.

4.1.3 Comparison between measured and calculated U-values

To verify the suitability of using the U-value calculation tool with old house components, this study compares the in-situ U-values measured with their equivalent calculated by the software. A particular focus of the comparison is the impact of lime and stone core of an old solid stone wall which is not considered in the tool, assuming a homogeneous buildability of masonry throughout the thickness of the wall. Since DesignBuilder U-value calculator is typically used as an assessment tool for new and existing stock to ensure their adoption with U-value requirement of house standards, the U-values measured in this study were subsequently compared with the calculated U-values using DesignBuilder U-value calculator, to assess the applicability of this tool when used for evaluating traditional building construction (80).

4.2 Case studies

Twelve properties throughout Scotland were visited for the experimental measurements. Houses with different kinds of materials, all of them constructed pre-1919 with traditional construction techniques, were chosen for this analysis. Eight of them are located in Edinburgh, one in Dalkeith, one in Lauder, one in Bonnyrigg and one in Duns. Thirteen walls were measured; just two walls were insulated. The measurement was conducted during a 90 hour period. The location of case studies is shown in Figures 4.2 and 4.3.

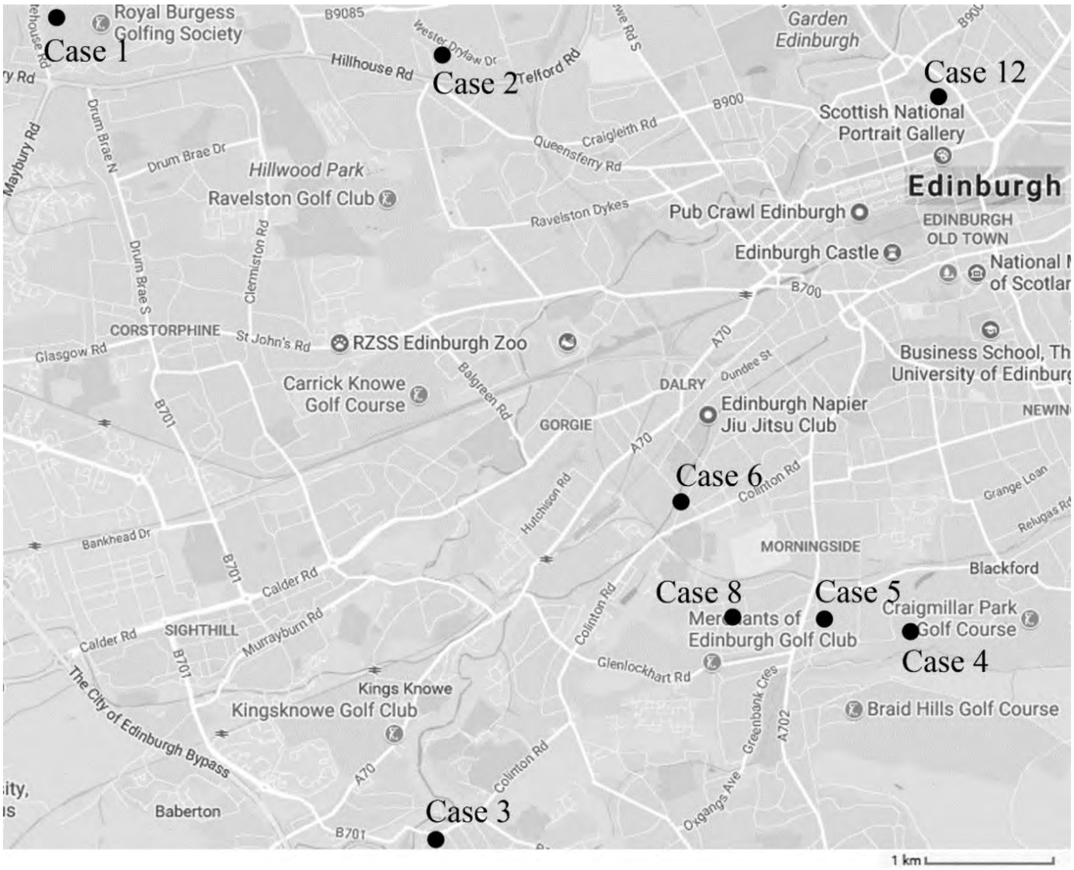


Figure 4.2. Location of the case studies in Edinburgh (source: Google Maps).

Figure 4.3. Location of case studies out of Edinburgh (source: Google Maps).

U-values of walls were measured reliably via heat flux measurements. Difference types of walls, varying widely in thermal performance, can be assessed accurately. However, concerns raised about the influence of external conditions on the outcome of the measurement. It is critical since heat flux measurements are performed in an occupied building in which stable conditions are difficult to reach. Fluctuation of inside temperature has a significant effect on the measured heat flux and the U-value. However, it is advisable to keep the interior temperature constant to reach a reliable U-value. The impact of the outside temperature on the heat flux is less visible but can also be substantial. Therefore a calculation would last 24 hours preferably, by taking into account the daily change in temperature.

4.2.1 Main characteristics of the houses and their measured components

Traditionally constructed walls in Scotland are usually 400 to 600 mm thick and built with stone (of differing rock types) either rubble or dressed stones bedded in lime mortar with a rubble mortar core. The wall is often finished internally with lath and plaster lining with a 10 to 30 mm air gap between the lining and stone wall. In some areas, walls are plastered directly onto the rock, on the hard, although this is less common in most residential buildings. Such stone walls are not homogenous in their build-up, but consist of inner and outer stone leaves with the centre of the barrier being pack with smaller stone and mortar. The basic characteristics of the houses are detailed in Table 4.1. The details of the measured elements are listed in Table 4.2.

Table 4.1. Basic characteristics of the measured houses.

Case	**Location**	**Gross internal floor area (m^2)**	**Year of construction (age)**	**Year of refurbishment**
1	Edinburgh	212	1915 (102)	1984
2	Edinburgh	184	1910 (107)	1977
3	Edinburgh	377	1902 (115)	-
4	Edinburgh	317.6	1891 (126)	-
5	Edinburgh	290	1885 (132)	-
6	Edinburgh	269	1877 (140)	-
7	Dalkeith	249	1866 (151)	1902 & 1982
8	Edinburgh	124	1857 (160)	-
9	Lauder	287	1853 (164)	-
10	Bonnyrigg	93	1848 (169)	-
11	Duns	196	1846 (171)	-
12	Edinburgh	363	1794 (223)	-

Table 4.2. Detail of the measured elements.

Case 1		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**
Brick	80	0.84
Air gap	10	-
Insulation	20	0.036
Brick	80	1.1
Plaster of hard	15	0.25
Total thickness (mm)	220	

Case 2		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**
Cement sand render	10	1.50
Blond sandstone	120	4.20
Insulation	20	0.04
Sandstone	250	5.00
Air gap	5	-
Gypsum plasterboard	10	0.70
Total thickness (mm)	415	
Case 3		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**
Gypsum plastering	25	0.40
Tuff stone	500	3.50
Air gap	5	-
Gypsum plasterboard	20	0.50
Total thickness (mm)	550	
Case 4		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**
Ashlar	100	1.50
Air gap	10	-
Blond sandstone	400	5.00
Plaster on hard	20	0.16
Total thickness (mm)	530	
Case 5		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**
Ashlar	200	1.83
Blond sandstone	400	5.00
Air gap	10	-
Plaster on laths	20	0.4
Total thickness (mm)	630	
Case 6		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**
Squared rubble	130	1.74
Locharbriggs sandstone	450	3.70
Air gap	5	-
Plaster on laths	15	0.6
Total thickness (mm)	600	
Case 7a (uninsulated wall)		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**
Brick	200	1.10
Sandstone	350	5.00
Air gap	25	-
Plaster on laths	11	0.88
Total thickness (mm)	590	
Case 7b (insulated wall)		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**

Brick	100	0.84
Insulation	80	0.036
Brick	150	0.3
Air gap	5	-
Plaster on laths	13	0.42
Total thickness (mm)	350	
Case 8		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**
Coursed Rubble	200	1.50
Blond Sandstone	350	1.83
Plaster on Hard	25	0.4
Total Thickness (mm)	575	
Case 9		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/mK)**
Rubble	250	1.83
Torridonian sandstone	300	2.3
Air gap	7	-
Plaster on laths	12	0.75
Total thickness (mm)	570	
Case 10		
Wall materials	**Thickness (mm)**	**Thermal conductivity (W/-K)**
Squared rubble	280	1.50
Kemnay sandstone	350	3.2
Plaster on hard	25	0.3
Total thickness (mm)	655	
Case 11		
Wall materials	**Thickness (mm)**	**Thermal conductivity(W/mK)**
Clay harling	200	2.1
Solid mud	300	2.5
Air gap	10	-
Timber lining	10	0.25
Total thickness (mm)	520	
Case 12		
Wall materials	**Thickness (mm)**	**Thermal conductivity(W/mK)**
Squared rubble	120	3.40
Craigleith sandstone	520	4.50
Air gap	5	-
Plasterboard	11	0.90
Total thickness (mm)	685	

4.2.2 The weather of Edinburgh

The climate of Edinburgh is cloudy, cold, moist and rainy, being influenced by the ocean. Winter is cold but not freezing, while summer is cool. July is the hottest month in Edinburgh,

January is the coldest with the most daily sunshine hours on August 10th. The average daytime temperature is about 18°C during the summer months. During the winter it is around 6°C (154). Rain falls throughout the year in Edinburgh and the wettest month is October. In Edinburgh, the length of the days is varied throughout the year from almost 7 hours of daylight (December 21st) to more than 16.5 hours of daylight (June 21st) (155).
Unlike temperature, which typically varies significantly between night and day, dew point tends to change more slowly, so while the temperature drops at night, a muggy day generally is followed by a muggy evening. The perceived humidity level in Edinburgh is muggy, and it does not vary significantly over the course of the year. The hourly wind speed in Edinburgh experiences significant seasonal variation throughout the year (156).
Edinburgh has about 1,400 hours of sunshine over year. The brighter period of the year lasts for 3.5 months, from April 29th to August 14th, with a daily average incident shortwave energy above 4.6 kWh/m^2. The brightest day of the year is June 22nd, with average solar radiation of 5.8 kWh/m^2. The darker time of the year lasts for four months, from October 22nd to February 22nd, with a daily average incident shortwave energy below 1.4 kWh/m^2. The darkest day of the year is December 25th, with an average of 0.4 kWh/m^2 (157).

4.3 Results and discussion

The results of the in-situ U-value measurements and the comparable calculated values are summarised in Table 4.3.

Table 4.3. Summary of results.

Description	**Calculated U-Value (W/m^{2}K)**	**Measured U-Value (W/m^{2}K)**	**Difference (%)**	**Main material**	**Insulation or air gap**
Case 1	0.906	0.79	-12.80	Brick	Both
Case 2	1.137	0.89	-21.72	Sand	Both
Case 3	2.1	1.93	-8.09	Sand	Air gap
Case 4	1.717	1.39	-18.46	Sand	Air gap
Case 5	1.788	1.61	-9.95	Sand	Air gap
Case 6	2.00	1.82	-9.00	Sand	Air gap
Case 7a	1.602	1.43	-10.73	Brick/sand	Air gap
Case 7b	0.317	0.302	-4.73	Brick	Both
Case 8	1.8	1.69	-6.11	Sand	-
Case 9	1.715	1.44	-16.03	Sand	Air gap
Case 10	1.896	1.45	-23.52	Sand	-
Case 11	1.738	0.999	-42.52	Solid mud	Air gap
Case 12	2.273	2.04	-10.25	Sand	Air gap

The results of the measurements performed in the twelve cases studies are always lower than the comparable calculated appraisement of the thermal transmittance.
U-value calculations for the brick cavity wall construction with better-defined build-ups gave closer agreement to the in-situ measurement results. This acceptable achievement is related to

the material with insulation layers. The insulating elements seem to have thermal properties similar to those declared by the manufacturers.
The mismatch of case 7b (wall insulated) is the smallest one. The thermal conductivity of hollow brick, according to the standard, is a function of thickness. Hence, the variation in the corresponding U-value is reduced.
The good performance of case 11 (without the insulation layer) mainly depends on the thick thermal block with excellent express thermal conductivity values as there is not a layer of thermal insulation. In addition, in case 11, the difference between the calculated and the measured transmittance values are higher definitely if compared with another thirteen samples studies. An explanation of this mismatch could be because of overestimating the thermal resistance declared by the manufacturer were used in the software U-value calculations. Probably, in this example, the wall is made of different layers that are not detectable by visual inspection. Another possibility is that the solid mud thermal conductivity value may be significantly different from the one provided by the standard. However, it is within the ranges of values that are experimentally occurring for the solid mud.
Then, the case 10 is characterised by the second highest percentage difference (-23.5%). The reason is that the house was the first one that was measured and was unoccupied so, too small differences between the indoor and outside temperatures resulted in increased measurements uncertainty. Another possibility is that the thermal conductivity value of Kemnay sandstone may be considerably different from the one provided (158). The walls plastered on the hard and with plaster on laths show a result in agreement with the values calculated by software better than the timber lining finishes which shows poor agreement with the measured U-values. Such different thermal characteristics imply several of the thermal transmittance values, which can influence the design phase of a modern construction significantly. On the other hand, reliable data about every single layer of the analysed wall is needed (152). In most cases, the stratigraphy is reduced according to the building construction year. In addition, the simplified method to label a home exclusively employs the value of a thermal transmittance, neglecting the information about the mass density and specific heat capacity of the materials constituting the walls. In these case studies, measurements results and the thermal transmittance has been calculated through the elements provided by the ISO 9869 (42).
Finally, another study on in-situ U-value measurement in a similar way (106), illustrated that the value of U-value could vary considerably from one to another house, also within one house itself. In both conditions, the calculated methods and standards tend to overestimate the U-values compared to the in-situ measurements results.

4.3.1 Internal finishes

Three kinds of internal wall finishes were included in the measurements:
• Plaster on laths.
• Timber lining.
• Plastered on the hard.

Except for the plaster on the hard, all finishes were fixed to studs/battens (made from timber) that then adjusted back to the wall faces. The depth of the studs/battens could vary, typical sizes are 26 mm for plaster on laths finishes.
Walls with interior finishes which incorporate an air-filled cavity (unventilated), such as timber lining and plaster on laths, have lower U-values than walls of the same thickness finished with plaster on hard. It demonstrates the insulating effect of an air cavity behind a plaster on laths and timber lining as shown in Table 4.4. In addition, the higher the thermal resistance of timber compared to lime plaster should be considered.

Table 4.4. Theoretical effect of air gaps in solid walls (159).

The width of the air gap (mm)	**The thermal resistance of air gap (m^2K/W)**	**The equivalent thermal conductivity of air gap (W/mK)**
5	0.11	0.05
10	0.15	0.07
15	0.17	0.09
20	0.18	0.11
50	0.18	0.38

For instance, where there are no headers bridging the airspace, it is more appropriate to consider the wall as a cavity wall, and where the airspace is spanned by connecting headers, then it is appropriate to find the wall as a solid wall. The air gap in the centre of a solid wall could be interconnected to some extent which may affect the U-values. Moving current air with these structures can rise the U-values, with static air are likely to diminish U-values.

4.4 Conclusions

The in-situ measurements permit an accurate assessment of the thermal performance of traditional walls. The results constitute a stable base for a better diagnosis of energy performance in traditional houses, especially where software calculation methods may suffer from deficiencies resulting from the lack of data of the modern and traditional construction. Overall performance depends on thickness, material type, and mass density of each layer. The outcomes of the in situ U-values measurements in the twelve cases studies are lower than the comparable software calculated values of the thermal transmittance. The results of U-value calculations of the brick cavity wall construction are closer to the in-situ measurement outcomes which are related to the components with insulation layers; since the insulating elements seem to have similar thermal properties to those declared by the manufacturers. In addition, it is essential to enhance the new energy simulation programs dedicated to traditional houses adding specific databases related to the thermophysical properties of house elements. As shown in the study, calculated values are usually higher than the in-situ measured ones; because U-value calculation tools only provide limited baseline data for some traditional buildings materials.

CHAPTER 5. ANALYSIS OF ENERGY-EFFICIENT METHODS FOR ACHIEVING HEALTHY BUILDINGS AND IMPROVING TRADITIONAL HOUSES SERVICES

The aim of this chapter is to analyse the issues affecting the indoor environmental quality and users' health in buildings to illustrate how to upgrade house services in the traditional houses applying energy efficiency and sustainable practices. First, the methodology followed in the study is presented. Then the main points faced by renovating of traditional houses are assessed. After that analysis, the issues related to the house service like sustainability and energy efficiency are discussed. Next, the study is focused on the subjects related to house fabric like materials and insulation layers. Also, it appraises the healthy parameters in the buildings and their relationship with the ventilation, lighting and polluting materials. Finally, the key results of twelve case studies and some methods for energy efficiency improvement are presented.

5.1 Methodology

This chapter describes the work on refurbishment, indoor air quality, house services, fabric and issues regarding the healthy building. The properties featured in the chapter are twelve typical case studies of pre-1919 construction in Scotland, the same case studies considered in the previous chapter. All the houses are of traditional construction (solid walls), occupied, and most are constructed from lime-bonded rubble or ashlar stonework, typically 300 to 600 mm thick, with natural slate or tile roofs, doors and timber windows.

First part illustrates how it is possible to put sustainable development into practice when upgrading house services in the traditional house stock. It promotes a holistic and interdisciplinary approach based on an appreciation and understanding of the highly individual nature of many older houses, reflecting the unique manner in which they have developed over time; the materials and methods of construction; the actual and intended performance; and the protection offered by legislation. The studies are followed by work on the house envelopes, thermal mass, and materials. In the final part, some subjects regard to the healthy building, such as the contaminations materials, ventilation, lighting, heating and even the orientation of the houses are shown. In addition, all the subjects relative to the case studies are presented in detail in Appendix E.

This chapter aims to focus on the research of indoor climate subjects and energy efficiency, discuss energy efficiency of house design and interior climate issues. The main activities are:

- Explain and identify the critical subjects (such as selection of components, house service, moisture management, toxicity, thermal mass, ventilation and healthy buildings) and supply an analysis of the dependence on historic houses.
- Research in detail the ventilation in traditional houses.

- Outline health considerations are resulting from poor ventilation and the kind of passive mitigation.
- Understand the subjects surrounding the toxicity of materials and the influence on the indoor air quality and the broader environment, and ways that traditional elements can play a part in mitigating the effects and articulate the role of natural interior finishes in passively managing interior humidity.

For example, sometimes, insulation can be added relatively quickly, while in other houses it may be aesthetically or technically unsuitable, or potentially damage or obscure historical features. In addition, in one building draughtproofing could be highly desirable, whereas in another it may cause internal moisture levels to rise unacceptably and perhaps lead to outbreaks of mould and rot.

In the appendix G, the plan for refurbishment working which considers the house service envelops and the health of residences is provided. When the plan of work is prepared, it is essential to develop a thorough understanding of the kinds of construction, the materials used and the likely impact of any proposed changes. Modern materials and techniques can often be incompatible with traditional construction, and careless alterations could cause serious damage to the house fabric, both directly and indirectly. Table 5.1 supplies basic information about the case studies.

Table 5.1. Basic characteristics of the houses. Source: Own elaboration.

Case study	Location	Gross internal floor area (m^2)	Year of construction (age)	Year of refurbishment
1	Edinburgh	212	1915 (102)	1984
2	Edinburgh	184	1910 (107)	1977
3	Edinburgh	377	1902 (115)	-
4	Edinburgh	317.6	1891 (126)	-
5	Edinburgh	290	1885 (132)	-
6	Edinburgh	269	1877 (140)	-
7	Dalkeith	249	1866 (151)	1902 & 1982
8	Edinburgh	124	1857 (160)	-
9	Lauder	287	1853 (164)	-
10	Bonnyrigg	93	1848 (169)	-
11	Duns	196	1846 (171)	-
12	Edinburgh	363	1794 (223)	-

5.2 Refurbishment

The interior spaces were designed to allow warm air to circulate in winter and cold air in summer seasons. Traditional houses had suitable kind of natural ventilation, radiant heat source, and natural light. The old method constructed structures with a healthy living condition and low environmental effect. In such houses, their site was chosen carefully for their healthy features.

In the past, the rate of ventilation in schools, hospital, and houses kept high. Recent researchers support the idea that high air change rates, via open windows, diminish the risk of respiratory infection (160). By contrast, the proposed regulations and codes by government leading up to the highly sealed insulated houses. Therefore, the ventilation rates are lower than the older structures, and heating is by convection rather than from a radiant source. As insulation layers increase, the heat loss from ventilation become of greater importance. The objective is to make a highly insulated element whilst, enhancing interior air quality. Nevertheless, it not clear how the best ´right´ ventilation will be achieved (161).

Regards to attaining the targets for diminishing carbon emission by 80 % by 2050, the house part has to perform better in energy efficiency rating than it does now (161). The refurbishment plan has to follow the same ventilation and airtightness programs needed in modern houses (162); however, the impacts of its health are not known. Growing the thermal performance of buildings can enhance the health (163). Nevertheless, the houses with high energy efficiency and these have not been enough evaluated yet may have an adverse influence (164). There is a little research into the function of low energy houses (165). Traditional buildings have a natural health advantage; the ´ventilate right, built tight´ method may nullify these advantages. The rates of ventilation in old houses have to be high enough to eliminate the humidity. On the other hand, moisture in the elements of the house will lead to the increment of toxic moulds, biological and microbial agents. Also, the risk of wood decay can affect growth (166). Today many of the house elements in use are not hygroscopic, and the materials can act as a barrier to movement of humidity. Moreover, many house materials include harmful potentially chemicals, such as formaldehyde and volatile organic components associated with indoor air emission (167).

Recently the residence spends 22 hours out of every 24 hours inside the building that prolongs the exposure to indoor pollutants. Interior contaminants can be several times higher than in the outdoor air, sometimes a hundred timers higher (168). Newer studies cited the hypothesis which residence in industrialised cities does not get adequate daily light (169). It may be a parameter growth in the prevalence of rhinitis, asthma, eczema and other allergic diseases which are very popular in Scotland (170). The seasonal affective disorder is a depression disease which occurs with daylight exposure (171). The changes in the indoor environment are applied, lessen carbon emissions comes with the warning regards to the health (172).

For refurbishment, historic houses have to meet modern needs. Approved Documents L1 and L2 of the House Regulations (173,174) recognise the particular nature of historic houses specifically. The precise wording of Document L2 is as follows (Approved Document L1 is similar):

‘4.11 The need to conserve the particular characteristics of such historic houses needs to be recognized: BS 7913; In work, the objective should be to enhance energy efficiency and to the extent that it is possible practically, always supplied the work not prejudices the character of the historic house, or improve the risk of long-term deterioration to the house fabric or fittings. For an appropriate balance among traditional home energy conservation and conservation, it would be suitable to consider the guidance of the local planning conservation officer of the authority’.

‘4.12 Particular issues relating to work in historic houses which warrant sympathetic treatment and where guidance from others could, so, be beneficial include, first, restoring the historic character of a house that had been issued to previous inappropriate alteration, e.g., replacement doors, windows and rooflights; and the second, rehouse a former traditional

home; finally, making provisions enabling the fabric to "breathe" to control moisture and potential long-term decay problems (175).

Simple measures such as repairing, upgrading existing fabric and installing secondary glazing can result to match of modern replacements. Such modern replacements may both detract from a house's character and be incompatible with the performance. Where replacements are essential for windows and doors, the materials and design are needed to be done with meticulous thought (176,177).

5.2.1 Design principle

The following fundamental principles are adapted from the list of '*the repair of historic houses: advice on principles and* methods' (178):

(i) Understand the purpose of repair or alteration.
(ii) Minimise intervention.
(iii) Avoid unnecessary damage.
(iv) Seek reversibility and minimise irreversible damage.
Summary of design principles appropriated for work in older houses is illustrated in Figure 5.1.

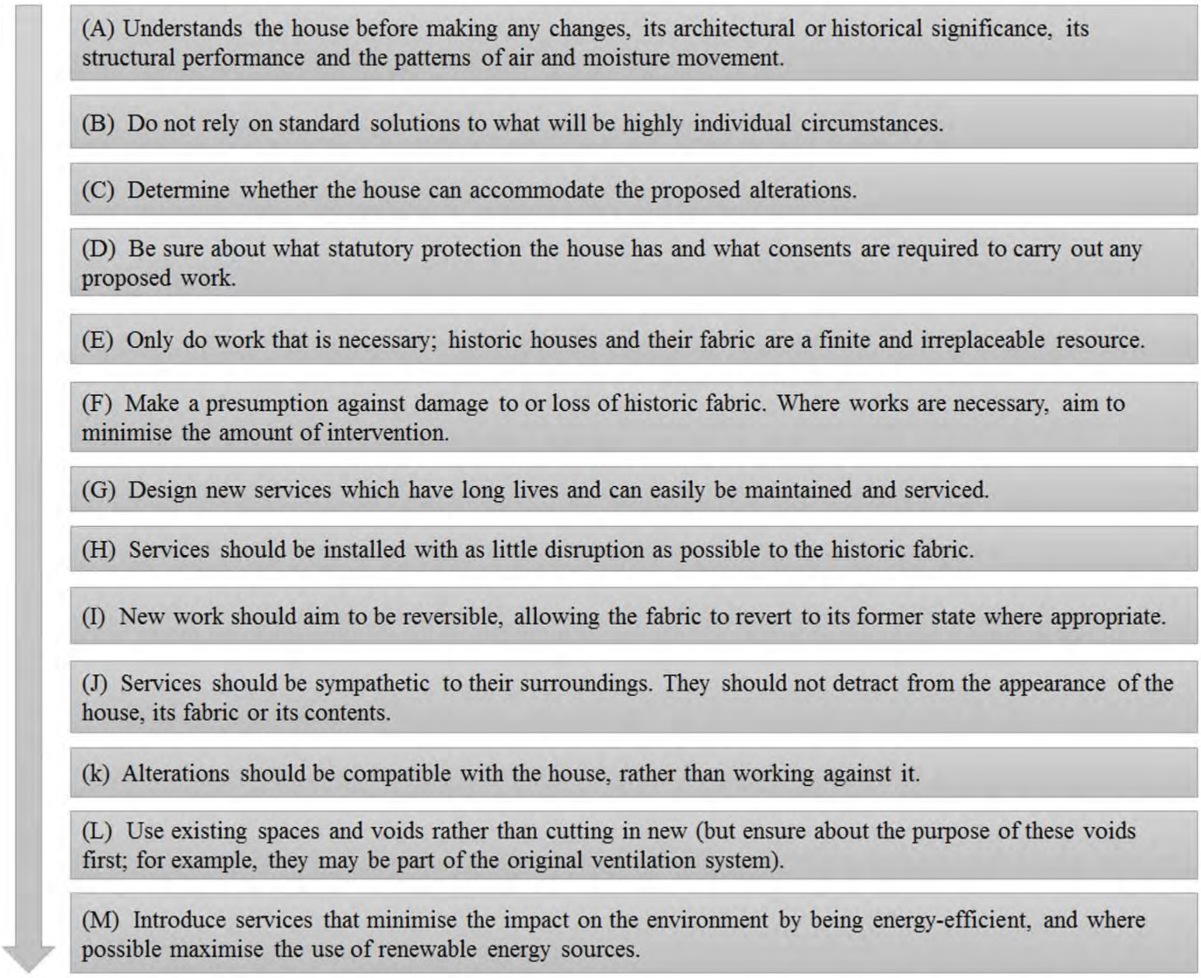


Figure 5.1. Design principles for traditional houses. Source: Own elaboration.

There are simple, nonintrusive ways of improving the energy efficiency of nearly all houses, including undertaking effective preventive maintenance, readily accessible, preserving appropriate records, proper management of current equipment, removing air infiltration, determining long-life efficient light sources, applying appropriate controls and selecting an efficient plant, particularly boilers. Most of these can be used without negative impact on the components, even in houses that cannot be altered physically due to their sensitivity, conditions, and significance.

5.2.2 Listed houses

In England and Wales, listed houses are protected primarily under the Planning (Listed Houses and Conservation Areas) Act 1990. The equivalent legislation in Scotland is the Planning (Listed Houses and Conservation Areas) (Scotland) Act 1997 and in Ireland is the Planning (NI) Order 1991. Listed houses are graded to present the relative historical and architectural interest. The grades are:

Grade I: houses of outstanding historical or architectural interest (2.5%).

Grade II: particularly essential houses (5.8%).

Grade II: of particular interest, warranting every effort to preserve them (91.7%).

In Scotland and Northern Ireland, similar grades A, B, and C are used.

Works that affect the character of a listed house require listed house consent. Listed house controls apply to works, both internally and externally, that would affect a house's particular interest, whether or not the feature concerned is mentioned explicitly in the list description. The listing of a home covers its curtilage typically so outhouses may also be listed. Any work that affects the character of the house can only be carried out once listed house consent has been obtained from the local planning authority. It is a criminal offence to carry out works without such consent. Planning Policy Guidance Note 15 (PPG 15) (179) supplies detailed advice and guidance for those making or considering applications for listed house consent (180,181). The case studies 9, 10 and 12 are listed buildings, means the houses at the age of 164, 169 and 223 years old, as shown in Table 5.1.

In conservation zones, there is a presumption in favour of retaining houses which make a positive contribution to the appearance of the area and the character; and consent is required to entirely or substantially demolish any house, whatever its quality. Minor developments are controlled to ensure that alterations do not detract from the conservation area’s appearance. Conservation area status alone does not provide the scope for stringent control. For a home in conservation zones, an ‘Article 4 Direction’ can give legal protection. There may also be control over adding external services, primarily to parts of the home visible from the street.

5.3 House service

The people expectations about heating, lighting, transportation and electrical services in houses are much higher now than in the past. Most historic houses have changed since they were built. The changes can trigger many alterations in services, for example, lighting, heating, perhaps some air-conditioning, cabling, power points, telephones and data links, plus modern standards of fire detection and protection. Figure 5.2 demonstrates the services that are most likely to be expected today. Historic houses cannot always accommodate them all.

Before any changes to a house, it is essential to assess the existing services (especially any original features) and understand how they work and how the house contributes to knowledge of the enhancement of services through the ages. If a house is listed, the listing protects everything, including the services and it is a criminal act to change anything without permission. The services may form an essential part of the house's history, archaeology, character or appearance, or may be necessary for their right. Before considering the removal of any items, it is essential to confirm whether it is needed or not.

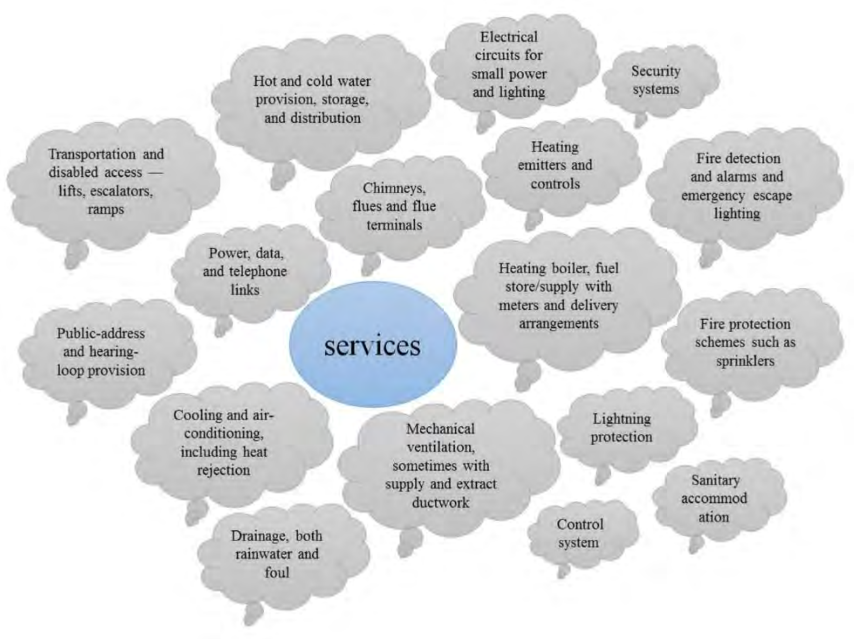


Figure 5.2. The most expected services today. Source: Own elaboration.

Building services are customarily designed to suit people and processes. In historic buildings, it is very important to consider the building itself. For example, one method to control the heating to regulate relative humidity, and not necessarily the comfort of the users. Similarly, fire safety systems may be designed to the higher property standard, not merely to give enough time to evacuate residents but to help protect the building. A good solution is a balance between the occupants, the needs of the house, and the global environment. Inevitably; some compromises will often have to be made, but great care is essential to ensure these do not devalue the aims of the project; for example; considering the client requirements while protecting the fabric and making the house more energy efficient.

5.3.1 Sustainability

House services often use large amounts of fossil fuel to maintain the conditions required. It has a detrimental impact on the atmosphere, owing to the release of the greenhouse gas carbon dioxide, acid gases including the oxides of sulfur and nitrogen and other pollutants. Pollution could be decreased by, using less fuel; using cleaner fuels, i.e., those with lower, or even zero, carbon dioxide emissions; using cleaner and more efficient appliances; reducing the thermal load, and controlling and managing systems effectively. Figure 5.3 shows the amount of carbon dioxide (CO_2) emissions associated with one kilowatt-hour (kWh) of energy delivered to a house in the form of different fuels. The following conclusions can be reached. Gaseous fuels emit less CO_2 than liquid or solid fuels that reflects the fuel's carbon/hydrogen ratio, the lighter the fuel, the more hydrogen. Hence less of the energy is locked up in carbon in natural gas than in the liquefied petroleum gas propane (C_3H_8), so for the more massive fuels.

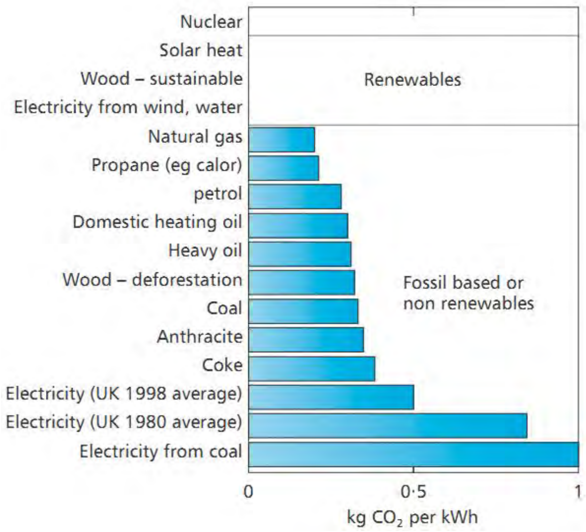


Figure 5.3. Carbon dioxide produced by different energy sources in the UK. Source: Growth in emission (182).

The UK mains electricity produces much lower CO_2 emissions per delivered unit now than it did before owing to higher efficiency, a more significant proportion of gas-fired generation and higher availability of nuclear plant. However, burning fossil fuels at a conversion efficiency of between 30% and 60% accounts for around 70% of UK production, therefore, to use electricity directly for heating can be considerably more polluting than using fossil fuels.

Renewable energy sources have close to zero CO_2 emissions; it is evident for direct generators such as wind power, hydro-electric generation, etc. It also applies when burning biomass such as straw and woodchip, apart from any fossil fuel in transport, harvesting, cultivation, and drying. The carbon dioxide produced by burning the woodchips is taken back up in the cycle if the coppice sourcing the woodchips is allowed to re-grow. Effectively, net zero CO_2 emissions are obtained, where energy from the sun is collected and harvested as a storable fuel source with minimal fossil fuel use.

5.3.1.1 Materials

It is important to materials will be chosen specified and carefully to ensure that they cause as little pollution; during extraction; in manufacture; during construction or installation; and finally when removed for re-use, recycling or disposal. Increasingly, the determiner has to be aware of the cost and impact of each material specified, it embraces the environmental and health implications throughout its life and uses including toxicity and the presence of dioxins and volatile organic compounds (VOCs). Only if an accurate holistic method to design is adopted, the risks to health and the environment will be reduced and genuinely sustainable solutions formulated. Views on specific materials can change rapidly, for example, many countries are becoming concerned regard to the consumer of polyvinyl chloride, owing to its perceived threats to environment and health, particularly during manufacture and if it is burned at the end of its life cycle.

Some traditional materials and a lot of modern synthetic elements are deleterious to indoor air quality. In most cases, risks happen after usage of the element when concentrations to the emissions are very important during the application. There is scientific uncertainty regard to the risk put to residences. It is because a lot of chemicals exist in the indoor environment. There are more than 70,000 chemicals, only 4% of them have been examined for carcinogenicity (183). In the 20th Century, 50 materials were used in houses. Now there are 55,000 house materials, and half are human-made (184). Where there is scientific uncertainty about the safety of material and credible evidence to determine, it has the potential to put a risk on the environment and human health; the precautionary principle can be adopted. It means that scientific uncertainty should not come in the method of presenting measures to support the quality of the indoor environment, for instance, many chemicals particle have been discovered to be animal carcinogens. In addition, humans are exposed to some different chemicals in their daily life and identifying the causative effects of one chemical is challenging.

Many materials have a deleterious put health risks throughout their life cycle and impact on the environment (185). There is an improved awareness about the influence of chemical toxicity. Some of it has been reflected in best practice policy and guidance as well as legislation. Berge (2000), Curwell (1986), and Liddell (2007) suggest the issue further. They affirm that usage of recycled and re-use materials may not be a positive activity on the environment because of embodied toxicity. As there are no mechanisms to vet the toxicity of recycled materials in place yet, and the responsibility lies with the contractor or designer, house owners need to consider the future liability for disposal of a toxic substance.

5.3.1.1.1 Traditional house Materials

One of the essential parameters in keeping indoor healthy is to preserve the permeability of vapour in historical elements which can be determined by the function of impervious finishes, whilst several new finish materials are impermeable. Using this kind of materials in historic houses decrease the ability of the house to overcome problems with high relative humidity, including mould growth. Several of the elements applied in historical houses are hygroscopic, so the materials of the wall allow moisture to pass via the fabric. These permitted traditional buildings by a combination of absorption and evaporation deal with moisture. The elements with hygroscopic components can be applied as a barrier of humidity to decrease the extremes of interior moisture. For example, lime has been used in case studies 3, 10 and 11; lime is one of the essential non-metallic minerals applied in the industry of house construction. It mostly applied both externally and internally. Lime plaster is being mostly applied as an interior finish because of its hygroscopicity features. When the level of pH is higher than 6.0, the mould will not also grow, as the limes are alkaline, they have been applied to protect against increasing fungal and mould.

5.3.1.2 Efficient system

Upgrading the energy efficiency of the fabric of a historic house can often be difficult, it becomes mainly essential to make the installed plant and systems as efficient as possible, even if they cost more. The main areas of concern are a boiler and air-conditioning plant efficiency and control, and any electric motors which run for extended periods. Condensing boilers should be at the top of the available efficiency range. These have been used successfully the case studies 2 and 7. However, condensing boilers create a much larger visible plume of water vapour at the chimney top and flue terminal than conventional boilers. Flues must, therefore, discharge away from areas susceptible to a build-up of moisture. Where it is impossible, a noncondensing model may be necessary. It is also necessary to provide a drain for the products of condensation which could be acid. It is necessary to compare boiler efficiency not just at the full output but across the possible performing range, e.g., at high and low firing. For domestic sized boilers in case studies 2 and 7, seasonal efficiency can be checked through the Seasonal Efficiency of Domestic Boilers rating (Sedbuk rating is the method used to evaluate the boilers efficiency) (186). Boilers in category A, are appropriate and suggested for case studies 9, 11.

Air-conditioning plant is suggested for case studies because it can have a significant physical impact. However, it uses much energy. It should only be installed where it is proven to be essential for the building operation. Moreover, micro combined heat and power (CHP) with biomass is suggested for all the case studies. It is a method of maximising the amount of energy from the fuel, so reducing carbon dioxide emissions. Micro CHP both produces power (usually as electricity, but sometimes as mechanical power), and makes available much of the otherwise wasted heat from this process. It can be used to supply hot water and heating or to run equipment, e.g., absorption chillers. It is important to consider that there are sufficient base loads of both heat and power to make the micro CHP plant run for enough time to produce a reasonable economic case for investment (typically at least 3,500 hours per year, as often occurs in hospitals and large hotels).

5.3.1.3 Low water use

In case study 1, new water appliance has been installed. In order to achieve a low water use, it is essential to consider water efficient types, e.g., low-flush (less than 6 litres) and dual-flush (two-button) WCs, low water showers (less than 8 l/min), urinals. Equipment and waterless WCs found in older houses can often be very extravagant, but its performance can sometimes be improved considerably, e.g., by fitting flow restrictors to taps. Convoluted hot-water and distribution systems could waste much heat, mainly if they are uninsulated; in more substantial houses, seek opportunities to rationalise and improve them. Sometimes, a decentralised system with local gas or even electric water heaters will be energy efficient and economical.

Water leaks are a serious threat, with risks ranging from significant flooding to slow drips; problems can be reduced by careful routing, proper specification using burst-resistant materials, excellent artistry, inspection, testing, and effective frost protection. In sensitive situations, safety guttering or electronic leak detection systems can be installed. Also for significant leaks, automatic alarms and shut-offs are recommended, as highly recommended for case study 11.

5.3.2 Re-using existing services

Existing house services plant must regularly be assessed to determine whether it is working correctly or not, for example; its efficiency, safety, life expectancy and any risks it poses. Many types of services, particularly heat emitters and lighting equipment, are often suitable for re-use and add to the character of a house. Such equipment must be checked thoroughly and upgraded as necessary. It is often possible to restore old light switches and luminaires and make them safe. Conventional radiators will require cleaning and pressure-testing. In case study 1, pipework has been re-used, so the water should be tested, and external and internal inspections of the pipework should be carried out. Chemical cleaning may be essential; the entire system should be sufficiently pressure tested in operation. Assess health risks associated with the use of the existing house services equipment can determine how to handle them and whether the plant can be re-used or not. The safety and health of the residents must take priority over. Dangerous electrical installations and equipment must always be made safe immediately. Fire is one of the most significant threats to the components and contents of traditional homes (187,188).

5.3.2.1 Temporary services

Temporary services, mainly those used during construction work (e.g., transformers, cables, lighting, dehumidifiers and heaters), could create hazards of their own. People may bring in their conventional equipment or misuse it, without thinking about the sensitivity of the house. Risks include not only fire, electric shock and oil spills from generators, but damage to the traditional elements by too vigorous use of heaters and dehumidifiers. Rapid decreases in humidity could cause crack and shrinkage, mainly in timber products. Where dehumidifiers and heaters are used, vulnerable contents will need to be taken into safe storage, and vulnerable home components protected. Alternatively, these temporary systems may need to be operated under the supervision of a conservator. In addition, dehumidifiers could often be ineffective because the drying space is not correctly sealed, with doors, flues, and holes remaining open.

5.3.3 Criteria for the selection of new services in historic houses

Exposing a historic house to unnecessary change increases the potential for irreparable damage. If it is essential to proceed, the new or upgraded services must be, compatible with the house; compatible with the performance of the fabric; and efficient, to minimise the impact on the environment. Where existing house services are retained, it is essential to ensure that the new services are integrated successfully in a manner that does not compromise installation, performance, efficiency, maintenance or life expectancy. For instance, most of the case studies have old heating systems which they often came up to temperature slowly, and the thermal shock from the faster response of modern boiler plant might cause leaks in existing pipework. Similarly, more compact, higher-resistance modern devices requiring high water pressures that may not work on the same circuit as old radiators which were designed for gravity flow.

5.3.3.1 Installing new services and upgrading existing ones

In case study 7, which added one new modern part to the old houses, new services have been installed, and existing ones have been upgraded. Finding suitable routes for pipes, cables, and ductwork needs careful thought and imagination to minimise interventions, and to avoid other problems for the fabric or, at worst, structural stability. In modern buildings, the services are not designed or specified in detail. Much is left to the discretion of the contractor, for example, the cable runs between switches and luminaires are very seldom shown. In many historic houses, such detailed design is essential to improve planning and appearance, and to minimise unnecessary physical intervention. The further investigations, drawings, specifications and collaboration on-site will inevitably add to the time and costs.

5.3.3.1.1 Notching, cutting and chasing

Work to accommodate services can seriously affect the condition, structural performance, and preservation of older homes, and should be carried out after appropriate specialist advice has been sought. A proper starting point is not to notch or cut any timbers, chase any walls, or make holes in prominent places. Cutting and chasing destroy historic fabric, may be unsightly and can severely weaken floors and old walls and partitions. Floorboards and wall finishes of historical, architectural or archaeological interest could be damaged irreparably or even lost. In case study 1, the covering surfaces (e.g., floorboards) have been removed safely and carefully (with the approval of the relevant officials), opening-up revealed opportunities for service runs. A good set of drawings reveals possibilities for vertical connections. Thick walls may also contain useful voids, as can be seen in case studies 5, 6, 10 and 12. Opening-up can also reveal decay, unexpected obstacles, and structure irresponsibly cut away by those installing previous house services installations. Strengthening will then be required. Ways to strengthen weakened floor timbers, for example by using folding wedges or iron plates are shown in BS 5268 (189).

5.3.3.1.2 Installing service runs

The first stage is to minimise the amount of pipework, cabling and ducting with any intervention to the existing fabric. Case study 1 demonstrates why fan-coil air conditioning was chosen instead of an all-air system. The house services engineer must work closely with the architect or surveyor (and then the builder) to minimise, and where possible avoid, situations that cause physical damage, surface damage or removal some parts of the structure and fabric. Any alterations to the drawn and agreed scheme should also be confirmed on-site before beginning the physical work.

5.3.3.1.3 Fixings

Regards to the mortar and masonry materials, in case studies 2, 3, 10 and 11, the mortar is high enough, and it is better to preserve the fixings elements in the mortar than in masonry. It provides a degree of reversibility and prevents damage to masonry, which is more difficult and expensive to replace. About timbers and plaster, where a large number of securing points is required, a separate fixing plate will provide a suitable surface and reduce the number of fixings to the historic fabric.

5.3.3.2 Exposed services

Use of exposed pipes, cableways and sometimes ducts can minimise the amount of physical damage and intervention to historic elements. In a formal room with excellent detailing in case studies 4 and 12, exposed services are not appropriate as they would detract from the first attention to detail and geometry. Unoccupied areas, attic spaces, cellars, roof spaces and other areas with less appearance, make good opportunities for exposed service. Exposing services can also be more reversible and improve access to inspection, alteration and maintenance, renewal and eventual removal. When exposed pipework and ductwork need to be insulated so, frost-protection strategies must be taken very seriously. This should be the design strategy for a house which could be empty and difficult to reach during an extended cold period, as happens in case study 10 which is unoccupied. Where cables are run exposed, it is essential to be carefully positioned, specified or protected to minimise their vulnerability to physical damage. Cabling in historic houses may also need to exceed minimum requirements, to reduce fire risks; and mineral insulated cables (MIC) or other specialist cable types may be appropriate. Although specialist cabling can be expensive, it has the benefit of minimising the use of polyvinyl chloride, that can last longer and may it need fewer fixings and supports. In case studies 8 and 12, where installation of cable runs is likely to be extremely difficult or damaging, radio and signal responsive systems can be considered. These look promising, but their long-term performance and their potential influence on health are unknown currently. The radio devices in inaccessible locations without mains supplies still need regular access to change the batteries, typically every few years.

5.3.3.3 Concealed pipework

Older houses often have voids and other spaces that can be used to conceal pipework and other services and to limit any damage to the historic fabric. The alternative options have been listed in Figure 5.4.

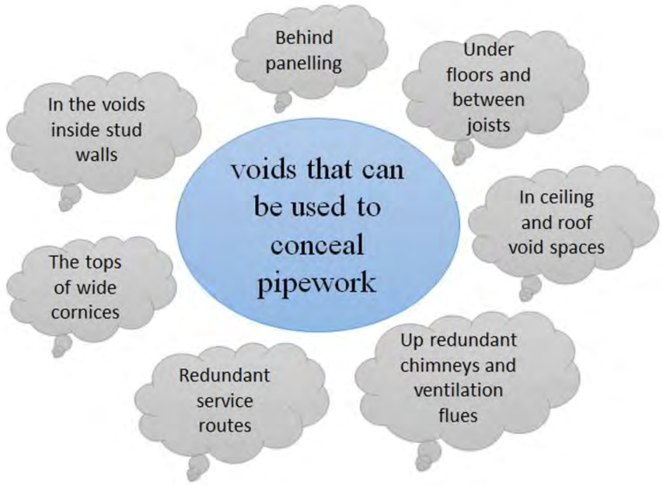


Figure 5.4. Voids for concealing the pipework. Source: Own elaboration.

Concealed routes have some limitations:

- Chimneys and ventilation flues are not accessible for inspection; for example, in case studies 5, 8 and 12.
- Hidden leaks can go unnoticed for extended periods, and could trigger severe decay.
- Fabric can be damaged by opening-up to find the concealed voids, or if invisible leakage causes a subsequent damp or decay problem.

It is essential that any services concealed behind fabric be entirely tested and recorded before these be enclosed, and the decorative finishes applied, mainly pipework that distributes water. Testing will provide some confidence that there are no leaks that might cause decay and require opening-up. Similarly, frost protection systems that cover all the house are essential where piped water services are present.

5.4 House fabric

5.4.1 Differences between traditional and modern materials

Traditional materials are often relatively porous, as in many stones, brick, earth and timber homes with earth and lime-based mortars and render. These materials used both externally and internally, enable the fabric of the whole house to breathe, with some levels of dampness in the fabric being controlled by allowing moisture to evaporate readily. Where moisture can freely evaporate, and the general breathing performance is not impaired, the walls of historic houses often remain relatively dry. Traditional lime plasters with breathable paint finishes, such as limewash, play an essential part in the mechanism, by not only releasing structural moisture but also absorbing excess moisture generated internally, dispersing any penetrating and capillary moisture over a wide area.

Externally, the porous materials of traditionally constructed homes are dried out by the wind and sun; and internally by evaporation, assisted by heating and ventilation. Internal air movement through windows, roof and the openings, all helps to evaporate moisture from the internal porous surfaces. The Industrial Revolution caused rapid changes in the ways of construction and the used materials. By the 19th century, there had been a major move away from traditional methods and materials to cavity walls, damp-proof courses, cement mortars and renders. Even modern substitutes for traditional materials are more impervious, e.g., denser bricks, cement, based mortars, and vapour-resistant paints.

5.4.1.1 Moisture movement in older houses

Traditional houses are of solid wall construction, mainly constructed with porous materials that let humidity evaporate easily also, absorbs humidity. Often it is named the ability of the house materials to breathe. In contrast, modern houses are usually made of harder, stronger and less previous materials. To exclude moisture, the construction relies on physical barriers such as damp-proof courses and membranes, wall cavities and impervious cladding.

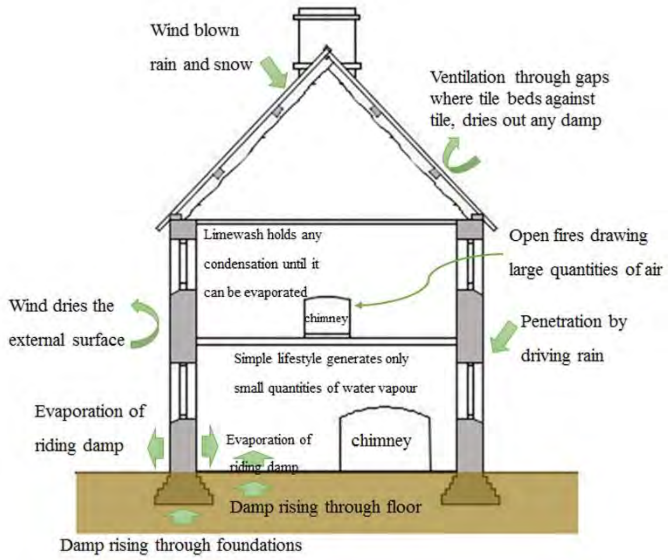


Figure 5.5. Moistures movement through the air and structure. Source: Guide to building services for historic buildings (182) *in own elaboration.*

Figures 5.5 to 5.7 illustrate the differences. In traditional houses for preserving the indoor environment healthy and the materials dry, more interior ventilation is needed to eliminate the humidity that evaporates. More humidity is eliminated when the house is heated. Therefore more heating needs extra ventilation. An older house uses evaporation and ventilation to reduce the moisture in the walls to an acceptable level that does not cause decay, mould growth, or damage to decorations. In contrast, many modern insulation techniques include impervious vapour control layers, designed to stop moisture from indoors diffusing out through the insulation and leading to interstitial condensation. However, if these same impervious layers are used in a traditional house, they could trap the moisture in the wall and stop it evaporating, making the wall damper and prone to decay.

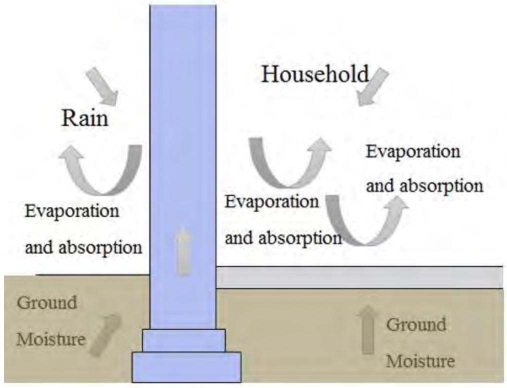


Figure 5.6. Moisture control in the traditional house.

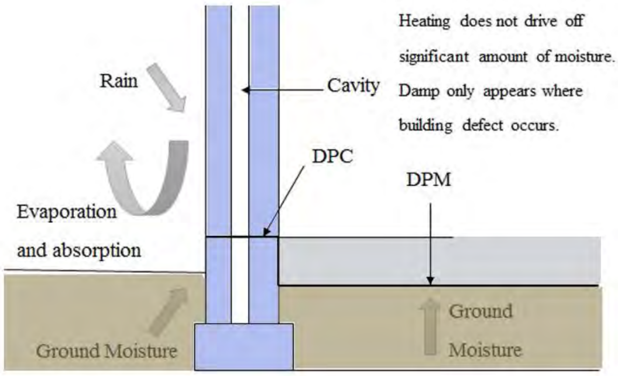


Figure 5.7. Moisture control in the modern house.

Source: Guide to building services for historic buildings (182) *in own elaboration.*

Another example of the dangers of inappropriate, less permeable modern materials is where a hard, impervious mortar is used to re-point soft masonry (brick or stonework). As shown in Figure 5.8, the hard mortar traps moisture and reduces the rate of evaporation from the outside of the wall, so leading to accelerated decay of the masonry.

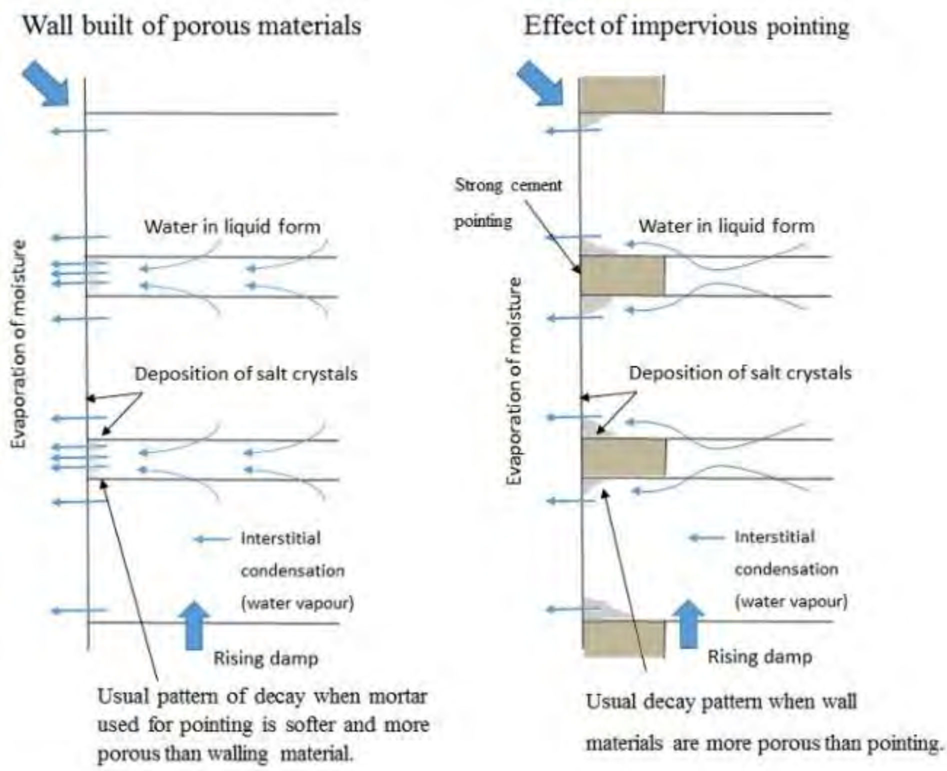


Figure 5.8. How hard mortar can damage masonry. Source: own elaboration.

The fundamental differences in moisture performance of traditional and modern houses make it imperative that, before making any detailed proposals, the materials, methods of construction and the past and expected performance are identified. Any programme of repair and alteration needs to take it into account. For excellent results, the problems must be addressed, and all repairs need to use materials and methods that are appropriate and consistent with the traditional performance, e.g., using lime-based mortars to repoint the wall, it would be useless to repair or replace any of the stone after the hard cement pointing had been carefully removed. Similarly, if a damp patch is found, it is essential to do not cover it up, but gain an understanding of why it is there and what needs to be done to make it go away.

5.4.2 Adding insulation

Older houses have complex structures, with an equilibrium function which is highly sensitive to variation. The new procedure of insulation, environmental control, and draught-proofing have to be presented with adequate attention depending on the characteristic of the house and proper knowledge of the suggested elements. When applying the insulation layers to a new structure, it is essential to consider the condensation construction. It occurs when moisture generated inside the house moves through the insulation until it reaches a cold part of the structure, where it promptly condenses. The standard method is to carry out a condensation check as set in BS 5250 (190). Also, section 7 of CIBSE Guide A (191) determine whether condensation is predicted by diffusion of water vapour. If it is predicted, a further calculation should be carried out to see how critical the moisture at the condensation is likely to be, both in its right and by putting any materials present at risk of decay. The reasonable solution for preventing of moisture accumulation in a modern house is to introduce a high-resistance vapour-control layer on the warm side of the insulation to prevent the water vapour diffusing out the structure. This method is repeated to confirm that the problem will be overcome.

In addition, even if a BS 5250 calculation shows that condensation by diffusion will not occur, caution is still needed. When there are air gaps or cracks through the structure, like case study 11 around the edges, and at joints, moist indoor air can infiltrate quickly and directly to the cold structure, by-passing the vapour-control layer and creating a risk of localised interstitial condensation. Therefore, significant care must be taken to seal any insulation on the warm side against bulk air movement. Interstitial condensation is most likely to occur where insulation is placed on the inside of a structure, as with dry insulating lining. However, even if the insulation and the vapour control layer are installed successfully to a standard satisfactory for a new home (e.g., with gaps and cracks well sealed), still can cause problems in a traditionally constructed house. The vapour-control layer intended to prevent moist indoor air from diffusing into a modern wall also blocks the low-vapour-resistance breathable path for structural moisture to escape internally, which can lead to increased dampness and even decay.

For all the case studies with older structures, it is therefore crucial that new insulation does not disturb the moisture balance significantly. One way to achieve it is to control interstitial condensation not by using a high-resistance vapour-control layer (e.g., a polyethene membrane), by adding a layer of much lower vapour resistance that is sufficient to prevent the interstitial condensation. The appropriate resistance can be calculated by the same BS 5250 equations, but a simple rule for initial consideration is that the vapour resistance inside of condensation (where the internal insulation meets the external fabric) should be at least five times the resistance between this point and the outside of the house (Figure 5.9). In this way, the water vapour can pass out faster from the condensation than it arrives from the inside. The procedure can often allow insulation to be added while the whole structure retains its fundamental breathing properties, with a relatively small water vapour resistance.

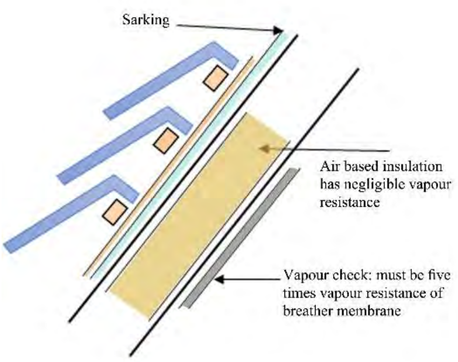


Figure 5.9. The 5:1 ratio

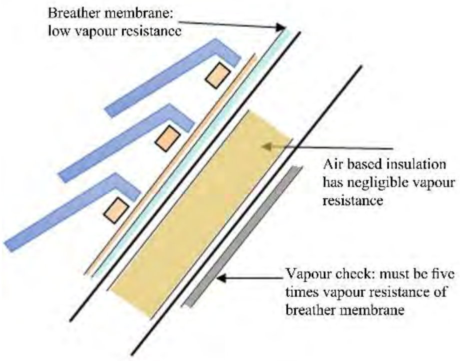


Figure 5.10. Low vapour resistance

Source: Guide to building services for historic buildings (182) *in own elaboration.*

Impervious external coverings can cause problems, for example, impermeable external coatings intended to keep rain out that could instead trap moisture and cause renders to break down. In roofs, bituminous and plastic underlayment put a high-vapour-resistance layer on the cold side of the structure, making it almost impossible to install insulation underneath without causing interstitial condensation. As shown in Figure 5.10, one solution for this is to use a modern breather membrane with a low vapour resistance for the underlayment, plus a small vapour check on the inside of the insulation (two coats of mineral-based emulsion) to provide the required 5:1 ratio. Breather membranes in roofs and walls are one of the few modern materials that could enhance traditional house design, although they have not been tried and tested over long periods of time, they offer a massive improvement on the impervious materials previously used. However, correct installation of a breathable roof requires all roof coverings to be stripped, so it can only be done when major roof renovation is essential.

Table 5.2 demonstrates the quantity of required insulation layer for each house to meet current building regulation. The uninsulated houses need around 18 cm insulation layers. When selecting insulation materials for them, a further degree of safety can be provided by using materials which are themselves hygroscopic, e.g., natural insulation materials such as sheep's wool and cellulose fibre; these could absorb some excess moisture without leading to condensation or decay, and release it when conditions are more favourable. Added insulation above ceilings can also reduce the temperature and moisture fluctuations of a lightweight structure, particularly plaster on laths in walls and ceilings.

Rapid changes in indoor environmental conditions could result in rapid changes in the temperature and humidity across plasterwork. In case studies 9, 10 and 11, such conditions had caused mould bloom on a historically painted ceiling. In these cases, insulation (also hygroscopic) can be inserted to help to stabilise conditions in the plaster and decrease the likelihood of further damage to the painted surface. In these situations, it would be wise to obtain advice from an appropriate expert on the appropriateness of the solutions being offered.

Table 5.2. The quantity of the required insulation layer. Source: own elaboration.

Case study	The quantity of the required insulation layer (m) to meet level 6 of zero carbon house	Kind of walls
1	0.13	Insulated / with an airgap
2	0.168	Insulated / with an airgap
3	0.184	with an airgap
4	0.183	with an airgap
5	0.184	with an airgap
6	0.185	with an airgap
7	0.140	Insulated / with an airgap
7	0.183	with an airgap
8	0.177	-
9	0.180	with an airgap
10	0.179	-
11	0.183	with an airgap
12	0.187	with an airgap

5.4.3 Ventilation, draught proofing and fan pressurisation testing

There has been a recent tendency for new houses to be made increasingly airtight, with purpose-designed ventilation added to obtain the desired internal conditions (build tight, ventilate right). However, poor site practice in the UK can often undermine this intent. In traditional homes, there is too much air infiltration that is causing discomfort and wasting energy. However, significant decreasing air infiltration has a negative influence on the health of residents and also on the buildings. Historical houses require ventilation not only to eliminate the regular humidity caused by the activities of residences and dilute emissions but also to take away the humidity which evaporates from a breathing system.

5.4.3.1 Mechanical ventilation or Natural.

The houses with level 5 or 6 rating in the code of sustainable houses also require mechanical ventilation with heat recovery to obtain an appropriate indoor air quality (164). After renovating maybe also require mechanical ventilation. In the past century, mechanical ventilation was perceived as healthier than natural ventilation (192). Later, Ms Nightingale claimed that natural ventilation was healthier than mechanical ventilation (193). With the work on the action of moving air, with Prof. Hill, the thinking in favour of natural ventilation was evaluated (192). The high roof and major windows of traditional houses moved 40 air changes per hour whilst the mechanically ventilated move 12 air changes per hour. However, practically, the mechanical ventilation obtained half of the air changes they expected to achieve (160). The mechanical ventilation in several hospitals does not correctly work due to shoddy construction, design or poor maintenance (194–197).

The tighter new houses are not healthy with mechanical ventilation, because pathogens can be delivered via ventilation systems (198). In addition, dust can be accumulated in ductwork and be a source of microbes, allergens, and chemicals. Respiratory illness kills one in four residences in the UK. It is over the European average, and it is the most common long-term illness between the kids. Also, for the National Health Service costs more than any other illness

(199). For NHS Scotland, care of asthma estimates the price of 140 million British pounds yearly (170). Nevertheless, the enhancements in IAQ, reduce the risk of allergy and asthma in houses (200).

5.4.3.2 Ventilation and Infiltration

One of the essential parameters in the cumulation of indoor pollutants is air movement rate. Infiltration means passing uncontrolled air in space through due to cracks in the wall, under doors around the window. Installing internal doors, draught-proofing window, and door and packing the cracks and holes decrease infiltration. Nevertheless, when justifying these measures, it is essential to consider fresh air and remove interior emissions and humidity.

Ventilation is designed to eliminate contaminants and dampness from the inside. There is no standard program for ventilation, so it is better to consider it individually for each space. Also, the single ventilation system is not appropriated for all parts of the house because of the different residence uses. Control moisture by applying passive measures such as hygroscopic elements without using polluting materials enhance energy savings and diminish the need for ventilation. In addition, the good maintenance of a house has an essential influence on the need for ventilate and dampness. The best method is moving from mechanical tools towards natural forces with mechanical tools rather than exchange them. Occupancy or air quality sensors enhance the effectiveness of ventilation systems. They monitor CO_2 or indoor moisture. Also, infrared sensors can be installed to adopt rates of ventilation rates depending on the room occupation, which decreases energy consumption.

5.4.3.2.1 Ventilation in Traditional Houses

In the absence of impermeable damp proofing, older houses need extra ventilation to remove structural moisture. Therefore, it is essential to determine how much ventilation is needed to provide a healthy, comfortable and draught-free environment economically, while also getting rid of the structural moisture and ensuring the health of the home fabric. As a rule, the typical air requirement for human occupation (8 l/s per person or an average of 0.4 air changes per hour) is similar in magnitude to that air required to eliminate damp from a breathing system in excellent situation. In some cases, historical houses are damper and require more.

The historic houses were ventilated passively with a different consequence. In addition, in cases studies 1, 4 and 8; some extra ventilation like extractor fans in services have been retrospectively installed that eliminated or restricted ventilation. Interior door has been increased when packing the chimney and flues (one or two chimneys of case studies 4, 6, 7, 8, 9 and 10 have been closed). Because of the nature of traditional houses, measure of energy efficiency focus on decreasing air infiltration. For this purpose, full consideration of the management of indoor pollutants and moisture is essential. Decreasing the ventilation rates or infiltration in traditional buildings via refurbishment have a significant influence on the structure ability to justify indoor humidity and pollutants. If the ventilation program is poorly designed and it is not appropriated for the health, extra ventilation will be needed. Therefore, the renovation has to be done aiming to enhance the ventilation of historic houses. For example, in case study 12, where vents of subfloor have been packed, it has an influence on the house ability to justify with ground humidity and the radon elimination. In this case study, re-establishing would be useful.

5.4.3.3 Fan pressurisation testing

Fan pressurisation testing is used to assess how airtight a house is. That had been done in case study 1. The technique is outlined in CIBSE Technical Memoranda 23 (201). A massive calibrated fan is sealed to an external opening (usually a door) and operated over a range of pressures between inside and outside, typically from 10 to 60 Pa (1-6 mm of water). To measure the leakage through the house fabric itself, it is normal to seal up any purpose-made ventilation openings such as fans, passive stacks and so forth before carrying out the test. The pressure test result is expressed either as air changes per hour at 50Pa, or the air permeability is expressed in m^3/hm^2 of the exposed surface area of the house including the ground (the units are sometimes simplified to m/h @50Pa). It is estimated that the average UK air leakage rate is around 10-15 m/h. Several countries (notably Scandinavian) insist on an air pressure test for a sample of all new buildings. In the UK, the new House Regulations Approved Document L2 requires pressure tests of new non-domestic houses of over 1000 m^2 gross floor area. The relationship between test results at 50Pa and natural infiltration (driven by wind and stack pressure differences averaging 4Pa) can be determined using the procedures developed in BREDEM-12 (202). In simple terms, these procedures use four parameters to predict an average ventilation rate, which is the result of an envelope pressurisation test, occupancy ventilation by regular window opening, any fans or passive stacks fitted, and the presence of full mechanical ventilation.

5.4.4 Thermal mass and controls

Thermal mass is the specific heat capacity of the component. It refers to the mass ability of the houses to supply thermal inertia over fluctuations of temperatures. For instance, heavyweight houses take more time for cooling and heating, whilst they do quickly in lightweight structures. The thermal lag refers to the speed of cooling down or heating up in the houses which can be designed according to the residence methods of life. In traditional houses with a high thermal mass, case studies 5,6,7,10 and especially 12, it is important that the heating systems do not have a harmful impact on the element of the house or the indoor air quality. The intermittent heating programs are justified frequently in historic houses with different residence method of life, but it can cause negative performance in high weight houses.

With the intermittent heating, the building cooling down overnight or when not occupied involves an energy saving. The low-temperature difference among indoor and outdoor demonstrates that less fuel is required which create problems for high weight masonry houses, as happens in case studies 5, 6, 7, 10 and 12, mainly if they are damp. When the house warms up, the inside element release humidity, so increasing the point of dew air which causes in condensation since the air is going to contact more cooling spaces or with thermal bridges. Then the moisture moves through the structure from warmer areas to colder ones which finally cause damages in the materials and mould growth. Sometimes air temperatures are high to neutralise the effect of the cold wall. These moisture and temperature changes result in a cycle of hygroscopic salts recrystallisation in elements.

The next problem is that the air has to be hotter than usual to supply a similar comfort degree to balance the cold radiation of the unheated masonry. Also, the changes in humidity and air temperature rapidly result in a negative impact on the elements, especially when salts are existing due to recrystallise which result in damaging the aesthetically and historical aspect of the house. Therefore, it is better than the high weight houses continuously are warmed to a low level. Also, it is cost effective if they are warmed with night set back.

5.4.4.1 Conservation heating

Cycles of rising and falling relative humidity can be very damaging, by causing salt recrystallisation and for components that made of mixed materials which expand and contract at different rates. In traditional houses, it is essential to consider the option of controlling the heating to keep relative humidity within a relatively narrow range. In the UK it usually means raising the average internal temperature by about 5°C above the average outside. In the summer it is often achieved by solar gain; in winter heat needs to be added. The amount of energy required is typically about one-third of that for comfort heating. Also, there is a lower temperature limit to protect the house against freezing. The National Trust has been using this technique since the 1980s; its specification for, relative humidity set point between 50 and 65%, depending on the conditions to which the home has been acclimatised; alarms at 40 and 75%; minimum room temperature 5°C from November to March; and maximum room temperature for heating: 18- 22°C from April to October.

5.4.5 Initial and ongoing monitoring

Unfortunately, none of the case studies has been monitored until now, but monitoring is strongly suggested. With any proposed changes to a historic house, it is wise to monitor temperatures, and relative humidity both before and after any changes. It will allow characterisation of the situation to provide the intended results, and provide information to help safeguard against adverse effects including condensation. A typical scheme might monitor temperature and relative humidity in each separate zone of the building, for instance, in a living room, a bedroom and a bathroom, together with external measurements for comparison. It is also possible to monitor structural moisture levels quite cheaply, using matchstick-sized probes built into the structure and connected to a data collection. Monthly inspection of the data is recommended to ensure that relative humidity is within an acceptable rate, typically 50-65% (higher levels in summer and lower in winter may be acceptable). If they are outside the range, it should be investigated whether it is due to too little or too much heating and ventilation or due to occupant behaviour.

5.5 Health and building

House services are intended to improve the indoor environment, but they can introduce hazards, directly or indirectly. The effects of dirty, unhygienic plant and ductwork and leakage of combustion fumes are now well known, and careful design is essential, followed by careful maintenance of cleanliness, safety, and performance. The overall effect of insulation, ventilation, and heating on the equilibrium of the environment are also significant. Damp conditions can not only cause house decay but can also affect occupant health both directly or by the products of biodeterioration, e.g., fungi which colonise the lungs. The materials used in the house services installation itself also need examination. The combination of new, chemically complex and sometimes unstable house products with changes in lifestyle have increased the exposure of residents to potentially toxic materials. Although the long-term effects of many products are not yet quantified, it is essential to assess the potential effect of all products on the health of residences (202).

5.5.1 Healthy house

Hippocrates Greek doctor wrote about the orientation of cities; he mentioned that the cities with an easterly aspect had healthier people (203). During the 1st century, Marcus Vitruvius Pollio redacted the outstanding ten books on architecture (204). He mentioned that the architects must have medical knowledge so they could choose healthy sites. He believed that careful design of construction deterred disease and planning the street help the cure of chronic sickness. Vitruvius opined excellent plan could shorten the course of illness, like Ms Nightingale who determined five essential characters of healthy houses that include: efficient drainage, light especially sunlight, pure air, pure water and cleanliness (205). She emphasised fresh air and sunlight deter the spread of infections and speeded the illness recovery (206). Later, Sir Leonard Erskine Hill achieved the same results. He described many parameters which improve health in the house. Moreover, like Ms Nightingale, he agreed with fresh air, a radiant heat source, and sunlight (207). In the past, proper building and city planning were as a factor for enhancing public health. However, now house design and city planning stopped being as health parameters. Comfortable conditions concluded more concern than improving health. It can be seen with moving towards the airtight house with mechanical ventilation, and sealed glazing.

5.5.2 Health and refurbishment

One of the most remarkable changes in building over the last 60 years is that radiant heating has been displaced by radiators convection. In the UK, in 1970, 30% of the house had central heating. By 2006, it had risen to 90% (208). In these years, indoor temperatures have growth, whilst the rates of ventilation have decreased because of packing of chimneys and window exchanging. The absence of central heating with a growth risk of dying in winter and winter mortality excess are significant health matters in the UK. The warmer, fewer humidity buildings enhance health; increasing temperatures to amenity rank and removing mould and damp have a good effect.

The attention to the maintenance and justification of central heating can save lives. However, it also has an adverse effect on health in the longer course. Raised the indoor temperature, decreased the rates of ventilation rates which caused improvement in the building dust mite concentration. So, it is the parameter in the enhancing of asthma (209). Between the 1960s and 1990s, researchers demonstrated that the prevalence of asthma enhanced by 5% per year in the UK (210). Moreover regards to asthma, growth in temperatures improved the incidence of obesity. The human body exhausts less energy in the typical temperature ranges for new houses (211). Residences uninsulated houses are vulnerable. In some part of the UK, where the temperatures were not as excessive, the burden was 2000 deaths (212). Residence in hot weather has hard justified in the summer; especially the ancient houses are vulnerable (213,214). In this kind of houses, just a little raised in heat gains caused by extreme temperatures, overheating can be a trouble in summer. Nevertheless, overheating may happen in renovation elements which are insulated deeply.

The houses with thermal mass (case studies 5, 6, 7, 10 and 12) are a better deal with overheating. Moreover, mechanical ventilation tools are not adapted to perform with high outside temperature. Usually, they supply fresh air at 1 to 1.5 air changes per hour, but it is not adequate to eliminate extra heat in summer. Eliminating undesirable heat in ventilation rate of 10 air changes per hour at night is essential according to the results of thermal models (215). According to the section 5.3.1 '*Mechanical ventilation or Natural,'* overheating is not a trouble for the low energy future house, but it is a risk for construction buildings according to the standards. Also, the risk will be worsened by changing the climate (216).

A conventional way of confining overheating is a plan for natural ventilation in high rank. The details of the windows have an essential effect as control ventilation in summer, for instance, the sash windows can improve the cooling of indoor. Also, they can arrange the sunlight directly during hot seasons, such as shutters and blinds (case studies 1, 3, and 11). Conversely, in modern improvements that confine the size of windows and exclude sunlight directly, decrease the risk of overheating, however, the small light levels, similar to small ventilation rates, are caused to the negative effect for the health in-house.

5.5.3 Health and indoor air quality

There is increasing public awareness and concern of the risk with poor indoor air quality in the houses and public places (167). The rates of ventilation in houses have decreased over the years. At the time, the tendency has been to design modern houses, also to the refurbishment of traditional dwelling to decrease the commitment of fresh outside air to interior ventilation. Studies demonstrate that a late Scottish house (case studies 10,11 and 12) had more than nine times the air flow rate of new timber frame building (217). Table 5.3 shows the conditions of chimneys in the case studies. Former studies propose that a conventional chimney would transfer 285 m^3 (10000 cubic feet) of air hourly. Also, a window would transfer 0.15 to 0.25 m^3

(300 to 500 cubic feet) of air hourly. The minimum rate of air exchange suggested for the health of residences was 85 m^3 (3000 cubic feet) per hour (218). At present, it is overdone by the standards. However, now fresh air in the houses is therapeutic and hygienic. Standards and codes arrange strict ventilation rates to limit the risk of contagion. Mainly, the minimum rates of ventilation required to avoid the spread of illness such as tuberculosis and influenza are not known yet (219).

Ms Nightingale believed that there was no mechanical ventilation tool that could provide fresh air because there was no warranty which the air does not mix with pollution air. Open chimneys and natural ventilation were the only proper tools for refreshing and heating the air which provided natural radiant heat, while air warmed by the surface of metal was prevented as it was provided by the ventilation tool, so health was not ceded due to save energy or designing wrong (206).

Table 5.3. The conditions of chimneys of case studies. Source: own elaboration regards to the information of assessors accredited by Elmhurst, an Approved Organization Appointed by Scottish Ministers (110).

Case study	Chimney stacks	Chimney breasts and fireplaces
1	The house has one chimney head on the gable wall which is of brick construction with a lead flashing. The chimney head and attendant flashing appear in serviceable repair with no visible evidence of leakage.	There is a brick built external chimney breast wall on the gable of the house. Internally, there is no fireplace surround or flue arrangement with regards to the chimney head. No testing of the flues or fittings was carried out.
2	The chimney stacks are traditional rendered masonry construction. These generally appeared in a fair condition consistent with age.	All flue linings should be checked, repaired as necessary and swept before the fires being reused. No testing of the flues or fittings was carried out.
3	Chimney stacks guttering replaced due to severe weather damage in winter of 2010/11. The damp readings noted at first-floor level are all below chimney stacks. Some flashing repairs have recently taken place to include the replacement of a section on the gable, and one has been patch repaired with flash band tape. Further flashing repairs are likely to be required in the future around the chimney stacks.	The fireplace in the dining room is fitted with a convector style gas fire. There are blocked or temporarily blocked fireplaces throughout the property, and the chimney breasts could not be inspected. The fireplaces within the house are mostly blocked. Dampness was located above a number of the fireplaces. The fireplaces should all be checked and cleaned down before any further usage. No testing of the flues or fittings was carried out.
4	There are chimney stacks on each of the gable wall heads which are of stone construction. Appear to be in reasonable overall condition at present although regular ongoing maintenance should be anticipated.	There are open fireplaces in the sitting room and maid's room. The fireplace in the dining room has been closed off, and other fireplaces have been removed. No signs of any defects were noted although if it is intended to use the fireplace in the sitting room, then the flue will require being checked and lined and appropriate.
5	Stone construction with a mixture of lead flashings and cement mortar skew fillets. Stonework at chimney heads shows evidence of some erosion due to weathering	There is no access to the roof or roof space over the property. There is a polished stone fireplace surrounds within the central accommodation, with gas fire points fitted. Fireplace surrounds

	over an extended period of years. Cement mortar skew fillets and lead flashings are weathered.	are well maintained. Flues have not been tested. No testing of the flues or fittings was carried out.
6	Chimney heads are of stone construction. These generally appeared in a fair condition consistent with age.	There is a multi-fuel stove in the Dining room. There are gas fires in the living room and front Bedroom. There is an open fireplace with a smaller rear Bedroom. All other original fireplaces have been sealed.
7	Five chimney stacks form part of the structure, four of them are of brick construction and one of which is of stone construction partly finished with the render. No evidence of significant defect was noted in respect of the stonework, brickwork, pointing and render. In respect of the stone built chimneys.	There are three fireplaces around the house, one of which has been fitted with a multi-fuel stove and the other two of which are open. The other fireplaces around the house have been removed. All original chimney breasts remain in place. No evidence of significant defect was noted in respect of the fireplaces and chimney breasts.
8	Masonry with render finishes. Concrete and stone cope. Chimney stacks appeared in satisfactory order.	The original living room fireplace is now occupied by gas living flame fire. Other fireplaces have closed.
9	Chimneys are of stone construction. These generally appeared in a fair condition consistent with age.	There are gas fires with a living room and games room. All other original fireplaces have been sealed. There are open fireplaces installed within the property incorporating modern living flame gas fires.
10	The chimney is stone. Evidence of weathering and general deterioration.	The chimney breast is plastered masonry. No testing of the flues or fittings was carried out. No significant defects were noted.
11	Chimney stacks are of stone construction, with flashings formed in cement. Open jointing was evident to work.	There is a fireplace in the sitting room, serving an electric feature fire. There is a further fireplace in the dining room. This was blocked up.
12	The chimneys are of stone/rendered masonry construction. The chimneys are generally satisfactory allowing for normal weathering commensurate with age.	The chimney breasts are of plastered masonry. There are some original fireplaces which do not appear to be currently in use. The chimney breasts and fireplaces appeared satisfactory allowing for age.

5.5.3.1 Indoor air contamination

Indoor chemical contaminants can be persistent. Recently a lot of them were recognised that were not known 60 years ago (220). Also, the regular rates of air change of new houses are low for chemical actions to happen (193), indoor organic contaminants can interact with ozone, inversely, also can interact with the mucous membranes and skin (221). The indoor air of new houses contains a mix of particulates such as pollen and dust, gasses such as VOCs, carbon monoxide, ozone, nitrogen dioxide and biological agents such as viruses, bacteria, and fungi. Pollutants come from outdoor and from indoor origins which contains house materials, furnishing, pets, the occupants, carpets and daily actions (222–224). Exposure to them has been raised due to the decrease in the rates of air flow and the inside time spending raise (172). Moulds can distribute microbial VOCs which have been linked with the irritation of the throat, a cough, wheezing, fatigue and a headache (167).

The primary objective of ventilation is to eliminate this kind of contaminant. Until now, Building in the UK construct regards to the fresh air of filtration air via voids in the house elements and opening window. It makes a change in the performance objective of the house standards, regulations, and codes. Mainly, the outside air required to maintain house residences healthy for years (225). When the rates of ventilation are calculated, the outcomes demonstrate the important differences among the function and the design. Researchers from many countries observe a major discomfort in houses when the standards of ventilation are reached (200). The primary objective of part F of the house standards of the UK is to keep and reduce the emissions and humidity which are harmful to residents (193). They arranged the extension for VOCs, carbon monoxide and nitrogen dioxide and suggested advice on how the regulations can be achieved but do not arrange a limitation for chemical pollutants from house elements, nor does mention the distribution of infection, also how houses must be planned to avoid it.

Since new standards performed, the Sick House Syndrome (SHS) rate in the users of new buildings has lessened (226). For instance, in Japan, the inefficient ventilation of high packed spaces has resulted in the troubles of health (SHS). Recently in Japan, chemical pollutions from the elements are measured, and the usage is limited. In addition, Denmark applies a labelling tool which calculates the VOCs pollutant from house elements (227). In the US, the Leadership in Environmental and Energy Design (LEED) schemes for sustainable refurbishment and the new house has been reviewed (193). Another scheme such as BREEAM, CSH, and LEED, are tended towards energy efficiency and put less emphasis on health and, the effect of the chemicals on gassing from house elements. The indoor circumstances will adversely impact on the health, as they are a parameter in breathing link to the disability. Studies demonstrate that in the UK, 1 in 13 residences have asthma whilst 45% of residences tolerate several kinds of allergies (228). The main reasons are high moisture, damp, formaldehyde, and the dust mite allergens.

5.5.3.1.1 Carbon Dioxide and Carbon Monoxide

Carbon dioxide (CO_2) is produced via fossil fuels combustion and person breathing. It causes the residences to feel drowsy and headache. The poor ventilation result in the significant rank of CO_2. It is crucial that appropriate levels of ventilation rates be preserved when improving energy efficiency. Carbon monoxide is a product of incomplete fossil fuels combustion containing oil, gas, coal, and wood which can murder rapidly. Its toxication is a risk by imperfect fossil heating tools, especially where fossil tools are not preserved properly, and there is inadequate ventilation.

5.5.3.1.2 Volatile Organic Compounds

Volatile organic components (VOCs) give out as gases from specific liquids or solids and contain substances that have a negative effect on the health. The sign of illness contains throat, nose, eye irritation, loss of coordination, headaches, central nervous system, nausea the liver and kidney problems (229). The range of VOC is highest in the modern decorated house, because of improving pollution rates of new materials and new finishes. A lot of materials applied in the historic house give out little VOCs. Also, several components of new houses do not give out VOCs, for example, insulation of cellulose and some type of paints.

5.5.3.1.3 NO_x

The prevalent oxides of nitrogen discovered in the dwellings are nitrogen oxide and nitrogen dioxide (NO_2) which are toxic also, result in throat and nose eye irritation, breathing diseases and took down lung function. Combustion of fossil fuel is the origin of indoor NO_x. Good preservation of the appliances along with adequately ventilation spaces decreases NO_x.

5.5.3.1.4 Damp and Condensation

Damp and condensation can be produced via inappropriate elements applied to renovation and repairs. The primary of damp origin in historic houses are condensation, rising damp and rainwater infiltration. It is one of the significant reason for the decay of historic houses (230). According to the Scottish Building, 1 in 10 houses have condensation, and 1 in 20 houses suffers from damp increasing (231). Regards to the English House Condition Survey, 7% of pre-1919 houses tolerated from mould and condensation. Moreover, 25% tolerated from the damp form (232) which considerably more than houses constructed after 1919. In a survey of 600 residences in London, Glasgow and Edinburgh; Glasgow, and London recognised the mouldy and damp and mouldy living situation hurt symptomatic health (233). In addition, research of 700 occupants in Finland demonstrated that people who lived in the houses with humidity problems are tolerated from tonsillitis, sinusitis, colds, cough, dyspnoea and sore throats (234).

5.5.3.1.5 Lead and Aldehydes

Although their ingredients are harmful to the health and environment emission, leads have been applied in houses for a long time. It causes brain and blood disorders and nerve problem. The risks of lead in historic houses grow via exist of it in the dust and from the elimination of lead finish paint (235). Lead finish paints were applied before the First World War. However, its usage followed up to 1980s (236). Lead finish paints were harmful when they are disturbed. Even though the use of lead finish paints had been banned since 1988, they were used for works of art or listed traditional houses. An aldehyde is an organic chemical shaped via the oxidisation of basic alcohols. It is the primary aldehyde recognised in the indoor environment and exists in a lot of natural elements like wood; also it is recognised in a composition which includes the adhesive urea formaldehyde like insulation and particle board. Moreover, it is a product of combustion, and it irritates the throat, eyes, and nose (237). In addition, formaldehyde is predominantly applied in modern furnishings and materials, and decreasing presentation in houses obtained via a proper choice of components.

5.5.3.1.6 Moulds and Bacteria

They generate toxins in airborne spores which can have a negative impact on the health and are linked to breathing problems. Also, they exist in damp zones like ventilated kitchens and bathrooms; the bacteria come from inappropriate cleaning via exposure to pollutant water. It is necessary to eliminate a fungal to support the health of residences. The widespread bacteria are dangerous; a little even may be useful. The preservation a relative humidity of around 65%, decrease the risk considerably for increasing.

5.5.3.1.7 Radon

It is given out from rocks and soils which include the small type of uranium and can give off from house elements. It is a radioactive gas. Naturally, it happens in some hazardous areas of the UK also, is the second primary reason for lung cancer after smoking (238). It disperses into the air rapidly and is typically not dangerous. Nevertheless, because of its high density, it can be accumulated below the houses, and penetrate via opening and cracks. Radon accumulation highly depends on the ventilation degree, kinds of construction, any refurbishment, and location. Testing radon has effortless progress. One of the effective programs is changing the ventilation method.

5.5.3.1.8 Particulate Matter and Dust Mites

Particulate matters are ingredients of a liquid or solid which is hanging in a gas. It is generated naturally or freed into the air via the fossil fuels burning in vehicles or industrial progress. The high rank of it is linked to lung cancer, breathing function and heart problems. Particulate matter is produced via house activities also, coming from outdoor. It was incremented due to inadequate cleaning, environmental tobacco smoke or outside air emissions rates. In historic houses, it is produced because of the function of furnace, stove, and fireplaces. Mites are discovered in toys, furnishings, carpets, pillows and bedding. The age of the house is not an important parameter in the concentrations of it. In the UK, 5 million residents have asthma, and 75% of them have an allergy to the dust mite. It equates to 6% of the people in the UK. The studies have determined that cleaning and hard allergen prevention can decrease asthma. Proper control humidity is an essential parameter in limitation dust mite which is active between 45% and 65% humidity. Also, appropriate maintenance decrease sensitisation and avoid distribution of allergies.

5.5.4 Health and lighting

Daylight innately is not better than artificial ones, but it is dominant for the health. Investigates opined that residences choose natural light and believe exposure to daylight results in less stress and more comfort; also, is good for the health (239–241). Further studies demonstrate that residences in industrialised cities do not expend too many hours outside as they do not achieve adequate light for a healthy life (242–244). The residence chooses the level of lighting that considerably is more than usual indoor lighting and also select daylight cycle (245). Two British scientists in 1877, claimed that light and sunlight has a bactericidal impact even if it has transferred via the glass (246). Their studies enhanced other researchers to work on the impact of presenting bacteria to the ray of the sun so, sunlight was an essential issue regards to the illness. The design should start planning the buildings with big windows on the south facing to avoid the illness. Also, balconies and terraces should be planed so residences could use the sun directly; nowadays, this is not usually considered.

5.5.4.1 Indoor lighting and Sunlight

Electrical lighting supplies a light ranges between 40 and 450 lux which is almost biological darkness for the human body system and requires to be 1000 lux for good impact. Moreover, it achieves the similar intensity of light that residence obtains outside. Sun can transfer 100,000 lux; moreover, in sunlit space, there are 60,000 lux (247). In addition, disordering body rhythm can lead to a health problem, associated with sleep problems, prostate and breast cancer, heart disease, obesity, depression, and diabetes (248,249). Formerly believed that sunlit building was healthy, the American Public Health, in 1938, determined the primary requirement for health is direct sunlight. Regards to the hygiene of building, they described it is not possible to arrange certain conditions. Nevertheless, it is essential to pass the direct sunlight even some hours even in cold seasons (250). The studies demonstrate that sunlight spaces can be healthier (251). Also, the researchers discovered the low ranges of sunlit increase the residence depression (252). Daily, bright, high-intensity light enhanced the depressive signs and sleep methods (253).

The code of practice for lighting, the UK standard on lighting and BS 8206-2:2008 lighting for houses (254), argues the matter of natural light in the satisfaction of residence. The revised issues suggest to the entrainment of circadian human rhythms and depression. It claims that a major range of daylight is essential to residents with limited conditions of mobility. Moreover, the standards include references to properties of sunlit and the critical impact of ultraviolet radiation, but the regulars that arranged in are not enough. In addition, the growing use of insulation layers in-house caused by increase the risk of overheating.

5.5.5 Health and orientation

For designing the house, the ray of sun is still important. Usually, the north side is for heating rather than for putting the residence well and comfort. The primary objective of solar design for energy efficiency is different from the improvement of health. For instance, southerner face orientation is suggested due to being most proper for energy saving (case study 11), but it is not the best. Also with putting a house in this ray, there are two negative effects; first, the north face is under a shadow for six months, the next, there is a long shadow or over shading more than with any other faces. Houses formerly arranged in various ray for health, partly, it was for sanitation. Also, it is challenging to clean outside that exposure to the little sunlight. The humidity on the wall dries rapidly with directly sunlit, without it, the wall holds the humidity which results in increasing the mould and microbes. Therefore, it is crucial in the way that exterior walls have a direct sunlit. Moreover, the residents can be exposed to the sun most of the time.

The characteristic of the best designs was when they had the long axis located as near to south-west and north-east (case studies 1, 2, 3, 4, 6, 7, 9, 10 and 12) since it received sunlight in winter and early morning. Also, the square houses with living rooms that are occupied most of the time were arranged on the diagonal, located at the southern point (case studies 1, 2, 3, 4, 6, 7 and 9). Case studies 4 and 9 have the best design regards to orientation, and case study 5 has the worst design because it can just use sunlight from the west and a little from the east. The residences of the traditional houses which were managed like that could experience from germicidal and therapeutic features of the sun. Unfortunately, if the houses are renovated, maybe this feature will be limited. In addition, for the buildings that are highly insulated, maybe overheating could be occurred, so the first option for designing is preventing the direct sunlight.

5.5.6 Health and heating

The studies of Ms Nightingale and Prof. Hill, demonstrate the methods that help the house to be warmed so could have an influence on the health. The Professor describes the best way of ventilating and heating are warm floor spaces, radiant heat and transferring of cold air such as the conditions of a sunny day outside in spring. His studies demonstrate the humid hot air of the modern new houses decreases the ability of the human body to generate heat. Inversely, it reduces the breathing ability, the circulation and the tone of muscular (255). Moreover, he considered a notable difference among health and comfort. In addition, he assumed that the people require challenging the thermoregulatory system. The sympathetic nervous organ of body manages the thermoregulatory and cardiovascular system, so a rise in the activity of cardiovascular, increase the outcome of metabolic heat that via the thermoregulatory systems inversely have to be managed (256).

The raised implementation of central heating leads to the increase in obesity. Prof. Hill in the 19^{th} century discussed that immovable heating and inappropriate ventilation system without mobility resulted in the health trouble. Nowadays, in codes and standards, the heating issues are not considered for improving the health. Nevertheless, there are care regards to the impact of the converted air warm such as MVHR tools on the health. The guidance of Word Health Organisation pointed out that warming via convective has to be planned and preserved that not increase the nuisance noise and prevent of distribution of bacteria and dust. Moreover, it mentioned that warming by radiant is the best option (257). Warming by convective effects on the skin, in turn, radiant heating has a biochemical impact, its effects on the interior human body system like nervous systems (258).

In addition, the temperatures with radiant origin can be held lower rather than the convective warming tools, because a radiant system makes warm interior area whilst preserving the comfortable and healthy situations. Researchers demonstrate that residences that distinguish indoor air quality were better at low temperatures. There is energy saving and health advantage, regards to the claims of ‘The Physiological Basis of Health standards for houses’ book which explain that comfortable situation can exist by warming via radiant at low temperatures, therefore with regular clothing, there is a freshness feeling (258). In the past, around two thousand years ago, the Romans people mostly applied radiant energy in houses. They planned to achieve the sun heat, and solar energy was crucial (259). Also, they added the technology of underfloor hypocaust radiant heating with the solar design. Later, the Koreans company improved underfloor heating systems. Mainly all houses in northern China and Korea use radiant heating floor (260). Also, in Denmark, Austria, and Germany, 35 to 55% of modern houses use underfloor heating tools (261).

The primary benefit of an underfloor heating system is that it favours flowing blood in the feet quicken via vasodilatation which can enhance vascular linked to the illnesses. Korean underfloor warming system was applied to treat elderly and weak persons in the 15^{th} century (262). The second advantage is using the carpet not necessary, so it eliminates a considerable origin of dust mite and another pollutant. Also, there is less transferring of dust; and the higher temperature decrease mould and condensation. Moreover, there is saving energy opportunely, because lower indoor temperatures decrease heat losses via ventilation (261). Another advantage is that it levels out the floor-to-ceiling temperatures. A decrease of 5°C in the vertical air temperature result in feeling cold in feet and reflex changes in the temperature of the breathing system (257). The radiant underfloor heating system warms the feet, which increases the temperature of the nasal mucosa (263,264). Prof. Hill claimed that the radiant energy was necessary for health because it was a substitute for sunlight. Also, he thought that the radiant energy of fire, open windows and the ventilation preserved by it, is the major healthful in the weather of cloud and mist (207).

It is possible to obtain thermal comfort through an interior radiant heating system which has an advantage for the health. Moreover, the temperatures are lower so, air tightness and insulation level may not reach the required standards. The warming by radiant saving energy through low temperature whilst enhancing health has been neglected. The new system of radiant heating is available. One benefit of applying them for renovation houses is that several components of old houses, especially tall ceilings, are not an obstacle to the good energy function.

5.6. Main results of the case studies and discussion

The following table demonstrates measurement that will enhance the energy and environmental performance of the twelve case studies.

Table 5.4. The recommended measures and their results on energy and environmental performance.

Recommended measures	Applicability in the case studies	Average indicative cost (£)	Average annual savings per year respectively (£/year)
Cavity wall insulation	1, 2, 10, 11	500-1,500	220, 420, 50, 35
Floor insulation	1, 3, 4, 5, 6, 7, 10, 11, 12	800-1,200	120, 260, 240, 280, 90, 150, 60, 230, 190
Boiler replacement	1, 3, 4, 9, 10, 12	2,200-3,000	200, 980, 300, 380, 55, 560
Solar PV panels	1, 2, 3, 4, 6, 7, 9, 10, 11, 12	5,000-8,000	250
Solar water heating	2, 7, 10, 11, 12	4,000-6,000	140, 110, 30, 65, 65
Replacement glazing units	1, 4, 5	1,000-1,400	80, 140, 65
Internal or external wall insulation	3, 4, 5, 6, 7, 8, 9, 10, 11, 12	4,000-14,000	1800, 1700, 1350, 500, 500, 140, 530, 250, 230, 950
Draught proofing	3, 4, 10, 11	80-120	345, 200, 20, 35
Low energy lighting	3, 4, 6, 7, 9, 10, 11, 12	80	60, 80, 45, 60, 65, 40, 55, 70
Hot water cylinder thermostat	3	200-400	220
Replace single glazed window with low-E double glazed window	3, 7, 10, 11, 12	3,300-6,500	260, 200, 55, 110, 220
Upgrade heating controls	3, 4, 9	350-450	175, 460, 95
Loft insulation	4, 12	300-400	220, 120

Change heating to gas condensing boiler	5	3,000-7,000	1950
Room-in-roof insulation	7, 11	1,500-2,700	600, 780
Wind turbine	12	5,000-8,000	550

The following table shows how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the house (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table 5.5. The current and potential energy cost.

Case study		**Heating (£)**	**Hot water (£)**	**Lighting (£)**	**Total (£)**
1	Current energy cost over 3 years	4,100	520	310	5,000
	Potential energy cost saving over 3 years	2,400	390	310	3,100
2	Current energy cost over 3 years	4,400	900	250	5,500
	Potential energy cost saving over 3 years	3,350	300	250	3,900
3	Current energy cost over 3 years	17,700	820	620	19,200
	Potential energy cost saving over 3 years	6,100	390	380	6,900
4	Current energy cost over 3 years	17,600	540	660	18,000
	Potential energy cost saving over 3 years	6,100	400	350	6,900
5	Current energy cost over 3 years	13,000	1,000	350	14,400
	Potential energy cost saving over 3 years	2,600	390	350	3,400
6	Current energy cost over 3 years	5,900	370	470	6,700
	Potential energy cost saving over 3 years	4,100	370	310	4,800
7	Current energy cost over 3 years	15,800	870	560	17,300
	Potential energy cost saving over 3 years	11,500	520	300	12,300
8	Current energy cost over 3 years	3,200	330	220	3,800
	Potential energy cost saving over 3 years	2,800	330	220	3,400
9	Current energy cost over 3 years	6,100	1,500	550	8,200
	Potential energy cost saving over 3 years	4,000	780	300	5,000
10	Current energy cost over 3 years	3,000	420	300	3,700
	Potential energy cost saving over 3 years	1,700	250	170	2,100
11	Current energy cost over 3 years	6,200	530	400	7,100
	Potential energy cost saving over 3 years	2,000	330	200	2,500
12	Current energy cost over 3 years	9,800	720	560	11,000
	Potential energy cost saving over 3 years	4,100	300	290	4,800

All the case studies were analysed, and several improvement recommendations were suggested. The wall insulations were suggested for all case studies. The priority is enhancing the house fabric, then replace the boiler and glazing units. The most cost-effective recommendation is to install draught proofing, with an indicative cost of £80-120 and also improving the lighting. Using renewable technologies such as solar photovoltaic panels and solar water heating is essential for all the houses to reach zero carbon houses level. The difference between current energy cost and potential energy saving cost over 3 years for case studies 3, 4 and 5 are around £12,000, for case studies 6, 11 and 12 are around £6,000 and for the rest of case studies are around £2,000; so, priority for improvement respectively belongs to case studies 3, 4, 5, 12, 11 and 6; especially in the heating system.

5.7. Conclusions

For the houses of the same age, it is essential to consider several general parameters, like materials, house location, the provision of adequate ventilation, furnishings and finishes, the state of repair and the house operation. There must be a balance between CO_2 emissions reduction and residences healthy. The ventilation rates determined by new standards are not adequate to prevent disease. A damp and cold building put health at risk. One of the methods to enhance indoor air quality would be to prevent determining elements which give out dangerous chemicals and avoid the moisture transfer.

The best alternative for the refurbishment of a traditional home is using radiant heating, which is efficient and guarantees the health of residences as the recent studies demonstrate that radiant heat is healthier than convective one because it supplies comfortable situations at low indoor temperatures with low ventilate heat loss. In addition, the types and kinds of lights and illuminations rates supplied are essential for healthy living. Daylighting is healthier than artificial ones.

The challenge is renovating traditional houses to the new standards of energy efficiency, which enhances and preserve the health issues because a lot of old houses were well planned for health according to the natural lighting, heating and ventilation. Also, supplying sufficient moisture and ventilation arrangement is a complicated subject and needs a knowledgeable answer. The finding of the chapter showed that the renovation of traditional houses needs a sympathetic approach. Moreover, refurbishment should enhance the inherent environmental performance features ideally.

CHAPTER 6. ENERGY EFFICIENCY AND THERMAL PERFORMANCE OF TRADITIONAL WINDOWS: MODELLING AND ASSESSMENT OF IMPROVEMENTS

This chapter aims to analyse and assess some parameters related to the energy efficiency of the traditional windows and shortly discuss future window technologies. It is divided into four sections. After presenting the methodology, a complete state-of-the-art and general guidelines to improve the thermal performance of windows are exposed. In the next section, the influence on the U-value and the Solar Heat Gain Coefficient (SHGC) of the windows elements, materials, and thickness are assessed. Finally, the influence of the windows (as a one house component) on the whole house energy efficiency is analysed, evaluating some potential improvements.

6.1 Methodology

First, worked on the windows energy efficiency and what influence on U-values, for example, the kind of windows, repair or replacement options, glass quality, frames and kind of them, windows painting. Then focus on the influence of these parameters on the energy efficiency and study on the future windows technology, zero windows energy, integrate surface, dynamic windows, highly insulating windows and concentrate on the vacuum glazing windows, because of its importance. Also, some subjects about thermal optimisation of windows and the marketing of new windows are discussed. In addition, briefly work on other factors like heat transfer, ventilation, condensation, noise insulation and ultraviolet protection.

Next, worked on the U-values and SHGC of the windows by the 'Window' software of Lawrence Berkeley National Labs (LBNL) (265) program and analyses all the windows elements, their materials, number, thickness and their influence on the U-values. First, U-values of whole windows are studied, analysing the different parameters on the windows elements; for example, the size of the windows, its situation, the number of divisions, and the kind of windows, frames, divider and glazing system. In the second part, worked on the U-value of a glazing system with analysis of the glasses quality and the gaps, their materials and thickness. The method is considering the reference model according to the prevalence kind of windows then change some condition, analysis of the obtained U-values and discusses its influence. As a whole, in this part worked on the effect of all related parameters on the U-values of the window by the software, also some economic examples are mentioned.

The third part worked on the conditions of windows in the building for studying their influence on the energy efficiency of the whole buildings; for this reason, the windows defined in chapters 4 and 5 have been chosen. The properties featured in this chapter are twelve typical case studies of pre-1919 construction in Scotland. Most of their windows have been replaced with double glazing window. Two of them have original single glazed windows, and three of them have both single and double glazing windows, and the rest have double glazing windows. Three of the case studies are using secondary glazing system. In the third part, all the windows are modelled by “Window” program, obtaining the U-values, SHGC and analysing all the conditions and alternatives of the windows. Then the optimisations methods are suggested for repairing or replacement to meet the required U-values. Finally, some economic subjects have been analysed.

6.1.1 Software program

Berkeley Lab “Window” is software for assessing the U-values, visible transmittance, shading coefficient and solar heat gain coefficient of windows. It supplies a heat transfer procedure with upgraded rating progress improved by the National Fenestration Rating Council (NFRC) which is incorporated with the ISO 15099 standard. The software is used to improve the energy codes of the houses, help to study the heat transfer via windows, and enhance and design new kinds of window. The software can analyse the windows made from any composition. It is possible to select any kinds of glasses, frames, gap, divider at any tilt and any condition. Another feature is upgrading algorithm for assessing the whole U-value and solar heat gain with ASHRAE; also, it can model the complex glazing system. Its library is directly accessible, its glass library has many alternatives, but its frame and divider have a fewer alternative and contain a little kind of material.

The algorithms in Window software of LBNL program follows the procedures presented in ISO 15099(266). The heat transfer through the centre-of-glazing zone in windows is a one-dimensional process. It is assessed with breaking down the glazing unit cross parts into an assembly of nodes and measuring the heat transfer between each node. Under steady-state conditions, the nodes temperatures are such that the net energy flux entering each node is equal to that leaving each node. To perform the energy balance, Window software models the user-defined glazing system as a one-dimensional, steady-state resistance network as shown in Figure 6.1. Then an iterative solution method is applied to converge upon the correct temperature distribution. From this temperature distribution, any desired performance index can be measured. The software ignores or makes crude assumptions in regards to the thermal bridges, as it causes and is the primary pathways for moisture and condensation of the house, it is essential to consider its influence on the analysis.

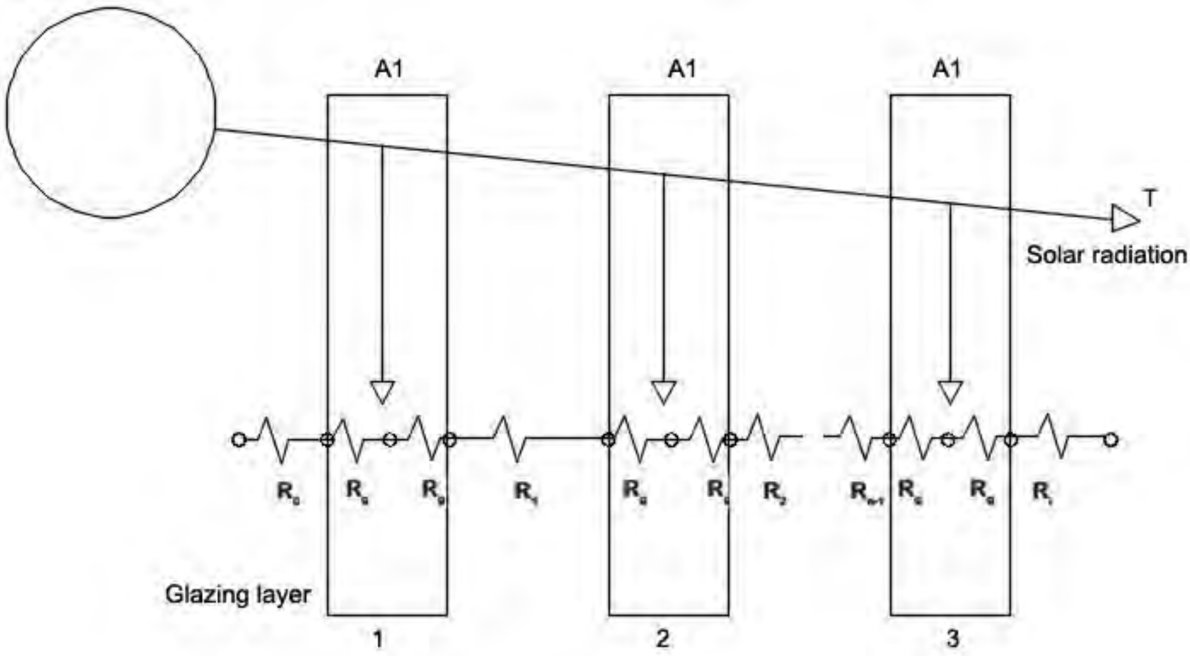


Figure 6.1. Resistance network applied to model centre-of-glazing heat transfer in the window (267) *in own elaboration.*

6.2 Improvement of the thermal performance of windows: state-of-the-art and general guidelines

6.2.1 Windows and doors

A window acts as a viewport out of a house and a source of light coming in a home. Often the functions of double-hung, casement, awning, pivot, hopper, fixed, or other from a distance are not discernible, yet the performance of windows are not interchangeable. A casement was used with the arts & crafts method, whilst double-hung windows are prevalent in Colonial & Colonial Revival style houses. Casement should be out of character in a house outdoor of the style, as should double hung window. The inside and exterior of the house are related by the windows. Window almost determines the character of the house with its period of construction and its style. The renovation can help maintain the house, keep its architectural integrity, and decrease costs. Unfortunately, windows, are the most attacked element of the house for heat loss, accused of being difficult to operate, being out of date and of wasting energy. A majority of the traditional window is made of wood, with steel to be used at the beginning of the 20th century. The performance of the windows differs with location and style, and the shape of the window, the number of glass panes, are a reflection of their age.

It is essential to recognise that the condition of a window comprises two factors, appearance and performance. If a window does not perform properly, and cannot be made to performance, then it likely will have to be replaced. Nevertheless, in regards to how unsightly a window may appear, almost it can be saved. Unfortunately, choices almost are made according to the exterior of a window and do not consider its performance. Fundamentally, if the frame of a window will be taken and will give an intense shake, and it will not be fallen out, the window could be saved and fixed. According to the need, exchanging various components is to be expected, and the replacement will not harm the accuracy of the window. It is less expensive to exchange $0.80 worth of sash cord than to displace the whole window. The critical subject is the windows can improve performance as initially intended.

Window types contain a wide range of patterns and styles that reflect their performance and the period of construction. Windows of traditional houses were made in different methods and continue to perform with little care. At the top, there is a frame, filled with glass, and hinged, horizontally or vertically. Regardless of kinds of style or house, double hung is the most extensively applied window, it has a sash on the bottom of the windows and one at the top. A simple counterbalance in the frames allows the lower and upper sash to slide down and up. Double hug windows that open from both top and bottom are the most prevalence in the traditional houses in Scotland. This kind of window offers natural ventilation. The treatment of traditional windows is also based on their contribution to the aesthetics of the house, window style and sizes were a reflection of architectural technology, social function, and styles. For instance, the elongated window has a Victorian style, an example of 19th-century improvements in the manufacturing of glass technology. In the South, the tall window was a response to taxes put on exterior doors.

The multiplex panes of glasses in modern windows ensnare air among the sheets that decrease heat transfer; nevertheless, those are air infiltration. Adding draught proofing on the traditional window will improve around 75% of the heat transfer problem, reaching the same standards as a modern window. Traditional windows often were mostly made of woods. Replacement window often is not as fundamental as the traditional ones and are made of fewer elements. Replacement windows are too deteriorated to would be fixed in type and kind, same materials, pattern, design, and size. Some studies demonstrate the influence of the shading, glass, orientation, and size of the windows on the indoor thermal environment of houses in warm weather (268). Also, another study demonstrates that the indoor environment does not enhance notably if the windows are replaced from single glazed to double glazing. Moreover, it shows that each m^2 of window surface can supply heating of 2-3 m^2 of floor surface in the winter. Moreover, the windows in a south surface have the most potential to enhance summer and winter inside comfort.

In the past mostly the timber was made of heartwood of Pinus sylvestris; in the 20th century, the prevalence source of wood was plantations trees. At that time, the farm significantly grown trees in the shortest course time, therefore there were a large quantity of sapwood rather than slow-grown ones. Sapwood is better penetrable than heartwood and includes starches and sugar which supply the best outfit for fungi that make them inappropriate for joints and vulnerable to decay. However, after the war, sapwood still have been used. Now can see the results that most of the traditional windows have to be exchanged. Heartwood is one of the most suitable and durable alternative softwood for replacing like Pinus sylvestris (European redwood or Scots pine). Applying acetylated softwood is recommended as it is stable and durable. Slow-grown pine that is resinous wood with ten rings per centimetre is the most effective for repairing or replacing the windows. The window needs well preservation such as other house elements. It is not possible to working overtime unless it is preserved. Mainly if it is located in the location with severe weather climate and internal central heating that cause closing and opening the windows continually.

6.2.1.1 Double glazing

The SHCS (269) concluded that the energy efficiency of the buildings has enhanced since the survey of 1996 (e.g., over 92% of houses have partial or complete central heating, 90% have some loft insulation, and 88% have double glazed windows). Table 6.1 demonstrates the portion of houses by age with double glazed windows (270). Pre-1919 houses have the lowest portion of double glazed. The research uses the National Home Energy Rating (NHER) (271) to calculate energy efficiency.

Table 6.1. The portion of houses by age with double glazing in Scotland (72).

Age of houses	**Percentage of dwellings with double glazing (%)**
Pre-1919	63
1919-1944	87
1945-1964	90
1965-1982	93
Post-1982	97

Table 6.2 presents the U-values of the various windows. According to this table and other studies, the heat lost via a single glazing window is round twice via a double glazing window meet the recent UK standards and dwelling regulations (for instance, a reference U-value of 2.0 W/m^{2}K is for Standard Assessment Procedure (SAP) measurements. While secondary glazed windows are efficient as a choice to maintain the current historical window, there is limited data on the function of old paths of decreasing heat lost, like curtains, shutter and blind.

Table 6.2 Typical U-values of the various windows type in EU countries (272,273).

Type	**U-value (W/m^{2}K)**
Single clear glass	5.4
Double glazing with 12 mm air gap	2.8
Double glazing with 20 mm air gap and Low-E coating	1.7
Double glazing with 12 mm air gap and Low-E coating and argon fill	1.5
Triple glazing with 28 mm depth	1.1
Triple glazing with 28 mm depth, a Low-E coating and argon fill	0.75

6.2.1.1.1 Insulated glass units (IGUs)

The insulated glass units (IGUs), similarly to the secondary glazed, depend upon multiple sheets of glass to limit heat transmission. However, the glass layers are situational nearer than in secondary glazed. For cutting heat transmission, the void has to be depleted or either accumulated with an inert gas like xenon, krypton or argon to decrease the heat transfer level. Sometimes Low-E coating is used to the interior glass pane to decrease thermal transfer.

Regular double glazing insulated glass units are 21–29 mm thickness. Double glazing 'Slim-profiles' have a thinner void among the glass panes, in overall thickness rates between 9-17 mm. Nowadays enhanced the kind of IGU that has around 6 mm thickness and a small gap that the air is eliminated to make a vacuum. Slim-profile double glazing exception of vacuum insulated glass units is less thermally effective than regular insulated glass units. Ordinarily single glazed is 4-6 mm thickness. However, the old single glazed is around 2 mm. On the other hand, slim-profile insulated glass units are notably bigger, so the total size of double glazing windows are several times thicker than single glazed.

The performance of insulated glass bases on the seals avoids air and moisture penetrating from the void. If they do not work perfectly, the glass will be less effective thermally also, caused to fog due to interior condensation. The lifetime of insulated glass units is anticipated to be 20-30 years. Insulated glass has payback periods that significantly can exceed the design lifespan, for windows accumulated with inert gases. If the seals slip up, so causes condense on the inside of the glass that is hard to fix also, are more challenging to recycling. In addition, the energy needed in transportation and manufacturing can be considered in the total equation.

6.2.1.1.1.1 Slim-profile insulated glass

Sometimes it is not possible to exchange current glass in multi-paned traditional units with double glazed, also if 'slim-profile' insulated glass is applied without altering the glazing, bars, and frame to balance to the added weight and thickness. If the sashes are exchanged in double-hung sash window that does not have glazing bars, so more weights are increased to an equivalence of the added glass weight. When applied in multi-paned units, the insulated glaze will be less effective than secondary glazed, even when the most effective parts will not dominate thermal bridging. Particularly if it is a subject that is incorporated into steel window. Which is why many replacement units are done with wooden bars instead of a single insulating glazing unit; this method also is cost optimal.

Wooden windows are often around 150 years old that is vulnerable. Observation has demonstrated that if slim IGU is added, often window sashes must be exchanged. So, for this and due to decrease the outlasting the traditional glass, the launching of insulated glass in the traditional window has severely harmed the concept. With the slim profile insulated glazing windows, it is feasible to provide a new double glazing window in old materials that may be coordinated to the characteristics of traditional houses than recent kinds of exchanging units. It is admitted that the incorporation of conventional double-glazing and modern windows in listed houses is not appropriate. If they are added, it caused to reduce the aesthetic aspects of the house and its profit. Where the significance of houses has been damaged by the incorporation of substitution windows of unsuitable format, maybe incorporation of new slim double-glazing substitution units is appropriate where:

- Undesirable harm to the housing element will not affect the outcome of the elimination of the current window.

- The recent units are of appropriate and sympathetic design and applied where the importance of the house will not be damaged.

The slim-profile insulated glass does not increase the qualities of traditional single glazing. Also, the detailing cannot match precisely with traditional fenestration, where the significance of a house warrants an accurate copy of a traditional window, this should be single glazed, attention is given to secondary glazing, draught sealing or compensatory measures to improve energy efficiency in other parts of the house.

Slim profile double glazing has a smaller thickness than regular double glazing windows, due to the thickness; in many examples, it is good option to fit and adapt it into the windows which designed for single glazing. Slim double glazing, as installed in new modern houses, consists of two sheets of glass up to 24 mm with inert gas or dry air. It decreases the heat transfer considerably because of the thermal conductivity of the gases and the extra sheets. Accordingly, triple glazing contains three sheets of glass and two gaps. This kind of glazing has a smaller gap in comparison to the regular double glazing, also, results in smaller total thickness. The thicknesses of different kinds of glazing are shown in table 6.3.

Table 6.3. Typical overall thicknesses of glazing units (65).

	The typical total thickness of glazing (mm)
Single glazed	4 - 6
Slim-profile double glazing	8.2 - 16
Conventional double glazing	20 - 25
Triple glazing	35 - 45

6.2.1.1.2 Acrylic double glazed

To resolve the double glazing weight problem and to prevent the requiring to removal current glazing, tools have been enhanced that apply more accurate in slicing acrylic than the glasses; even though the void cannot be depleted or accumulated with gases to limit heat transmission; for example, plastic has a greater thermal inertia than the glasses. Previous examinations have proved that the hybrid double glazed can decrease thermal transmission by around 42%. Thicker acrylic is required for larger panes to overcome deformity; it does not focus on the heat transmission via the frame. Subsequent difficulty contains discolouring, acrylic scraping, and clearing. Nevertheless, the use of high-grade acrylics can minimise the risk of scratches and discolouration.

6.2.1.1.3 The influence of double glazing on traditional window

The sealed double-glazed makes them too thick for adapting to traditional casement or sashes. International standards suggest the sealed zone between the two panes in the sealed unit would be more than 12 mm and about 20 mm; it is nearly the total depth of a lot of sash and casement frames. Adapting thinner sealed in a traditional frame should compromise the appearance and strength of the traditional window; although would not affect the outcome in effective thermal insulation. The sealed unit does not stop air filtering through cavities at the edge of the frames or around the unit.

6.2.1.2 Secondary glazing

Secondary glazed is an independence kind of windows used on the inside part of units. The main units stay in the current situation in the changed shape. Secondary glazed windows are present as fixed, open-able and easy moving panels. The open-able units can be sliding sashes or casements which are accessible to the exterior window for opening and cleaning of both the external window and secondary glazing for ventilation. Another kind of secondary glazing is designed to be replaced when its thermal benefits are not needed for example in warmer months. For case studies 9, 11 and 12 (see section 5), before installing secondary glazing, it is essential to first check with the local authority may be the permission is needed. For the best result in thermal insulation, there should be a cavity of at least 20 mm thickness between the external window and the internal unit. A 20mm cavity may be taken if the staff bead (the bead holding in the lower sash) is replaced with a bead supplied with the unit. Secondary glazing can be built custumal to justify to original traditional houses. Piggy-back is one of the most prevalent methods of secondary glazing that directly hangs to the original sash frames. By using this method, it is possible to open the window that is a little harder because of additional weight, also can apply weather stripping in the casement windows.

In case studies 4, 5 and 10, where there is a shutter set close to the sashes it is possible to obtain the 20mm space by disabling the shutters. Invasive options should never be carried out to adapt secondary glazing panels. Traditional shutter helps with insulation as well as safety and security. In addition, they decrease the noise and air infiltration, preserve traditional wood windows and repair them appropriately along with applied suitable secondary glazing panels can give energy saving as well as exchange the windows; also, for a lower cost. By preserving the window perfectly, it causes to keep the traditional character of the house. In addition, it can supply the insulation benefits of windows replacement with a lower cost and lower influence on the traditional form of the house. Moreover, this method causes noise diminishing in the house.

Interior secondary windows mostly are made of acrylic glazing that is almost strong, lightweight, easy to replace and locate in the previous place. Whilst beside of these abilities it is possible to open and close the windows. In addition, they eliminate or decrease condensation which creates single windows. If moisture makes between the single windows and the inside of secondary windows, one solution is to drill small weep holes into the outside of frames that the moisture can escape, or also, using too much draught proofing cause to condensation. The kind of windows has less influence on the function of installing secondary glazing panels since they conceal most of the windows. The secondary glazed windows cause overheating if it limits hot time ventilation. Nevertheless, glare coatings and some kinds of blinds can be applied to make the space colder. Some of the secondary glazings will be able to be moved down in the summer.

6.2.2 Repair and replacement

Repair has a higher priority than replacement. One of the main reasons is the craftsmanship and materials applied to traditional houses are far preferable and superior to what is now available. The wood of windows was handmade, using hardwoods and adapted joints. Now the standards are different; in most of the cases, it is a synthetic material, such as a vinyl that is glued together. The main advantage of a new modern window is the value of insulating glazing;

for traditional windows, it can always be achieved by installing secondary glazing and adding draught proofing. When thinking about whether to repair or replacement, the performance of the windows is separate from the visual conditions. A window may be unpleasant, but still performance. The portions of the frame may be rotted, glazing may be falling out, and the paint may be peeling from the sash, but as a whole, the window still can perform correctly. Figure 6.2 illustrates the general path for repair or replacement.

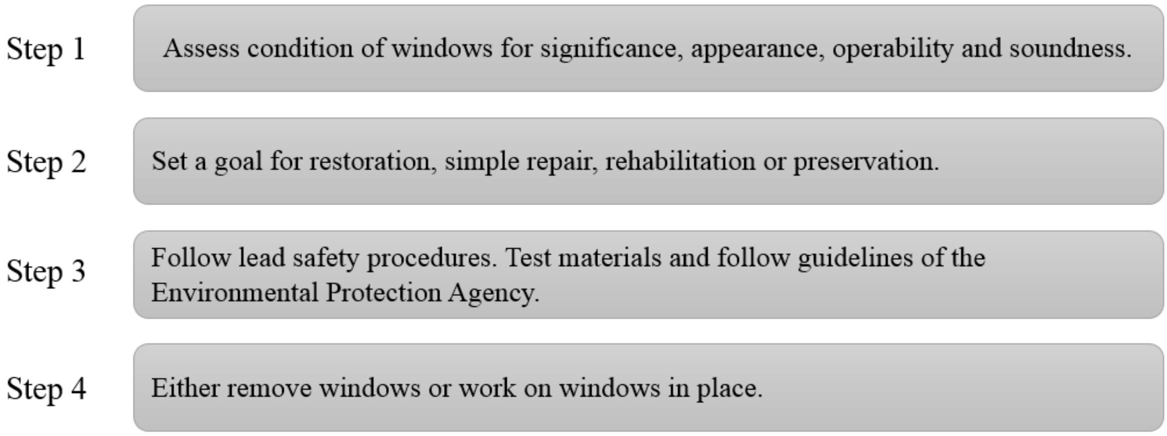


Figure 6.2. The general path for repair or replacement.

Identifying whether a part of a house should be replaced or repaired has to be done in two phases. The first phase tests the feasibility and possibility of repair. The second step is to look at the most prudent course of function. Approving the feasibility of fix window starts with assessing the conditions of the materials or tools. An effective but non-scientific way of identifying if traditional windows can be fixing is to take hold of it and shake it as hard as possible. If it is in its frame, then it is possible to repair it; if not replacement is the best choice. The glazing and finishes of the windows can be easily upgraded and repair by using heat plates, removing paint of lead, installing draught proofing, consolidating the wood. Repair is economical almost in all cases when the cost of fixing is compared with the same kind of replacement.

Energy conservation is one of the main reasons mentioned for window replacement. It can supply a short-term advantage but has an opposite result in a long-term. The modern new window is energy-conserving; it has the most effective and efficient draught proofing to reduce notably air infiltration, also it can have double- and triple-paned glazing. The traditional window is drafty as it was not made with draught proofing. Nevertheless, the long-term cost of exchanging traditional windows are high enough, and there is no payback. According to the 25-year life-cycle analysis, exchange the windows cannot be justified by the energy conserving by applying new windows (274).

Renovation traditional windows are no more costly than an applied a replacement; also, substantially cost less. In addition, according to lifespan costs, repairing traditional windows are economical. On example prove that the seal joining the multiplex panes of glass which supplies the values of superior insulating of double and triple-glazing windows, takes a limited warranty, when seal breaks, the values of insulating is lost, and the space among the glass sheets fogs up, diminishing the ability to see by the window, the window has to be exchanged, for this condition there is no fixing. The lifetime of traditional windows is more than the current double-glazed windows. On the other hand, the historic windows have been replaced with new units that not only don't match the historic metal casements but also make the windows smaller. This change is an adverse effect on the architectural character of the building, and under rehabilitation, can be replaced with new metal casement windows that match the original. Doing works to traditional windows is improving the value of something that can withstand wear and weather if the window requires major upgrading or fixing, the historic window has shown their quality by passing over centuries.

Repairing window omits unnecessary waste, decrease the pressure to create new plastic, metal or timber products, and is more sustainable. In some instances, the windows are exchanged every time a house is sold, producing thousands of tonnes of unnecessary waste. Producing of new timber window is consuming far less energy than metal and plastic. However, it is only sustainable if the wood is produced from a managed plantation environmentally. Some new framing elements and patented locks, hinges and catches cannot be fixed and maintained. Commonly recycled traditional timber is applied for low-grade consumes for instance, as a woodchip. Painting the windows can make great complication as it wears the access doors. Removing the paint of windows jamb can help for better repairing that make repair and preservation easier although it has a positive impact on the cost and time. The colour must match the original, however, repeat the underlying colour is not essential. It is imperative to consider the texture of the material as timber after painting also has texture in comparison with the steel, plastic to metal materials.

Weather stripping for sliding applies where abrasion happens ahead of the windows jamb sides. Its metal kinds are the most durable and impressive, however, are costly. The felt and foam kinds of weather stripping are the most prevalent and cheap kinds that stick to the casement window or the bottom and top of the double hung window. However, when the windows are open, it is visible, and it does not have a long lifetime especially when it exposed to the humidity. Over the past 25 years, one of the most popular enhancements has been adding double glazed windows. However, using secondary glazing, draught-proofing or repair are cost optimal rather than exchanging with double glazed. In the multiplex panes window, double glazed are less effective than secondary glazed, because of the thermal bridging via the glazing bars and frame, especially for the metal frame.

6.2.2.1 Thermal performance (part L, Approved Document L) of UK building regulations

Part L refers to the conservation of encompasses lighting, power, and fuel. Upgrading energy conservation for existing houses, only is needed for thermal components which are to be renovated or replaced substantially. If the window is being replaced or if they create part of a house undergoing an alteration of apply, so they require covering the requisite of Part L. The future modern unit should agree with the recent U-values.

6.2.2.2 Repairing or replacement of listed houses windows

Redecorating of listed houses, generally will not need consent but maintenances may need permission if these necessitate the revival of material. Article 4 Directions (275) in many conservation zones allow local planning authorities to control replacement which damages the individual characters. Based on the Building Regulations, modern windows are managed adapted and would require reaching specific standards covering ventilation, safety, heat transfer and spread of fire. A certificate of compliance can be obtained by using an installer that is registered with a scheme of a competent person.

It is necessary that the renovated unit justify the operation, detailing and form of the unit to be replaced. It will be essential to identically use the same profiles style of all the unit elements contain sill, jambs, and head of the frames, the stiles rails, and bars of the casements or sashes. It is better if the former glass reuse and salvage carefully. For exchanging sliding sash window ordinarily counterweighting springs that applied in as a replacement for weights and pulleys as this significantly alters the appearance and detailing of the unit. However, in plenty of instances, substitute productions do not match the traditional designs. A lot of traditional houses have windows with the name ‘divided light sashes’ that the glass sash is divide into multiplex parts by muntins (wood dividers). When the divided glass is exchanged, the renovated one should have real divided sashes which exactly match the former form. The fibreglass or aluminium and vinyl kinds of windows are not acceptable replacement options for original windows of wood in traditional houses.

6.2.2.3. Glass

Windows through the decades may preserve its original cylinder glass or crown glass but sometimes they are not entirely flat, in some cases may slightly have air bubbles or curved ridging which give character and depth of the facade. The traditional glass always should be preserved in place and maintenance is taken to support it whilst working. Add insulated glass into sashes of windows is another way to enhancing the energy efficiency of traditional houses, first remove the single pane with the original glazing element, then the sash of the opening is arranged so the new glazing elements and insulated glass can apply in the opening. Also, it is possible to add draught-proofing or caulking. Despite too much work, applied insulated glass is far less expensive than replacing the whole windows.

6.2.2.3.1 Repair and replacement of glass

The traditional glasses of case study 7 have scratches and corner on the surface so, should not be exchanged. If the sash needs to be repaired or the glass is broken badly, individual panes should be removed carefully. If traditional glass can be salvaged, it should be renovated. For case studies 10 and 11, where the panes are cracked, there are some kinds of glass which are suitable. The French cylinder glass is one option that is a newer copy of the 19th-century cylinder glass layer. However, it is expensive. The horticultural glasses is more economical that have a parallel streak (music line); it emulates 20th century drawn glass. In addition, using float glasses are suitable for decrease the weight on the sashes and maintain the joints.

6.2.2.3.2 Re-glazing the windows

The method to re-glazing is similar whether the frame is timber or metal. First, the rebate has to be cleaned and also dusted before new linseed-oil bedding putty is used given metal casement putty for the metal frame and a thin coat of primer for a wood window. Then the glass pane pressed in position then tightened with repairs which repeat the primary method. In the end, further putty is applied to tighten the joint among the glass and frame. With using coatings, the radiant energy transfer via glass is reduced because the reflection of infra-red wavelengths is letting pass the visible light. In hot time, solar heat is reflected, then preserving the space colder. Moreover, in winter, heating is reflected inside.

6.2.3 Frame

Windows are one of the house elements that cause a source of concerns, exceptionally the window frames. The frames are an almost complex element because of specific situation regards to the acoustics, operability and mechanical function. For floors, roofs and walls, the maximum thermal transmittance in most of the European countries are noticed between 0.1-0.3 W/m²K. The guidelines are strict for windows; typically the thermal transmittance varies between 0.8-2.6 W/m²K in Europe. Modern commercial double glazed with Low-E coverage and argon gas accumulating have a thermal transmittance around 1.1 W/m²K; whilst for vacuum glazing and triple glazed thermal transmittance goes around 0.5 W/m²K. The data on thermal performance in the scientific literature is rare (276,277). Gustavsen worked on the influence of the thermal conductivity of thermal breaks and materials of the frame to determine the performance of material that aims for currents window designs (278,279). Also, Byars and Arasteh investigated the effect of thermal conductivity on the frames U-values (280).

The most significant method of heat transfer is conduction in the timber frame, while radiation and convection are substantial in rest of the profiles. Figure 6.3 presents three kinds of frames.

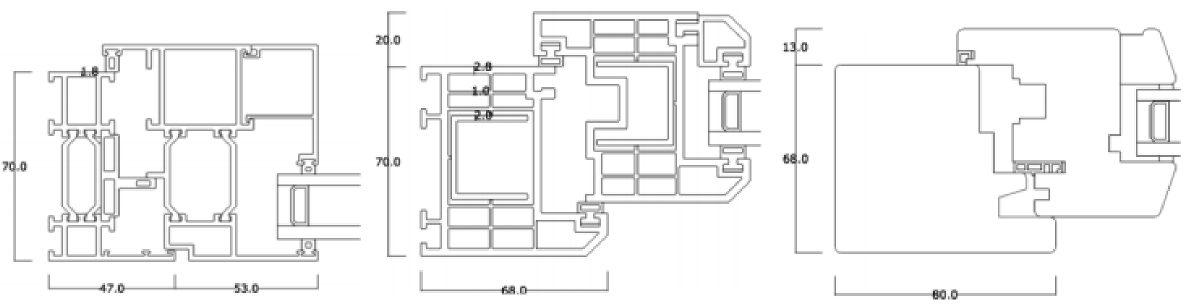


Figure 6.3. General aluminium window frames (left), vinyl (middle) and timber (right). The designs assumed as principal, not a proposal for the house practice; the method is for evaluating and measuring the effect of various development methods.

The European standard EN ISO 10077-2 (280) supplies a numerical measurement strategy to measure the frame U-values (U_f), that is done with commercial 2D heat transfer software like Bisco (281) or Therm (282).

6.2.3.1 Material

If aluminium frames are painted, it allows the design of slimline tools that fit with the staff bead depth of sash windows, in such manner window sills and shutters can be preserved. Tools with more fundamental framing parts are strong that can counterweight, repair and accommodate seals. They apply an aluminium outer frames adapted to a seasoned hardwood or softwood ground surround according to the fixing details and design. Removable lightweight tools are also a good option that is fixed by magnets and use acrylic glazing. The providers of these tools supply installation services, manufacture, and design. In addition, the claims of no- or low-maintenance drop short when the siding look shabby and the colours faded. One of the limitations of vinyl siding is the function of the siding in cold weathers. It will shatter and becomes brittle when compacted with a light as a rubber ball. In addition, vinyl sidings have a low melting point that any exposure to high heat becomes the siding to sag then; it needs replacement.

6.2.3.1.1 Vinyl

The steel reinforcement is the weak factor of vinyl frames. Initially, there are several methods to overcome this problem; one of them is renovation material of frame, another one is renovation the reinforcement via using an insulating layer, like composite elements (λ=0.2 W/mK) and stainless steel. In addition, no amplification is required when making the total frame with supreme compound, for example, glass fibre (λ=0.2 W/mK), the best methods are given with the composite reinforcement with vinyl frames. Nevertheless, when the central gaps are filled with insulating material, the compound frames obtain a preferable function in comparison to the amplificated frames (283).

6.2.3.1.2 Metal frame windows

If the metal frame is bent or corroded, it is better to remove the windows to clean and fix. It is possible to add secondary glazing, but applied draught proofing along the sliding surface is not easy. Moreover, it is an excellent option to caulk metal windows to avoid air infiltration.

6.2.3.1.3 Plastic PVC-u windows

The character and appearance of Poly Vinyl Chloride un-plasticised (PVC-u) window make it unsuitable for traditional houses, especially listed buildings or houses in preservation zones. These kinds of units are assembled from manufactory elements planned for thermal transmission, pure producing and rigidity. The operation, design and detailing make this kind of windows vary entirely from historical windows. Windows maker have not been able to copy the style of glazing bars applied in steel and wood windows because of the reduced strength of the extra weight of the secondary glazing panels and the materials. PVC-u units are manufactured from non-renewable natural sources. Also, the chemical compounds contain phthalates, PCBs, and dioxins. The embodied energy applied in the factory is less three times of wood.

In addition, repair PVC-u windows are a main challenging due to the nature of PVC-u. Often complete renovation is the only viable alternative that is an unsustainable solution in comparison to steel and timber. The PVC-u unit frame requires regular cleaning to avoid discolouration by ultraviolet light and dirt. In addition, they require annually to be adjusted and lubricated; also, gaskets and weather-seals renovated at least every ten years. What the recycling exists for PVC-u window is confined to waste parts in the factory rather than for complete redundancies the window, therefore, threw away the window inland site with the potential for recharging of the significant harmful industrial emissions.

6.2.4 Paint

Paint can be one of the biggest traditional windows enemies depending on where they are suited. For most of the windows, professionals do not suggest to paint the sash jams because of leads to sticky. Two of the best choices of paint are, solvent-based and water-based, both are synthetic paints with additive content and highly liquid. These have topcoat formulations undercoat and primer. They made to be approximately the last five years before renovating, dry quickly and easily applied. They recover the surface thoroughly, also do not penetrate the wood, supplying support for the wood as long as the paint is used regards to the instruction of manufacturers. Moreover, it is repainted before it breaks down. Water-based paints, acrylic kind, are compatible with current lead paint coats. However, solvent-based paints, alkyd kind, are not. Nevertheless, alkyd paints are applied to steel.

Paint that is used to historic houses applied natural ingredients, called natural or traditional paints that are made of linseed oil and pigment with few additives. It soaks into the wood, supporting it actively. Linseed oil paint applied for all coats with various portions of pigment and oil. Linseed oil paint applied to wood as well as metal. Linseed oil paints along with lead oxide have been used on joinery for hundreds of years. It is made of linseed oil with high-quality and crushed pigment. Some manufacturers apply additives, such as citrus oil to speed up the drying time. Whilst lead oxide becomes forbidden is for general use. Paint can be eliminated with a paint scraping tools, heat gun, and strippers and coated with varnish or packed with a good quality sealant that preserves the unpainted timber finish which was original to the building.

6.2.4.1 Window colour

Oil paint during the early 18th century appears to have been used in all of the universal finishes for sash window. Stone-coloured or white (yellow ochre and white with a partial black). One exception is the wealthiest that built in 1770 that are more modest houses were used the alternative paint finishes, such as black, brown, green, grey and grained. Especially the dark colours were popular in comparison to the stone facades and light-coloured stucco.

Green was very popular for more rustic houses by the end of the Georgian time, however white still was retained to be the best suitable colour for massive buildings. Nevertheless, purple-brown paints were favourite for window joinery by the 19th century. Moreover, Brunswick greens were applied widely for doors and external window frames, whilst graining stayed popular external and internal finishes. The most expensive paint colours were white and off-white were in the 18th and 19th centuries, having white pigments were expensive than the dark pigments. Black, brown, dark green and purple-brown were cheaper and widespread. Still, it is the case with the paints of linseed oil. Dark colour improves to decrease the visibility of the frames, especially the glazing bars, even though the light colour underlines the frames. With using white colours can cut down thermal movement because it deflects the ultra-violet light, but dark and black colours absorb it. Therefore, the paint has a shorter lifetime.

6.2.4.2 Lead paint

Lead paints were the high-quality historical finishes for metal and wood and are incredibly long-lasting. Its usage continued into the 1960s. The linseed oil is used as the binder and white lead as the pigment. The paint was oil-based, with pigment adding for the colour. The leads were added to the mixture due to the strength of colour and supplied superior adhesion. On the other hand, lead poisons the people and causes severe damage to children brains. In addition, the cost of eliminating lead paint is expensive. Among all of the reasons explained for renovating traditional door and windows, the fact is almost all of them have been coloured with multiplex coats lead-based paint.

6.2.5 Energy efficiency

The windows are the critical elements in the design of energy-efficient houses. In existing house practice; notably, the window is less well insulating than other elements of the structure. For decreasing consumed energy, designing and planning the fewer windows that are favourable as an aesthetic or architecturally point of view. In adverse, decrease the potential for governing sun heat in the cold weathers. The energy lost via the window is significantly more around 3% of overall consumed energy (284). Even in some other countries such as Sweden, the result is higher, at 7% (285). The heat transfer rates for the open window is limited to air penetration. This rates in blocked windows are obtained with three different methods: air heat flow on the hotter part to the glass; via the window; then from the more cooling glass spaces to surface. The heat transfer ranges in a unit area from and to the external glazed area are presumed to be commensurate with the diver temperature among the glass area and the surrounding air. The heat transfer processes are recognised as U a heat transfer coefficient (W/m^2K), for a glazed zone A (m^2), the heat flow rate to the area Q (W) for a temperature difference ΔT (K), can be calculated using equation 6.1.

$Q = UA\Delta T$ (eq. 6.1)

Increasing the distance between the glass layers reduce transmission via the gas. However, the range of heat transmission via convection grows. Heat transmission at low ranges obtained by combining Low-E coverage with a transparent feature on the inside part of both of the glasses in double glazed windows. The thermal conductivity of insulated glass near the edge is higher than in other parts due to flow the heat with warm glass layer to the edge via the seal age, after that with cold layer faraway the edges, toward the circumambient in cooler part. In multiple or double glazed, a significant diminution in the edge conductivity is obtained by applying a thermally insulated edge spacer (286). Low energy (Low-E) or energy efficient glasses were produced to reduce the heat lost. It is more suitable for glazing new casements and sashes. Adding interior secondary glazing with Low-E glasses is one of the best alternatives for enhancing the thermal transmission of traditional windows. Also, Low-E glass is available for double glazing and single layers.

6.2.5.1 Future window technologies

The value of energy is significantly growing in the world; also considering the energy efficiency values in all the objects is emphasised. For this reason, the new regulations and standards have been arranged to enhancing the element efficiency of new houses, and when possible improve thermal transmission of current houses via progress of effective renovating (2). One of the countries that bring up energy efficiency is essential for current, and the new building is the UK (287). The new schedule of consolidating regulations of a building is admitted for most of the area in the UK that new houses must obtain an energy labelling regards to the pollutions and consumed energy (288); also concurrent the rest of EU counties arrange new plans.

For ease the schedule, the government target at decreasing the greenhouse gas pollutions around 80% until 2050, the residential part responsible for 28% of whole pollutions (289). In addition, in the UK, the schedule justify the energy efficiency of component regulation. So, new houses must obtain the requested energy annually until a specific range. For example, a detached house should obtain heating energy demand around 45 kWh/m^2 year. As a consequence, the window U-value must be around 1.3 W/m^{2}K year that to reach to the standards of energy efficiency (290). The same in Germany, Passivhaus Institute of Darmstadt arranged the Passivhaus Standard that determines the energy demand for cooling and heating in the houses have to be around 15 kWh/m^2 year, as a consequence the window U-value of 0.85 W/m^{2}K is required (291).

The current technology of windows cannot reach the high level of thermal regulations, so it caused increasing the consumed energy and CO_2 pollutions. Recent windows marketing is confined to double glazing accumulated Argon or air because of the perfect thermal transmission in comparison with single glazed, and the existence of full detail of manufacturing progress. Nevertheless, the U-value of a current window is high as shown in table 6.4 and not appropriate to meet the low or zero carbon house (292–294). So, as a theoretically, all the researchers have a general agreement on the essential demand of new windows technologies that are effective, environmentally and cost optimal.

Table 6.4. U-values of glazing products.

Kinds of glazing	**Cuce and Cuce** (293) **and Cuce and Riffat** (294)	**Pilkington** (292)
Argon filled double glazed window with Low-E	1.90	1.80
Air filled double glazed window with Low-E	2.10	2.00
Air filled double glazed window	2.53	2.70
Argon filled the triple glazed window with Low-E		0.6 - 0.8

Nowadays, windows are more efficient than before; still, they account for the energy lost. Enhancing windows by high-functional methods are essential for meeting zero energy house elements. Obtaining zero energy window when enhancing the efficient function of existing windows by 60-80% (295,296). By following these development function, if all the windows were enhanced, it would be possible to save $300 billion in the 20 years (297,298). As a whole, it is anticipated that improvement the zero energy windows have a great effect on zero energy house.

6.2.5.1.1 Zero energy windows

The window has a great impact on the amenity of residences and peak demand for energy. If applied efficient lighting method in the house, it is possible to save an extra one quad of lighting. Nevertheless, if all the existing windows are replaced by new efficient ones, the consumption of energy will be almost two quads (295).

Windows can refuse sunlight to decrease the cooling capacity, compensate the required lighting during the day in the house, diminish the peak demand of house electricity and can transfer sunlight to compensate required heating energy. For improving these advantages, first windows have to contain properly fixed features, such as a lower U-values rather than current standards, also consider the dynamic ability of the houses between the summer and winter. Moreover, it is essential to put significant attention to the using the daylighting as much as possible over the years. The lifespan of windows are 20 to 50 years so, residences before choosing/applying, and windows builder before designing must have comprehensive knowledge about windows as the technologies are not self-optimising also, in most of the cases are expensive.

6.2.5.1.2 Integrate surface for arranging and controlling daylighting

For the commercial building, the integrated surface can redirect and arrange the lighting whilst keep the visual aspect. A skylight which let lighting transfer to the building, switching glass to arrange the glare, controlled shading systems dynamically, darken of artificial light automatically, light shelves or pipes are several examples of current technologies. Using the combined of these technologies have a great effect on energy efficiency. The function of current examples of these technologies has not been recorded yet. Two of the dispute regards to this kind of technologies are reducing cooling in the summer via daylighting to compensate artificial light and reducing the heat lost in the winter via the surface. Moreover, planning the proper controlling tools and software are essential to will arrange the function of the different kinds of façade and materials.

6.2.5.1.3 Dynamic glazing

For enhancing the energy efficiency of windows it is needed to manage solar light dynamically (299) which behaviour in regards to the different climate and seasonally or daily. Also, in the house, the windows that transfer light in the winter have to refuse it during the summer. The windows in the offices have to control and arrange to light. For this kind of windows, it is anticipated that using glazing control of inherent optical and systems of add-on shading. Their technologies contain thermochromic, photochromic which are passive dynamic glazing that changes the visual features regards to the change the environmental aspect such as automated shading system, dynamic façade control, and active dynamic glazing that change features regards to the voltage and absence or present the lighting system.

6.2.5.1.4 Highly insulating windows

Enhancing the insulated aspects of windows glazed (293,300) is the target for investigation from the 19th century. Enhancing the future methods of zero energy windows will supply windows for both replacement windows in the existing house and future windows in the next zero energy houses. Three main methods for enhancing the value of insulating windows have been proposed, as outlined below.

6.2.5.1.4.1. Low-emissivity (Low-E) gas-filled windows

It contains three layers, decrease significantly radiate heat transfer via double glazed windows with U-value of 0.1 W/m^{2}K, a few of them by reflecting infrared radiation, decrease the total solar heat which has a significant influence on the cold climates. This kind of window needs the highly insulating spacers and frames. There is some dispute as their progress in manufacture is not optimised, growth the width of layers which is challenging to fit in most of the existing house, growth the weight, applying double spacer tools so, increase concerns regards to the gas leakage and enhance the costs of workers. The new study at LBNL (Lawrence Berkeley National Laboratory) (301) is concentrated on a future alternative with non-structural centre glazing thin, and lightweight sheets. It is anticipated that for the future windows applying hollow activities to develop the insulation of frames and applying solid insulation such as foams with a long-lasting coating (302,303). This appearance of kind of windows is like another one. Now their market is good; it was used in 1985 for some percentage, and in 2005 have been applied for more than 50%.

6.2.5.1.4.2. A microporous insulation component

This component is under R&D in order to reduce its cost of production (3).

6.2.5.1.4.3. A vacuum glazing

It presents high function windows via applying a vacuum to removing convection/conduction among the glass layers. Their function is combined by arranging the structure which keeps apart edge, the layers of glass; and the Low-E enhancement which can keep high temperature when processing the edge welding. This kind of product now is used in Japan with U-value of around 0.25 W/m^{2}K. Vacuum glazing window is highly functional and inimitable technologies that can minimise the heat lost with high transmittance (304). In 1913 the concept was initiated by Zoller (305,306), although they were not favourably manufactured up to 1989 (307). The promise prosperous fabricating of vacuum glazing window was obtained at the Sydney university by Collins and Robinson (308). The composition method of glazing operated continues brazes of edge seal that only generated at a temperature around 450°C. At the next level, it enlightened this requisite by creating an edge seal of vacuum glazing at near 200°C (309–311).

The fabrication technology of vacuum glazing is not complicated. A common kind of it contains two layers of glass apart via the vacuum with an array of protective pillars preserving the glasses as demonstrated in Figure 6.4 (8). The protective pillars from a distance around 3m are invisible. However, their visual impact is insignificant (312–314). The vacuum among the glasses is for removing the convection and conduction that has a great impact on the fenestration products U-value. Three different kinds of vacuum glazing windows known as Laminated SPACIA, SPACIA-21 and SPACIA were manufactured in Japan. The thermal conductivity of a supportive pillar and glass material have a significant effect on the U-value of vacuum glazed especially after aerogel. The total coefficient of vacuum glazing heat transfer enables to be decreased to 0.2 W/m^{2}K by optimising with Low-E coverage.

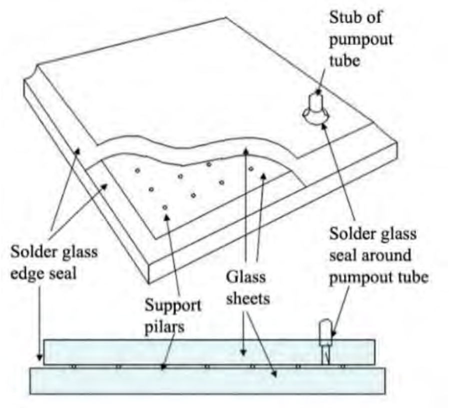


Figure 6.4. Schematic of a vacuum glazing (315) *in own elaboration.*

6.2.5.1.4.3.1 Experimental works

Fang et al. (316) managed an experimental research study to assess recent hybrid vacuum glazing thermal performance with Low-E coverage and air gap. They work on the influence of the vacuum gap on the total thermal insulation function as illustrated in Figure 6.5. Manz et al. (317) in Switzerland performed a similar study on a triple vacuum glazing product. Also, Collins et al. (318) carried out similar work in a laboratory by its manufacture, and they concluded that low heat transfer of it depended on the low emissivity coverage of glasses, edge constraints, and edge insulation. Erdem et al. (293) evaluated the next generation of vacuum glazed and the latter enhancements. His studies assess the performance of vacuum glazing via simulation, numerical, theoretical and experimental. Also, the technology and fabricating of this kind of glazing have been evaluated. In Korea, prior research affirmed that the different U-value depends on the kind of gas, coverage and the thickness of glass (319). Baek (320) cited that the variation depends on the gas and the type of gas via analysis by simulation the pillars effect on the U-value of vacuum glazed for keeping the vacuum gap. Therefore, the pillar interval requires being appropriately selected for the glass tensile stress (321).

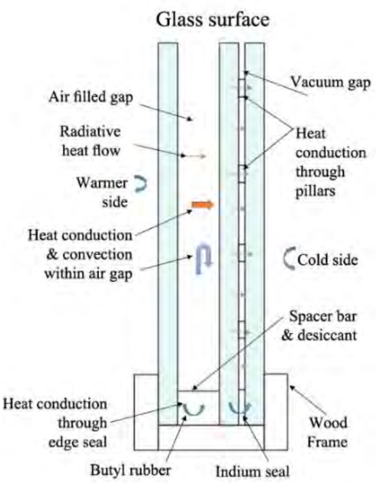


Figure 6.5. Variation configurations of hybrid vacuum glazed improved by Fang (316) *in own elaboration.*

6.2.5.1.4.3.2 The environmental effect of vacuum glazed

The designation of the window in greenhouse gas emissions and global consumed energy is precise. Windows are considered the greatest energy lost between the components of the house because of their significant heat transfer. Around 60% of heat lost via the house component is regarded as the glazing zone (2). So, renovating the traditional windows with newfound technology is essential for carbon reduction. The technologies of vacuum glazed are promising in the building parts for incisive reduction of energy consumption and diminish greenhouse gas pollutions. In the UK, the windows U-value have to be around 1.3 W/m^2K to reach the standard of element energy efficiency (116).

In the UK, if all of the 25.5 million houses were renovated by efficient windows, a significant carbon reduction of 13 million tonnes yearly would be obtained, according to the information of Energy Saving Trust (322). The technology of vacuum glazing has almost three times better insulation feature that results in a reduction of carbon to 40 million tonnes annually. The technology of vacuum tube window supplies the maximum energy saving with the shortest payback course as shown in Table 6.5 and Figure 6.6.

Table 6.5. Payback time for new glazed technologies for the house in the UK (323).

Glazing type	**Capital cost (€)**	**Annual savings (€/year)**	**Payback (years)**
Solar pond window	2,400	107.60	22.30
Heat insulation solar glass	3,000	89.02	33.70
Vacuum tube window	2,600	181.33	14.34

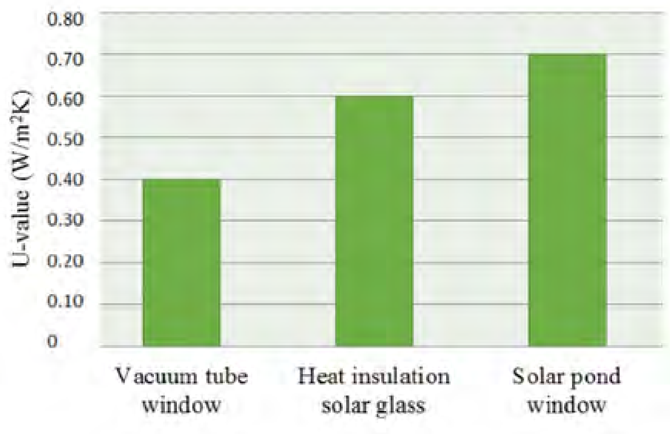


Figure 6.6. The U-values of new technologies of glazed for the similar thick (323).

Moreover, there are some disadvantages in regards to vacuum glazing; vacuum glazing despite gap area does not have a high level of sound insulation. While the two layers of glasses are excellent mechanically connected, the supportive pillar array has to be very stiff and moving together under the differential pressure in a wave of sound. Also, it is essential to consider the full potential of vacuum glazing in the market. Accordingly, it has to be fabricated with competitive prices in order to compete with other kinds of insulated glazing.

6.2.5.1.5 Phase change material (PCM)

A phase change material (PCM) can release and absorb the energy to sustain and adjust the temperature. Some studies present the SHGC and U-values for various kinds of PCM gaps and glazing system (324,325). The mentioned research concludes that it is thermally effective and prove the important impact of PCM in decreasing heat lost via the windows by using PCM curtains. Moreover, they concluded that in this method during PCM phase change, almost all the energy is absorbed so, PCM can block the thermal radiation and reduce the heat loss. In addition, other studies show that double glazed windows with PCM are more effective rather than the same kind with air (326,327).

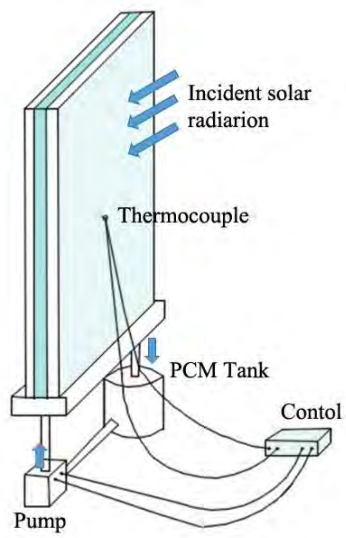


Figure 6.7. The scheme of the window with PMC curtain (328) *in own elaboration.*

6.2.5.1.6 Semi-transmitted solar cell

Another technology that enhances the house energy efficiency is composing the house with photovoltaic, which is known as a BIPV (Building Integrated Photovoltaic) (329). The method is integrating solar photovoltaic technology with house elements (330–332), which decreases environmental impact with solar energy through the generation of on-site electricity (333). This system now is the centre of attention because of the thermal characteristic of windows units (334). When the window is integrated with solar cells, it can decrease the required off-site electricity. Also, it improves the thermal comfort of residences (335). The suitable element and proper transparency colour significantly improve the light transmission (336).

6.2.5.1.7 Thermal optimisation strategies

Several points of windows can be enhanced by various methods. For instance, the gaps among the thermal break can be accumulated by insulating materials or the thermal break can be a partition to various cavities to reduce the heat convention and limitation the radiation. In addition, the gap among the frame and insulated glazing can be performed in various methods. Via shifting the glazing deeper toward the frames or via expanding the gasket glazing, it is possible to detach cavities. By incorporating various optimisation methods, the overall impact is not equal to the sum of the different method as some method results reciprocate.

6.2.5.1.8 Influence of energy on recent windows unit

The influence of windows on energy use in the houses come into sight in the bills of other house equipment, for instance in bills of lighting or air conditions. They are accountable for around 30% of loads of house cooling and heating which have an effect of 4.2 quads of annual primary energy. It contains the influence of undesirable gains and losses, as future technology is managed, it is essential to be sure about the infiltration methods from manufacturing. Integrated surfaces for arranging and controlling daylighting, dynamic windows that can change the transmittance for instance from reflective to clear and extremely insulated windows with U-value of 0.1 W/m^2K are three future technology for windows that have potential to be zero energy technology.

6.2.6 Heat transfer through the windows

In the hot climates, heat lost through the windows is complex, with a three-way. First, via air infiltration or uncontrolled air leakage, it even happens when the windows are not opened. Second, via the colder part of the windows that take infra-red radiation from the spaces. Then, via conduction and convection. All the heat lost, transferring through the frames and glasses are as conduction whether it transfer the room via radiation, conduction or convection. The most conductive section of the windows are glasses, also at the lower range heat lost via the frames. The study of Bordass, Wood and Baker (337) demonstrates that it is possible to diminish the heat lost by radiation and conduction via the windows over 62% via applying secondary glazed with Low-E coverage, by 50-60% via applying blinds and shutters with reflective surface and by 40-50% via lessen plain blinds or closing the curtains, also it is possible to diminish it over 70% by combining the above methods. The experiences demonstrate that an existing secondary glazing Low-E windows accurately reach the required standard of new houses and work well at the night especially when the shutters and blinds are closed.

6.2.6.1 Heat loss by air leakage

The air leakage has to be minimised for any windows to be energy effective element. Near the opening part and the sashes are the most prominent parts for penetrating the air. It is essential to seal these parts to decrease the air infiltration. Heat lost via air infiltration is resulted in different air pressure over the assembly of windows and identifying the relevance of the pressure and airflow. The rate of leakage over the windows were 183 m^3/h at a pressure of 50 Pa. Repairs reduced the leakage to the 120 m^3/h, and by draught-proofing, leakage reduced to 26 m^3/hour; also by secondary glazing, the leakage went to 8 m^3/h. Replacing windows will not cut the whole air filtration but is the efficient way that also decreases rattling of windows. Wet rot also maybe make a holds in timber frames, especially where putty or paint is not proper; the harmed wood parts have to cut, and new wood would match. The basic phase is caulking around the outside of frames, also putting the foal filler on the gaps and larger holes among the frames and siding is useful. Applying sash pulley coating on the inside of the windows is an active path to decrease air infiltration via the weight pocket.

6.2.6.2 The parameters that influence the heat transfer through the windows

6.2.6.2.1 Draught-proofing window

Draught-proofing windows are the cost-optimal method of enhancing the residences tranquillity and decreasing applied energy for heating with no variation on the outward of the house. Also, it decreases the rattling and noise. The new studies have demonstrated that the energy requirements for heating can be decreased by 50% and windows air leakage decreases by around 32%. There are some kinds of method, some methods are surface mounted, but most seals are full of grooves routed in the wood.

Draught proofing knew as silicon rubber tubes, polypropylene with foam filler, pile, nylon brushes and gap-fillers. One of the disadvantages is when the frames are thin, it can hurt joints in sashes. The suitable material for draught proofing is moulded mastic. After applying, the mastic makes itself to the form of the voids. It is better for replacing it every 10-20 years as they will not last as long as a sash. To assess the effect of windows draught proofing need a laboratory base on the BS EN 12412-2:2003 (338). There are several traditionally kinds of window alternative which decrease cold or heat transfer such as an awning, films, blinds, shades, curtains, and shitters. Awning, blinds and timber shutter are cost optimal alternative for enhancing the window energy, when energy became available and cheap they were abandoned.

6.2.6.2.2 Curtains

The curtain is enhancing the amenity. In regards to their weight and coating, they can decrease the impact of direct sunlight and limit the draught. The heavy curtain is a prevalent method of avoiding draught and decrease heat lost via conduction. The blinds that arrange perfectly with the reflective material can be efficient as well as secondary glazing. Moreover, they could style and adjust to preserve a look of traditional houses.

6.2.6.2.3 Shutters

Shutters apply for enhancing U-values in all kinds of window. They are mostly used for decorative aspects, especially exterior shutter so, they are not efficient weatherization measurement. Interior shutters supply shades in the summer and privacy. They keep out the sun in the summer perfectly but not supporting as well for the winter. Also, it is possible to insulate it. One of the best material for the shutter is timber softwood frame with insulation of Gutex in the centre.

6.2.6.2.4 Blinds, shades, awning and films

Blind is enhancing energy efficiency as much as insulated shades, they are prevalence today. They have almost no influence on the house outside appearance. Shades can improve the indoor amenity and comforts like curtains and shutters, whilst decreasing the direct sunlight if they insulated perfectly can significantly enhance the energy efficiency of the home and the windows U-value. The awning is impressive in the summer, they applied to shade the inside of the building from the sun, they are gatherable, and thereby the sun can enter the house for heating in the winter. The film has been improved recently so that it can be applied to residences. It is decreasing the sunlight whilst deflects some of the lightings. They are not considered as a windows weatherization method.

6.2.6.3 Ventilation and condensation

The deterioration of windows results in the inappropriate preservation and water infiltration. Putting and caulking for air leakage and smoothing all the finishes parts will minimise the deterioration of windows resulted in moisture. The joints and the sills are the most influenced by humidity, so more affected by deterioration. However rotted parts can be fixed by epoxy, and damaged joints can be re-glued. In the case studies 2, 3, 4 and 6, it is feasible to close some windows for a period because there are several windows and enough air can be supplied via mechanical tools or windows. In the case studies 5 and 10 with secondary glazing, the most comfortable option is to open internal windows to supply ventilation. The only problem is that maybe it causes condensation. When warmer part of windows goes in touch with more cooling outside air, condensation happens. It forms by any kinds of windows such as newer or secondary glazing windows. It is linked directly to the air infiltration leakage. Condensation can cause the increased mould and deterioration of elements.

6.2.7 Noise insulation and ultraviolet protection

One of the most vulnerable elements of the house to noise transfer is window due to its lightweight construction. The single glazing windows without seals just obtain a noise diminish of 17-24 dBA. However, it depends on the seals quality and the number of opening. Applying secondary glazed with the thick glass of acoustic laminate improve the acoustic installation function. Secondary glazing with sound insulation of around 44 dBA, decrease the resonance among the glass layers via separate the movement of layers with a 100 mm air gap. Greater enhancement is possible with gaps of 200 mm. The double glazing windows due to stiffly connected to the glass layers with a minimal gap work a little better than single glazed windows as the glass layers resonate each other. The secondary glazed windows incorporated by 100 mm air space, decrease the resonance among the glass panes, so sound insulation around 44 dBA is obtained.

6.2.7.1 Improving sound insulated

Internal secondary glazed decrease harmfully low and high noise frequency. It is better to justify it in a suitable place with 7 mm glass and without shutter disabling. For more enhancement, it is better to draught-proofing the windows. When the internal layer is located between 50 mm and 150 mm interior the traditional window, the sound insulation is the most impressive. In addition, heavy curtains can decrease the sound. Moreover, the sounds can enter the house via the chimney and air vents. Moreover, it is important to consider that although sound can be decreased, enough ventilation is required.

6.2.7.2 Protection from ultraviolet light

Sun ultraviolet (UV) light can be harmful to furnishing, element, and painting. The film preventing UV sunlight can be used to the inside part of glasses to filter the UV rays. With the usage of films to the original window in the secondary glazing or apply the films in laminated glass, the harm risk can be decreased, and the UV sunlight can be cut down. Nevertheless, the lifespan of this kind of films will be reduced over the time, around ten years. Moreover, inappropriate adjusting causes air bubbles under the film that decreases the effectiveness. Also, particular attention is needed when decide to remove it from traditional glasses because the glass can break.

6.2.8 In-situ U-value measurement: main findings of different scientific studies

With software windows program is not possible to calculate the effect of some elements such as draught-proofing and secondary glazing on the U-value. In such cases, with in-situ U-value measurement, the actual U-values can be estimated. This part shows the finding of other scientific studies regards to the in-situ U-value measurement (72,166,346,347,337,339–345).

According to the studies, single-glazed windows adjusted with secondary glazed obtained better U-values (around 2 W/m^2K) than window adjusted with the double glazed best-function gas-filled (around 2.4 W/m^2K). Therefore the results shown for the windows that restraint to replace with double glazed, the impressive alternative is secondary glazed, nevertheless slim profile double glazed along with vacuum gaps obtained the best U-values around 1.3 to 1.8 W/m^2K.

The vacuum glazing windows obtain the U–value of 1.8 W/m^2K that is the best thermal performance in comparison to other methods. Glazing with gaps filled with various gases obtained variant U-values from 2.4 to 3.1 W/m^2K based on the kinds of gas and the thickness of cavities. The worst results regard to the air filled glazing with around U-value of 3.5 W/m^2K.

The overall U-values for single glazed windows is calculated from 2.0 to 3.5 W/m^2K. However, the measured U-value for single glazing with secondary glazing was 2.1 W/m^2K. Renovating the same window by gas filled double glazed obtain a U–value of 1.7 W/m^2K.

Draught proofing is a prevalence method to protect wind to blow in via the historic window. The curtain decreased the heat lost by 16%, a new roller blind decreased the heat lost 24% and a regular roller blind decreased the heat lost 28%. Secondary glazed is the most impressive method because it decreases the heat lost 66% via the windows. As a traditional alternative, the wooden shutter is the most impressive way that decreases the heat lost 52%. Applying secondary glazed windows or combining of shutter and blinds, decreased the windows U-value to lower than 2 W/m^2K. The most diminish the heat lost is obtained by incorporating several methods such as curtain, shitters, and blinds all closed with applied more insulation layers.

Windows renovated with slim profile double glazed obtained a diminution of 34% to 64% in the heat lost in comparison to the original single glazing. The lowest vacuum glazed U-value measured is 0.20 W/m^2K via applying four Low-E coverage and steel stainless pillar. More than 30% U-value improvement of vacuum glazed can be obtained via significantly aerogel protective pillars insulation.

Secondary glazed with a Low-E coverage decrease the heat lost 70%. By adjusting wide roller blinds and heavy curtain, the heat lost can decrease considerably by respectively 37% and 40%. In addition, the literature proves that the thickness of the timber frame decreases the heat lost.

6.3 Analysis of the influence on the U-values of the windows elements, materials, and thickness

The ‘Window’ software of Lawrence Berkeley National Labs (LBNL) program has been used for calculating U-value, SHGC, and analysis all the windows elements, their materials, number, thickness and their influence on the U-values. First, study on the U-values of whole windows with analysis of the different parameters on the windows elements, like the size of the windows, its situation, the number of dividers, and the kind of windows, frames, divider and glazing system. In the second stage work on the U-value of a glazing system with analysis of the glasses quality and the gaps, their materials, and thickness. First, the reference model has been considered according to the prevalence kind of windows then changed some condition; the obtained U-values have been analysed, discussing its influence. As a whole, this part work concern the effect of all related parameters on the U-value of the window by the software, and suggest the best alternative and example.

For assessing the function and the act of various kinds of windows; it is regular to consider the U-values and the SHGC. The U-values are the rate of heat transfer via the building components that are calculated according to the equation 6.2, where R_{si} is the internal resistance, R_{so} is the external resistance and R_1, R_2, etc. are the resistance of all elements; the SHGC is the fraction of solar radiation that moves via the windows that are calculated via multiply the SC (Shading Coefficient) value by 0.87. Moreover, the software ignores or makes crude assumptions in regards to the thermal bridges. Table 6.6 demonstrates the default SHGC of various kinds of windows.

$$U-value\ =\frac{1}{Sum\ of\ R-value}=\frac{1}{R_{si}+R_{so}+R_1+R_2+\cdots}\ \text{(eq. 6.2)}$$

Table 6.6. The range of window sophistication and their corresponding solar heat gain coefficient (SHGC) (348).

Glazing type	SHGC
Single glazed, clear	0.86
Single glazed, tinted (bronze or grey)	0.73
Double glazed, clear	0.76
Double glazed, tinted (bronze or grey)	0.62
Double glazed, high-performance tint	0.48
Double glazed, high solar gain, Low-E	0.71
Double glazed, moderate solar gain, Low-E	0.53
Double glazed, low solar gain, Low-E	0.39
Triple glazed, moderate solar gain, Low-E	0.50
Triple glazed, low solar gain, Low-E	0.33

6.3.1 Whole window

At the first stage, a reference model with specific U-value is considered, then the characteristic of windows elements are changed and the influence of different alternative on the windows U-values according to the reference model is analysed. In this section 6.3.1, the glazing system condition for all options is similar, while in the next section 6.3.2, work on the glazing system condition. All the software outcome is provided in the appendix H.

<u>Reference model</u>

A dual vision vertical windows (1.2 m × 1.8 m) with double clear air (5.7 clear glass + 12 air +5.7 clear glass) and timber frame, divided 6 over 6 with 18% frame surface, this kind of window is prevalence in the traditional houses, the total window U-value is 2.790 W/m^{2}K.

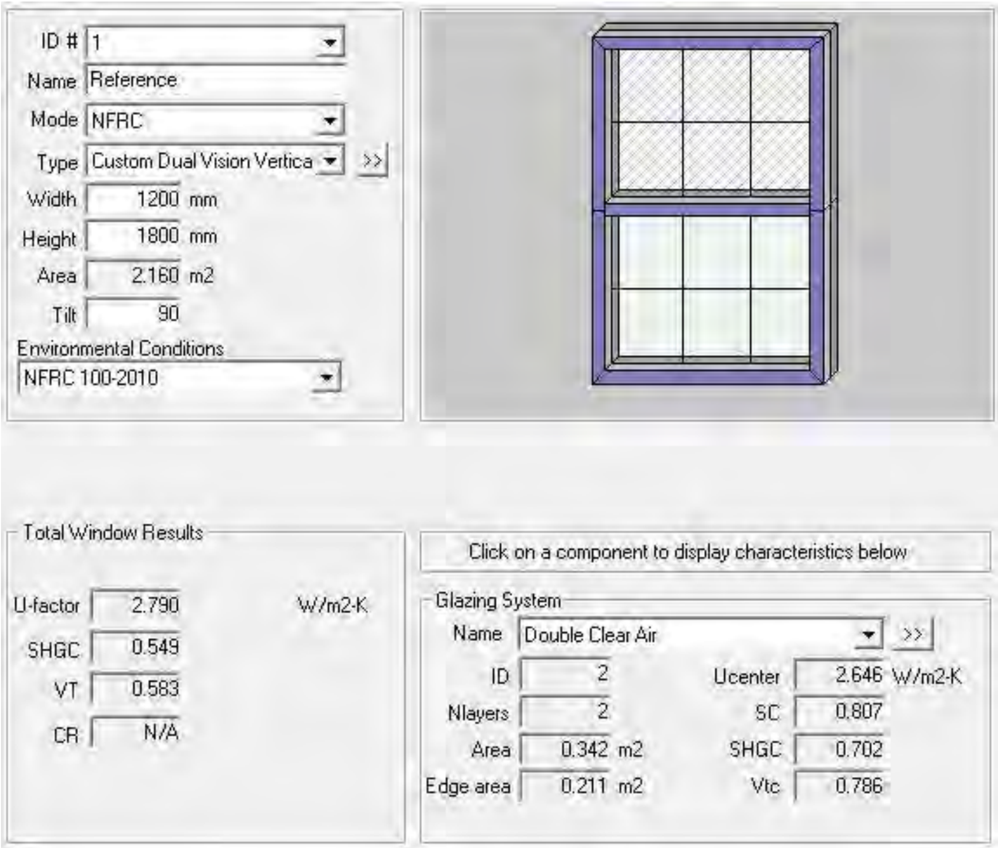


Figure 6.8. The characteristic of whole windows as a reference model.

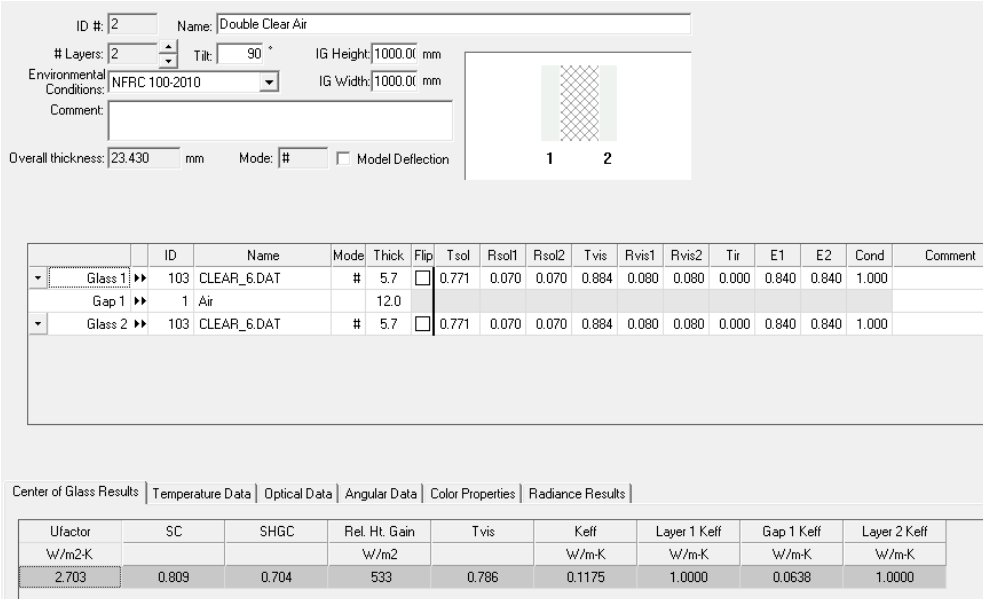


Figure 6.9. The characteristic of the glazing system of windows as a reference model.

6.3.1.1. The condition of the window

Table 6.7. The calculated U-values and SHGC of the analysed option by LBNL software, (all with 18% frame surface).

	Kind	Size (m)	Number of divisions	Environ. condition*	U-value W/m²K	SHGC	Differences (W/m²K)**
Reference 1	Dual vision vertical	1.2 ×1.8	6 over 6	NFRC 100_2010	2.790	0.55	-
Option 1	Dual vision vertical	**2.4** × **1.8**	6 over 6	NFRC 100_2010	2.770	0.59	0.02
Option 2	Dual vision vertical	**1.2** × **0.9**	6 over 6	NFRC 100_2010	2.860	0.49	-0.07
Option 3	**Dual vision horizontal**	1.2 × 1.8	6 over 6	NFRC 100_2010	2.863	0.53	-0.073
Option 4	Dual vision vertical	1.2 × 1.8	**1 over 1**	NFRC 100_2010	2.691	0.57	0.099
Option 5	Dual vision vertical	1.2 ×1.8	**15 over 15**	NFRC 100_2010	2.864	0.53	-0.074
Option 6	Dual vision vertical	1.2 × 1.8	6 over 6	**NFRC 100_2010 summer**	2.898	0.55	-0.108
Option 7	Dual vision vertical	1.2 × 1.8	6 over 6	**NFRC 100_2010 winter**	2.790	N/A	-
Option 8	**Single vision** (without division)	1.2 ×1.8	6	NFRC 100_2010	2.765	0.57	0.025

* Environmental condition. The National Fenestration Rating Council (NFRC) is incorporated with the ISO 15099 standard to supply a heat transfer procedure with upgraded rating progress.

** Differences in the U-values between the reference model and options.

Table 6.7 demonstrates that using one big window has a little better thermal performance rather than two small windows; it means that the size of the windows has no significant impact on the U-value. Also, the horizontal window and single vision window has a little better U-value. In addition, consider the window with more division has a little negative effect on the U-value. As a whole, there are very few differences on the U-values and SHGC (Max. difference is 0.1 W/m^2K). Therefore, the variables analysed in Table 6.7 are not very significant in relation to the U-values and SHGC of the whole windows.

6.3.1.2. Kind of window.

In this analysis, the size of the window is predefined by the software, and it is not possible to change it.

Table 6.8. The calculated U-values and SHGC of the analysed option by LBNL software.

	Kind	**Size (m)**	**Number of divisions**	**Environ. condition**	**U-value W/m^2K**	**SHGC**	**Differences (W/m^2K)***
Reference 1	Dual vision vertical	1.2 × 1.5	6 over 6	NFRC 100_2010	2.790	0.59	-
Option 9	Casement-Double	1.2 × 1.5	6 over 6	NFRC 100_2010	2.868	0.52	-0.078
Option 10	Fixed	1.2 × 1.5	6	NFRC 100_2010	2.779	0.57	0.011
Option 11	Projecting (Awing-Dual)	1.5 × 1.2	6 over 6	NFRC 100_2010	2.831	0.53	-0.041
Option 12	Horizontal slider	1.5 × 1.2	6 over 6	NFRC 100_2010	2.847	0.53	-0.057
Option 13	Vertical slider	1.2 × 1.5	6 over 6	NFRC 100_2010	2.808	0.54	-0.018

* The difference U-value between the reference model and options.

Table 6.8 demonstrates that there are very few differences on the U-values and SHGC (Max. difference is 0.08 W/m^2K). Therefore, the kinds of windows are not very significant in relation to the U-values and SHGC of the whole windows. In this point the cost of windows units is important, several factors impact on the cost of double glazed windows such as installation and labour, access, the windows size, the material and the different kinds of windows.

6.3.1.3 Kind of frame and divider

In this part, the kind of glazing for all options are dual vision vertical with U-value of 2.7 W/m^{2}k and SHGC of 0.81.

Table 6.9. The calculated U-values and SHGC of the analysed option by LBNL software.

	Size (m)	Kind of frame	U-value of the frame (W/m^{2}K)	Frame percent age %	Kind of division	U-value of division (W/m^{2}K)	% of the frame	Whole U-value (W/m^{2}K)	SHGC
Option 14	1.2 × 1.8	Timber	2.27	16%	Wood	3.37	4%	2.8	0.58
Option 15	1.2 × 1.8	Aluminium *	5.68	16%	Aluminium	5.65	4%	3.5	0.61
Option 16	1.2 × 1.8	Aluminium **	3.97	16%	Aluminium	5.65	4%	3.3	0.60
Option 17	1.2 × 1.8	Vinyl	1.7	16%	Vinyl	5.65	4%	2.9	0.58

*aluminium frame without thermal bridging.
***aluminium frame with thermal bridging.

In this part match, the material of the divider with the material of frame as they connect and their junctions are critical. Table 6.9 shows that between the existed materials in the software, the best material for windows frames and divider are wood or vinyl materials. Using aluminium for frame or divider is not suggested. However, there is little difference between vinyl and timber; timber frames are prevalence in the traditional houses; in most of the cases, the residences prefer timber frames because of aesthetic aspects. In addition, the kinds of the frame have no significant effect on the SHGC, however, the timber and vinyl frames have a better SHGC rather than aluminium, as the aluminium allows a greater amount of solar radiation to pass through, on the other hand, the timber and vinyl keep solar radiation better than aluminium; in another word, the timber and vinyl have a lower shading coefficient.

Table 6.10. The typical cost of various kinds of the frame (349).

Material	Cost
PVC-u	£250-570
Aluminium	£500-605
Composite	£575-625
Wood	£845– 910

Table 6.11. The typical cost of various kinds of the frame for different sizes (349).

Material	60 x 90	90 x 120	120 x 120
PVC-u	£250-570	£460-625	£625-895
Aluminium	£500-605	£655-735	£770–875
Composite	£575-625	£600-650	£675-725
Wood	£845–910	£1,245–1,300	£1,365-1,405

After analysing the elements of windows thermally and structurally, the cost is another important factor for choosing between the alternatives, according to Table 6.10 and 6.11 PVC-u frames are cheaper but regards to Table 6.12, the PVC-u frames last around 20-25 years, while timber frames last more than 30 years, in some cases 100 years (350).

Table 6.12. Average life expectancy and typical replacement period of windows regard to the kinds of frames (351).

Frame type	Average life expectancy (years)	Typical replacement period (years)
PVC-u	20-25	10-20
Polyester powder coated aluminium frames	20-40	10-15
aluminium frames	20-35	10-15
Steel frames	40-60	30-40
Hardwood timber frames	30-70	10-15

Regards to the cost of frame repairing, typically £75 for each u-PVC window that needs to be fitted and £85 for each hardwood window that needs installing. About the glass, a stained glass window that needs a specialist, it cost around £30 to £100 per square metre; replacing a sash window will cost around £1,000 per window replacement (352).

6.3.1.4 The percentage of the frame

Table 6.13. The calculated U-values and SHGC of the analysed option by LBNL software.

		Size (m)	Kind of frame	U-value of the frame (W/m^2K)	% of the frame	Whole U-value (W/m^2K)	SHGC
Group 1	Option 18	1.2 × 1.8	Timber	2.27	20%	2.80	0.56
	Option 14	1.2 × 1.8	Timber	2.27	16%	2.82	0.58
	Option 19	1.2 × 1.8	Timber	2.27	10%	2.85	0.62
Group 2	Option 20	1.2 × 1.8	Aluminium	3.97	20%	3.30	0.58
	Option 15	1.2 × 1.8	Aluminium	3.97	16%	3.30	0.60
	Option 21	1.2 × 1.8	Aluminium	3.97	10%	3.19	0.63
Group 3	Option 22	1.2 × 1.8	Vinyl	1.7	20%	2.85	0.55
	Option 16	1.2 × 1.8	Vinyl	1.7	16%	2.89	0.58
	Option 23	1.2 × 1.8	Vinyl	1.7	10%	2.97	0.61

Table 6.13 demonstrates as a whole, the various percentage of frames has more influence on the SHGC rather than U-values and, increasing the percentage of frame improve the SHGC. Also, it enhances the U-values except for the aluminium frames that have a different condition. Increasing the percentage of the frame has a negative effect on the U-value because the thermal conductivity of aluminium is more than glass so, more than 10% frame is not suggested. Regards to the timber frames, the percentage of frames has a little influence on the U-values (doubling the percentage of frame improve just 0.05 W/m^2K). Also, if the high price of wood will be considered it is not economically to widen the frame so, around 16% frame is suitable. However, for the vinyl, widen the frames until 20% is suggested that it causes improving U-value of 0.12 W/m^2K per windows. As aesthetically, more than 20% is not suggested.

6.3.1.5 Kind of glazing system

In this part, all the windows are 1.2 × 1.8 m, 6 over 6 with 18% timber frame.

Table 6.14. U-values regards to the changing the kind of the glazing system.

	Kind	Glazing system	U-value (W/m^2K) of glazing system	SHGC of the glazing system	Whole U-value (W/m^2K)	SHGC of the whole window	Difference (W/m^2K)
Reference 1	Dual vision vertical	Double clear air 5.7+12+5.7	2.703	0.81	2.790	0.59	-
case study N.4	Dual vision vertical	Single glazing 5.7	5.820	0.94	4.486	0.59	-1.696
case study N.10	Dual vision vertical	Single glazing 3	5.910	0.99	4.680	0.62	-1.890
case study N.11	Dual vision vertical	Single glazing 3.9	5.760	0.87	4.660	0.58	-1.870
case study N.12	Dual vision vertical	Single glazing 5.7	5.800	0.94	4.710	0.64	-1.920
Option 24	Dual vision vertical	Double clear with argon 3+15+3	2.582	0.76	2.704	0.59	0.086
Option 25	Dual vision vertical	Double low-e (argon) with ext. perforated screen 0.6+12.7+5.6+12.7+5.7	1.081	0.05	1.819	0.04	0.971
Option 26	Dual vision vertical	Double low-e (argon) with int. horizontal VB (45 degree) 5.6+12.7+5.7+12.7+18	1.227	0.26	1.907	0.20	0.883
Option 27	Dual vision vertical	Double low-e (argon) with in between horizontal VB (45 degree) 5.7+1.3+7.2+1.3+5.7	3.212	0.30	3.314	0.22	-0.524
Option 28	Dual vision vertical	Double low-e (argon) with ext. horizontal VB (45deg) 53.9+ 12.7+5.6+12.7+5.7	1.037	0.10	1.820	0.06	0.970
Option 29	Dual vision vertical	Double low-e (argon) with ext. vertical VB (0 degree) 76.2+ 12.7+5.6+12.7+5.7	1.075	0.38	1.834	0.28	0.956
Option 30	Dual vision vertical	Double high solar gain low-e 4.7+16.5+4.7	1.935	0.69	2.294	0.53	0.496
Option 31	Dual vision vertical	Double low-e (air) – deflected 6+12.7+3	1.663	0.36	2.150	0.30	0.64
Option 32	Dual vision vertical	Double low-e vacuum 4+0.1+4	0.6634	0.35	1.698	0.3	1.092
Option 33	Dual vision vertical	Double clear (air) with white frit – 50% coverage 5.7+12.7+5.7	2.689	0.50	2.778	0.37	0.012
Option 34	Dual vision vertical	Double low-e air 3.2+12.7+5.7	1.684	0.43	2.161	0.35	0.629
Option 35	Dual vision vertical	Pleotint 12.6 (Suntuitive glass)+12.7(air)+3 (clear glass)	2.630	0.52	2.815	0.42	-0.025
Option 36	Dual vision vertical	Sage blue 8.8(sage blue glass)+12.7(air)+3(clear glass)	1.834	0.31	2.313	0.26	0.477
Option 37	Dual vision vertical	Sage green 8.7(sag green glass)+12.7(air)+3 (clear glass)	1.834	0.27	2.313	0.23	0.477
Option 38	Dual vision vertical	Sample glazing system 4.7(clear glass)+16.5(air)+4.7 (Low-E glass)	1.935	0.69	2.294	0.53	0.496
Option 30	Dual vision vertical	Thermo chromic azuria 12 mm 12+12.7(air)+3 (clear glass)	2.666	0.22	2.839	0.19	-0.049
Option 40	Dual vision vertical	Thermo chromic gray 12 mm 12+12.7(air)+3 (clear glass)	2.666	0.31	2.839	0.26	-0.049
Option 41	Dual vision vertical	Thermo chromic laminate 7 mm 7+12.7(air)+3 (clear glass)	2.751	0.57	2.862	0.46	-0.072
Option 42	Dual vision vertical	Triple clear 5.7+12.7+5.7+12.7+5.7	1.744	0.62	2.180	0.05	0.61

Option 43	Dual vision vertical	Triple low-e vacuum air 6+0.2+6+0.2+6	0.278	0.1	1.531	0.1	1.259

Regards to the table, structurally the best option for glazing system respectively are triple Low-E vacuum air, double Low-E vacuum and double Low-E with argon structurally. These results are just based on the windows elements, it means that if the location, weather conditions, and the economic aspects would be analysed, maybe the outcome will change, but as a first step, it is good to work on the thermal performance of windows. Except for these kinds of windows, the rest kinds of windows are not acceptable according to the standards and regulations. Now the recommended U-value in the EU countries for the windows is 1.8 W/m^{2}K, so the thermochromic windows or double windows with air are not admissible. In addition, the double Low-E (argon) within between horizontal (45 degrees) with the U-value of 3.314 W/m^{2}K is not allowable because its glass is generic clear and its gas is not pure argon which is why it has the worst U-value. The details of all the options are provided in the appendix H.

6.3.2 Glazing system

In this part, the glazing system, the material and the thickness of the glasses and the gaps are analysed.

6.3.2.1. Gaps

6.3.2.1.1. Kind of gap

Table 6.15. U-values of glazing system regards to the changing the kind of gaps.

	Kind of glazing system	Kind of glass	Kind of gap	U-value (W/m^{2}K)	SHGC	Difference U-value (W/m^{2}K)
Option 44	Double glazing	Generic clear glass	Air	2.730	0.81	-
Option 45	Double glazing	Generic clear glass	Air – EN673	2.732	0.76	-0.002
Option 46	Double glazing	Generic clear glass	Argon	2.568	0.76	0.162
Option 47	Double glazing	Generic clear glass	Air (10%)/ Argon (90%) mix	2.584	0.76	0.146
Option 48	Double glazing	Generic clear glass	Air (12%)/ Argon (22%) krypton (66%)	2.563	0.76	0.167
Option 49	Double glazing	Generic clear glass	Argon – EN673	2.567	0.76	0.163
Option 50	Double glazing	Generic clear glass	CO_2	2.739	0.76	-0.009
Option 51	Double glazing	Generic clear glass	Helium	4.111	0.76	-1.381
Option 52	Double glazing	Generic clear glass	Krypton	2.519	0.76	0.211
Option 53	Double glazing	Generic clear glass	Air (5%)/ krypton (95%) mix	2.532	0.76	0.198

Option 54	Double glazing	Generic clear glass	Krypton- EN673	2.519	0.76	0.211
Option 55	Double glazing	Generic clear glass	N_2	2.728	0.76	0.002
Option 56	Double glazing	Generic clear glass	Neon	3.083	0.76	-0.353
Option 57	Double glazing	Generic clear glass	Octofluorpropane	3.289	0.76	-0.559
Option 58	Double glazing	Generic clear glass	SF_6	3.083	0.76	-0.353
Option 59	Double glazing	Generic clear glass	Vacuum-air P=0.001 (pr-1.5 ps-30)	2.265	0.76	0.465
Option 60	Double glazing	Generic clear glass	Xenon	2.477	0.76	0.253
Option 61	Double glazing	Generic clear glass	Xenon – EN674	2.476	0.76	0.254
Option 62	Double glazing	Generic clear glass	Air (5%)/ Argon (95%) mix	2.576	0.76	0.154

According to Table 6.15, as expected the best gas for the glazing system is vacuum air. As a consequence, xenon, krypton, and argon are allowable, but helium, Octofluorpropane, neon and SF_6 have the worst U-values and not suggested at all. Another important point regard to the table is that the pure gas has a better U-value rather than mix gasses; for example, the option 46, the glazing system with pure argon has a better U-value rather than option 47 and 62, glazing system with mix argon and air.

6.3.2.1.2 Thickness of the gap

Table 6.16. U-values of glazing system regards to the changing the thickness of the four kinds of the gap (Air, argon, krypton, xenon).

		Kind of glass	**Kind of gap**	**The thickness of gap (mm)**	**U-value (W/m^2K)**	**The difference of U-value in each group (W/m^2K)**
Group 1	Option 63	Generic clear glass	Air (10%)/ Argon (95%) mix	15	2.590	0.278
	Option 64	Generic clear glass	Air (10%)/ Argon (95%) mix	6.35	2.868	
Group 2	Option 65	Generic clear glass	Air	15	2.730	0.393
	Option 66	Generic clear glass	Air	6.35	3.123	
Group 3	Option 67	Generic clear glass	Krypton	15	2.535	0.002
	Option 68	Generic clear glass	Krypton	6.35	2.537	
Group 4	Option 69	Generic clear glass	Xenon	15	2.477	0.045

	Option 70	Generic clear glass	Xenon	6.35	2.432

Table 6.16 demonstrates the influence of the thickness of gas on the U-values depends on the kinds of gaps. For example, increasing the thickness of gap, has a positive effect, if the gas is air or argon but, has a negative effect, if the gas is xenon. Also, if the gas is krypton, adding the thickness of the gas, does not affect the U-value. It shows that, if the selected gas is argon, air or xenon, their thickness is important, but if the selected gas is krypton, its thickness does not effect on the U-value. In all the options the SHGC value is 0.76.

6.3.2.2. Glass

6.3.2.2.1 Kind of glass

The kind of glazing system in all options of this part are double glass with Argon, the thickness of argon in all option is 12.7 mm.

Table 6.17. U-values of glazing system regards to the changing the kind of glasses.

Option	ID	Source	Thickness of each glass (mm)	Manufacturer	Product	U-value (W/m²K)	SHGC
71	1682	IGDB v39.0	5.970	China Southern Glass (CSG)	Triple Low-E on Clear	1.009	0.15
72	980	IGDB v17.3	5.720	AGC Glass Co. N.A.	Comfort TiAC28 on Clear	1.013	0.24
73	1067	IGDB v41.0	3.180	AGC Glass Co. N.A.	Comfort Select 28	1.019	0.24
74	1663	IGDB v39.0	5.970	China Southern Glass (CSG)	Double LowE on Green	1.038	0.15
75	2026	IGDB v16.4	3.000	Cardinal Glass Industries	LoE² 270 on 3mm Clear	1.054	0.32
76	1666	IGDB v39.0	5.970	China Southern Glass (CSG)	Double LowE on Clear	1.056	0.24
77	1674	IGDB v39.0	5.970	China Southern Glass (CSG)	Double LowE on Grey	1.056	0.15
78	1037	IGDB v28.0	3.150	AGC Glass Co. N.A.	Comfort Select	1.09	0.52
79	288	IGDB v32.0	3.277	Saint-Gobain Solar Gard LLC	Ecolux 70	1.173	0.35
80	3163	IGDB v44.0	2.972	Guardian	Guardian Neutral 70 on 3mm Clear	1.254	0.53
81	19765	IGDB v47.0	0.076	Eastman Chemical Company	Heat mirror 22 Suspended Film	1.331	0.07
82	15014	IGDB v43.0	3.760	AGC ASAHI GLASS CO., LTD.	Low-E AquaGreen T 4mm	1.375	0.33
83	3179	IGDB v20.0	3.175	Guardian	SunGuard® IS 20 Interior Surface LE on 3.2mm Clear	1.397	0.68

84	13006	IGDB v34.0	3.900	arcon	arcon N33 on clear4	1.416	0.53
85	15010	IGDB v43.0	2.790	AGC ASAHI GLASS CO., LTD.	Low-E PureClear 3mm	1.431	0.50
86	3238	IGDB v20.0	2.972	Guardian	ClimaGuard 80/70 on 3mm Clear	1.511	0.63
87	15007	IGDB v43.0	2.750	AGC ASAHI GLASS CO., LTD.	Low-E Silver 3mm	1.549	0.50
88	1032	IGDB v31.0	3.120	AGC Glass Co. N.A.	Comfort Select 73 on Clear	1.624	0.62
89	9738	IGDB v18.0	2.850	Viridian	3mm EnergyTech	1.656	0.64
90	9921	IGDB v17.4	3.000	Pilkington North America	Energy Advantage	1.656	0.67
91	200	IGDB v16.3	3.023	Saint-Gobain Solar Gard LLC	Silver AG 25 Low-E	1.661	0.12
92	907	IGDB v11.4	3.099	AGC Glass Co. N.A.	Comfort E² on Clear	1.731	0.63
93	17145	IGDB v33.0	3.864	Saint Gobain Glass India	Evolite Clear	2.186	0.35
94	207	IGDB v16.3	3.023	Saint-Gobain Solar Gard LLC	Solar Bronze 20	2.269	0.10
95	239	IGDB v16.3	3.023	Saint-Gobain Solar Gard LLC	Sterling 20	2.286	0.12
96	19734	IGDB v44.0	3.000	Eastman Chemical Company	Vista Harmony Terre	2.287	0.22
97	8619	IGDB v27.0	3.178	Madico Inc.	OPTIVISION 5	2.313	0.10
98	255	IGDB v16.3	3.251	Saint-Gobain Solar Gard LLC	Grey/Silver 15	2.387	0.12
99	253	IGDB v16.3	3.251	Saint-Gobain Solar Gard LLC	Bronze/Silver 15	2.399	0.12
100	238	IGDB v18.2	3.277	Saint-Gobain Solar Gard LLC	LX40	2.420	0.26
101	220	IGDB v17.4	3.251	Saint-Gobain Solar Gard LLC	TrueVue 40	2.421	0.32
102	202	IGDB v16.3	3.277	Saint-Gobain Solar Gard LLC	Hilite 70	2.454	0.33
103	2401	IGDB v43.0	7.096	Cytec Surface Specialties	Laminate with UV Curable Interlayer	2.471	0.70
104	226	IGDB v16.3	3.023	Saint-Gobain Solar Gard LLC	Stainless Steel 10	2.490	0.12
105	407	IGDB v46.0	9.291	Vitro	Clear Float Glass	2.491	0.64
106	241	IGDB v47.0	3.251	Saint-Gobain Solar Gard LLC	Sentinel Plus SX 50 OSW	2.493	0.28
107	1904	IGDB v33.0	6.380	Eastman Chemical Company	Vanceva® Sahara Sun "4"	2.502	0.60

108	1800	IGDB v31.0	4.980	Eastman Chemical Company	Saflex® R series	2.522	0.70
109	225	IGDB v16.3	3.035	Saint-Gobain Solar Gard LLC	Slate 40	2.523	0.30
110	2900	IGDB v23.0	5.831	XYG Glass	_XYG Float Glass French Green 6mm	2.537	0.44
111	258	IGDB v16.3	3.251	Saint-Gobain Solar Gard LLC	Bronze/Silver/Bronze 10	2.546	0.16
112	259	IGDB v16.3	3.251	Saint-Gobain Solar Gard LLC	Grey/Silver/Grey 10	2.55	0.16
113	400	IGDB v46.0	4.775	Vitro	Tintex_5.vto	2.552	0.48
114	426	IGDB v46.0	4.036	Vitro	Cristazul	2.562	0.50
115	1223	IGDB v17.1	3.900	Asahimas	Indoflot Clear 4.0	2.564	0.74
116	14704	IGDB v43.0	3.800	Glas Trösch AG	Low-Iron EUROWHITE NG 4 mm	2.565	0.84
117	1560	IGDB v13.8	3.071	Southwall Technologies, Inc.	VIP by V-Kool	2.566	0.16
118	417	IGDB v46.0	3.296	Vitro	Filtraplus	2.572	0.26
119	712	IGDB v17.3	3.150	AGC Glass Co. N.A.	Krystal Klear	2.574	0.84
120	1002	IGDB v27.0	3.150	AGC Glass Co. N.A.	Solarshield Meadow Green	2.574	0.52
121	9811	IGDB v38.0	3.200	Pilkington North America	Optiwhite	2.574	0.84
122	437	IGDB v46.0	3.171	vitro	Filtrasol	2.574	0.56
123	100	IGDB v11.4	3.124	Generic	Generic Bronze Glass	2.575	0.60
124	104	IGDB v11.4	3.124	Generic	Generic Grey Glass	2.575	0.60
125	102	IGDB v11.4	3.048	Generic	Generic Clear Glass	2.576	0.76
126	412	IGDB v46.0	3.004	Vitro	Clear Float Glass	2.576	0.76
127	9705	IGDB v17.1	2.980	Viridian	3mm VFloat	2.577	0.76
128	17115	IGDB v33.0	3.565	Saint Gobain Glass India	Reflectasol Green	2.580	0.26
129	17111	IGDB v33.0	3.443	Saint Gobain Glass India	Reflectasol Light Gold	2.581	0.39
130	204	IGDB v17.4	3.251	Saint-Gobain Solar Gard LLC	NightSky 20	2.604	0.27
131	30010	IGDB User vUser	7.000	LBNL	Thermochromic1_24	2.623	0.56
132	1703	IGDB v17.0	3.160	A & B Films Pte Ltd	Blackstone 10	2.631	0.19

133	252	IGDB v47.0	3.251	Saint-Gobain Solar Gard LLC	CX 60	2.651	0.50
134	17304	IGDB v44.0	3.394	RavenBrick	RavenWindow Gen2 on3mm_Dark	2.664	0.40
135	1575	IGDB v14.0	3.047	Southwall Technologies, Inc.	Huper Optik Ceramic 60	2.665	0.45
136	273	IGDB v16.3	3.378	Saint-Gobain Solar Gard LLC	7 Mil Graffitigard	2.670	0.74
137	262	IGDB v16.3	3.251	Saint-Gobain Solar Gard LLC	Quantum/Silver/Quantu m 10	2.685	0.16
138	260	IGDB v16.3	3.251	Saint-Gobain Solar Gard LLC	Quantum 37	2.701	0.37
139	19724	IGDB v44.0	3.040	Eastman Chemical Company	Signals Defenses Film	2.711	0.18
140	274	IGDB v16.3	3.277	Saint-Gobain Solar Gard LLC	Black Opaque	2.714	0.16
141	270	IGDB v16.3	3.556	Saint-Gobain Solar Gard LLC	14 Mil Clear	2.716	0.70

There are lots of kinds of glasses. In this part, 71 kinds of glasses have been analysed. Their details are provided in the appendix H and the useful data summarised in Table 6.17 illustrates. The table shows that triple Low-E and double Low-E glasses have the best U-values and generic clear glasses and quantum glasses are not appropriate for improving the U-values. In addition, the Sunguard glasses work better than what expected, on the other hands, the Filtrasol and Reflectasol glasses do not work well as much as expected. Now the China Southern Glass (CSG) company make the glasses with the best U-values, also, the product of Saint Gobain Glass India manufactory is not thermal effective as much as original Saint-Gobain Solar Gard LLC Company. Moreover, the colour of glasses thermally has no significant impact on the U-value but regards to Table 6.18, economically the cost is different.

Table 6.18. The price of two kinds of Colour of PVC-u casement windows (353).

Size	**Colour**	**Price**
1.2 cm x 1.2 cm	White	£350 – £400
1.2 cm x 1.2 cm	Wood Grain	£400 – £450

6.3.2.2.2 Thickness of glass

Table 6.19. U-values of glazing system regards to the changing the thickness of the five kinds of glasses.

		Kind of gap	**Kind of glass**	**The thickness of glass (mm)**	**U-value (W/m^2K)**	**SHGC**	**Difference of U-value (W/m^2K) in each group**
Group 1	Option 142	Air (10%)/ Argon (95%) mix	Generic clear glass	3 + 3	2.576	0.76	0.037
	Option 143	Air (10%)/ Argon (95%) mix	Generic clear glass	5.7 + 5.7	2.539	0.70	
Group 2	Option 144	Air (10%)/ Argon (95%) mix	Clear float glass	2.1 + 2.1	2.589	0.80	0.079
	Option 145	Air (10%)/ Argon (95%) mix	Clear float glass	7.9 + 7.9	2.510	0.68	
Group 3	Option 146	Air (10%)/ Argon (95%) mix	Green float glass	2.8 + 2.8	2.579	0.59	0.124
	Option 147	Air (10%)/ Argon (95%) mix	Green float glass	12.1 + 12.1	2.455	0.34	
Group 4	Option 148	Air (10%)/ Argon (95%) mix	Low-E green glass	2.8 + 2.8	1.452	0.36	0.011
	Option 149	Air (10%)/ Argon (95%) mix	Low-E green glass	4.8 + 4.8	1.441	0.35	
Group 5	Option 150	Air (10%)/ Argon (95%) mix	ParsolH green	3.5 + 3.6	2.570	0.56	0.061
	Option 151	Air (10%)/ Argon (95%) mix	ParsolH green	8 + 8	2.509	0.40	

Table 6.19 illustrates that the thickness of the glasses has a little impact on the U-values. For example, for option 147 that the thickness of glasses increased more than four times rather than option 46, but the U-value just improved 0.125 W/m^2K. In other cases, the U-values improve averagely around 0.05 W/m^2K, with considering the cost of heavy glasses, their problem regards to the weight and thickness. The heavy glasses are not recommended, so it is better to focus more on the kind of glass rather than its thickness.

6.3.3 Results discussion

Table 6.20. Comparison of the main results of section 6.4.1.

Parameter	Minimum U-value (W/m^2K)	Maximum U-value (W/m^2K)	Difference between Max & Min (W/m^2K)	Respective interval between U-values in each part (W/m^2K)*
Kind of glazing system	**1.629** Triple Low-E argon-deflected	**3.314** Double Low-E argon	**1.69**	±1
Kind of frames and divider	**2.80** wood	**3.50** Aluminium	**0.70**	±0.2
The percentage of frame	**2.8** Timber (20%)	**3.3** Aluminium (20%)	**0.50**	±0.05
Number of divider	**2.691** Less divide	**2.864** more divide	**0.17**	±0.08
Different season (climate)	**2.790** Winter	**2.898** Summer	**0.11**	±0.05
Kind of window	**2.779** Fixed window	**2.868** Casement	**0.09**	±0.08
Size of window	**2.770** Big size	**2.860** Small size	**0.09**	±0.04

* The column shows the respective interval between all the U-values of each part.

Table 6.20 summarises the main results of section 6.3.1 and shows the influence of each parameter on the whole U-values of the window. Selecting the kind of glazing system is very important because it has a significant effect on the U-values, then choosing the appropriate materials for frame and divider is important. The rest parameters have a lower effect on the U-values, but it is essential to consider all the parameters especially when there are many windows. Table 6.20 shows that the kind of glazing system has a significant impact on the whole U-values, now Table 6.21 summarises the main results of section 6.3.2 to show what parameter has a significant influence on the U-values of glazing system.

Table 6.21. Comparison of the main results of section 6.4.2.

Parameter	Minimum U-value (W/m^2K)	Maximum U-value (W/m^2K)	Difference U-value (W/m^2K)
Kind of gap	**2.265** Vacuum air	**4.111** Helium	±2.74
Kind of glass	**1.009** Triple low-E on clear	**2.716** Clear glass	±2.17
Thickness of gap	Depend on the kind of gap		±0.1
Thickness of glass	Depend on the kind of glass		±0.05
The colour of the glass	Depend on the kind of glass		±0.00

Table 6.21 demonstrates that the kinds of the gap have more impact on the U-values rather than the kinds of glasses. Also, it happens for the thickness; it means that the thickness of the gap has more effect on the U-value rather than the thickness of the glasses. In addition, the colour of the glasses does not influence the U-value. However, it is essential to consider that in this chapter, 71 kinds of glasses have been analysed but only around 11 kinds of gaps have been studied because the library of the software just provides these kinds of gaps. As a whole, it is

clear that the kind of glass and gas have a significant effect on the U-values rather than their thickness and other parameters. Regards to the all above information, the appropriate windows with the lowest U-value is the monolithic triple single horizontal vision window with at least divide, vinyl frame, triple low-E glasses and vacuum air as illustrated in the following figure. Regards to the software calculation, the U-value of this glazing system example is 0.278 W/m^{2}K, and its whole U-value is 0.830 W/m^{2}K.

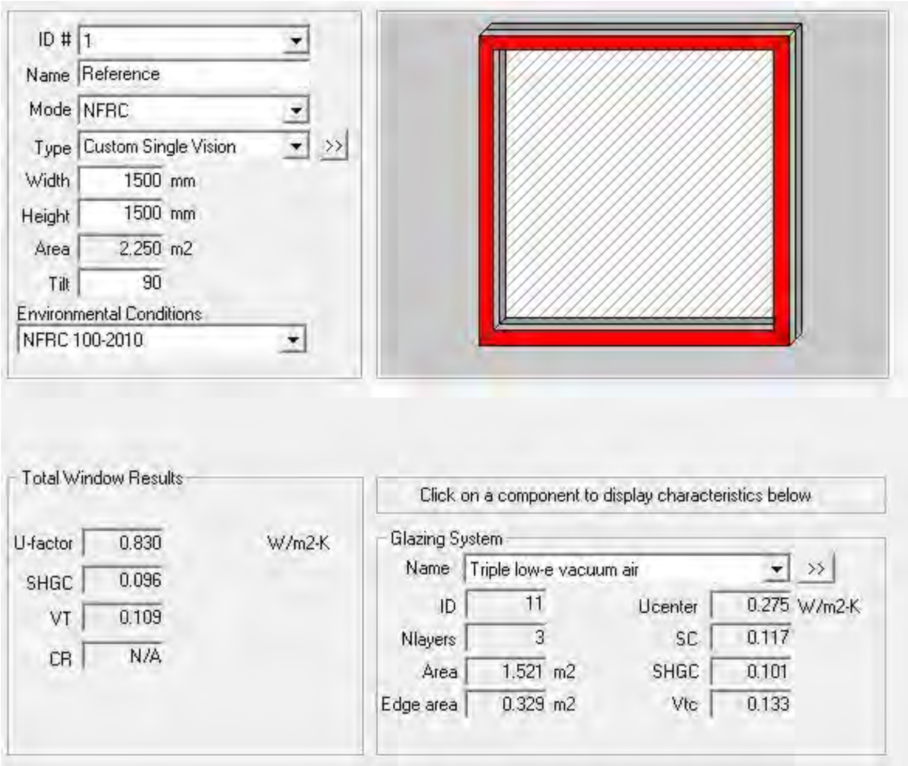


Figure 6.10. Characteristics of the whole suggested window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

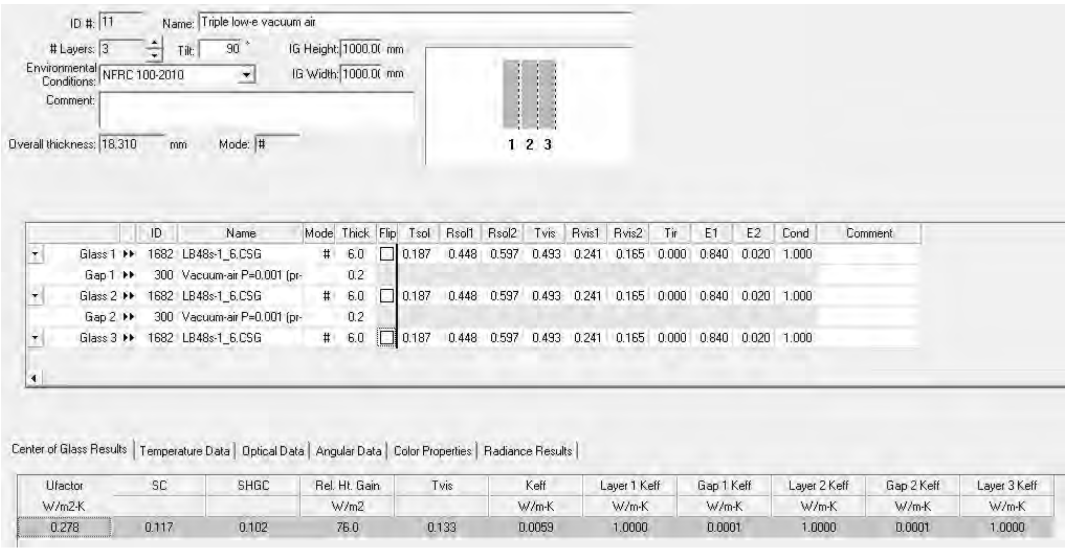


Figure 6.11. Characteristic of the suggested glazing system, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

6.4 Case studies

In this section, the windows of the case studies have been analysed, the properties featured in this study are twelve typical case studies of pre-1919 construction in Scotland. All of the houses are of traditional construction (solid walls). Most of their windows have been replaced with double glazing window. Two of them have original single glazed windows, and three of them have both single and double glazing windows, and the rest have double glazing windows. Three of the case studies are using secondary glazing system. In this section, all the windows are modelled by Lawrence Berkeley National Laboratory program to obtain the U-values. Then all the conditions and alternatives of the windows will be analysed. Also by considering the economic aspects, the optimisations methods will be suggested for repairing, or replacement to meet the best alternative as a structurally and required U-values.

6.4.1 Description of the installed windows in each case study

Case 1. The window of a traditional house (age = 102)
The property retains original timber-framed windows which are double glazed. External doors are of timber frame and panel construction. The windows and external doors and eaves timbers have an oil based paint finish. Windows and external doors appear in serviceable repair and are well maintained. Old glass removed from patio doors and new toughened double glazed units fitted to existing frames.

Case 2. The window of a traditional house (age = 107)
Windows throughout are of timber framed single glazed and double glazed and box windows type. Access doors are of timber construction. The windows as a whole appeared in a miserable situation regards to the age. Installed two double glazed sash windows instead of an old sash window in the ground floor side bedroom; Changed kitchen door into the full double glazed door; Installed new French doors leading to the back garden; added canopies and upgraded steps to both backdoors.

Case 3. The window of a traditional house (age = 115)
The windows are predominantly traditional timber sash and case single-glazed design. The majority of windows were locked or paint jammed throughout, and a general overhaul would be beneficial. The lock is not only for security objective. It pulls the sashes sturdy together and limitation air leakage. After the decades, as a whole, it is better to reuse the original locks as they made of the better material than new ones. The lock of some of the windows screw holes which are deteriorated; it is possible to repair by using an epoxy filler or re-drilled and reinstalled. There are a few missing and broken sash cords, and there are cracked areas of the mastic pointing to the external frames. There is localised decay to the door frame on the side porch, and the metal doors are accessing the balcony are now dated.

When humidity penetrates the wood, it leads to decay; it is possible to avoid the decay via swift fixing, preservation, and painting. Identification of wet root is easy via cracked paintwork. It is important to eliminate the reason for the humidity. It happened because like most of the traditional windows constructed from (pine) slow-grown deal, for repairing must consider the same kind of timber as the original ones. Timber sill is the most vulnerable part of decay, so hardwood is more suitable for sills like local or English Oak as a result of its resistance to fungi and great ability of weathering. The spliced repair must be done via removing rotten timber and scarfing and splicing wood embeds that are formed to get the best stability and to justify the current elements. The front and rear doors to the property are double timber units. There is a further timber door to the side of the property and metal framed glazed doors leading to the balcony. There is a porch to the rear of the property. There are roughcast lower walls with timber and single-glazed windows. Adjusting the draught proofing, insulated strips near doors and windows, enhance the amenity in the house.

Case 4. The window of a traditional house (age = 126)

The window frames are of the traditional single glazed double-hung sash and casement design. A few of the frames have been fitted with secondary glazed units. The front and rear doors are of timber construction. The window frames, doors, and rainwater fitting have a paint finish. Secondary glazing replaced in front rooms and installed in some other rooms. The window frames would benefit from a general overhaul regarding freeing paint fast frames, replacing defective sash cords. Regular ongoing maintenance should be anticipated to prevent weathering.

Case 5. The window of a traditional house (age = 132)

All the windows are double glazed. Installation of double glazing/secondary glazing probably during the 1980's. Windows comprise a variety of types including original timber sash and case windows which are single glazed, although they have internally fitted secondary glazing. There are modern PVC-u framed and double glazed window to the 4rear offshoot. The front entrance door and the door in the kitchen is of single leafed timber-framed and panel construction. There is a double-leafed aluminium framed and double glazed storm door on the rear wall of the dining room giving access to the rear garden. Timber framed windows and cast-iron gutters and downpipes and timber-framed external doors have an oil based paint finish. Dormer windows and surrounding flashings are again weathered. Some degree of ongoing maintenance should be anticipated. Windows and external doors appear in serviceable repair commensurate with age, although they do show evidence of weathering. Re-painting of timber framed windows and doors will eventually be required. Older style double glazing can be prone to condensation within the sealed units although this may only be apparent during certain periods of weather. Gutters and downpipes and windows require re-painting.

Case 6. The window of a traditional house (age = 140)

All the windows are double glazed. There are PVC-u French doors within Kitchen. Windows are replacement PVC-u double glazing. Windows and doors are not forced open. The windows as a whole appeared in a miserable situation regards to the age. The garage window was noted to be in poor condition and required repair.

Case 7. The windows of a traditional house (age = 151)

The windows around the house take the form of timber frame sash and case windows, timber frame casement windows and Velux windows, some of which have been fitted with double glazed sealed units. Access to the house is using a single leaf timber door to front. Twinleaf timber and glazed doors give access to the study to and from the garden ground to the rear. A single leaf timber and double glazed door and twin leaf timber and double glazed doors give access from the kitchen/breakfast room to and from the garden ground to rear. The fascia boards around the dormer windows built into the front slope of the roof take the form of softwood. The ogee rone, gutters, downpipes, windows, doors and external timbers have been painted with oil-based paints.

No evidence of significant defect was noted in respect of the window fabric. The weights and sash cords (ropes) of the window are cracked, and they are separated that caused a problem with closing and opening the windows because the sash goes out of balance. At the first step, it is essential to get access to the gapes to repair or counterweighting the sashes. The new sashes cord last for a decade but have to consider to do not paint the sashes cord as they cause extra problems.

No evidence of significant defect was noted in respect of the doors giving access to and from the house or external timbers. No evidence of significant weathering was noted to have affected the external paintwork to the ogee krone, gutters, downpipes, windows, and doors. The fascia boards around the dormer windows to the front have weathered resulting in some deterioration of the decoration. The residence decided to add an accessory dwelling unit (ADU) to its original house, so in some cases, larger windows were needed for an AUD to justify with the traditional houses. In such condition, it is essential to match the size of the windows and use the frame with the same materials as another original window.

Case 8. The window of a traditional house (age = 160)

The windows are Irish windows that are robust, better control the ventilation and need little preservation. Its sashes counterweighted with hiding weights and simply slide in the frame. Timber casement was prevalence as it was inexpensive. Also, its sashes had small pane and blocky bar glazing. All windows are timber sash and case double glazed and timber double glazed Velux windows. External door is the threshold door in timber. Skylight and common parts have joinery and paintwork. There is no evidence of a reportable defect. Regular re-pointing and localised maintenance to timber sash and case windows, in particular, are to be expected. Replacement window has been installed in first-floor bay window (living room).

Plate glass was improved and entered the market in the 19th century that mostly applied to the main hall room in renovation and modern homes as it allows uninterrupted view via glazing bar. Also shown the fashion and fortune of residence; It was prevalence until after the Second World War when the sash windows introduce to the market. In some cases, the most impressive decorative characteristic of small houses are the windows so naïve glazed or surrounding make them impressive.

Case 9. The window of a traditional house (age = 164)
Double glazing. The windows as a whole appeared in the right situation regards to the age. Doors and windows were not forced open. Cast iron rainwater goods are painted, and external timbers are finished with a decorative stain. Windows throughout are replacement timber frame sash and casement style double glazing. Access doors are timber.

Case 10. The windows of a traditional house (age = 169)
The windows are a mixture of timber and plastic. The windows have a mixture of single and double glazing. The door is timber. The fascia boards (gutter boards) at the eaves of the roof are timber. The barge boards at the verges (sides) of the roof are timber. Evidence of dampness noted behind the window shutter in the front bedroom and within the vestibule. These are due to external defects in the downpipe and mastic seals.

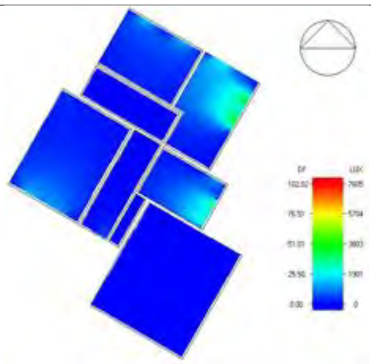
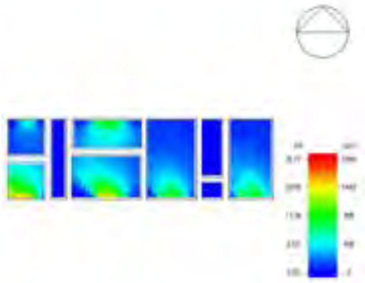
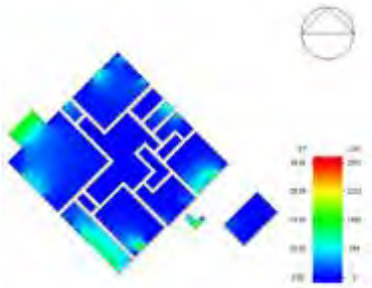
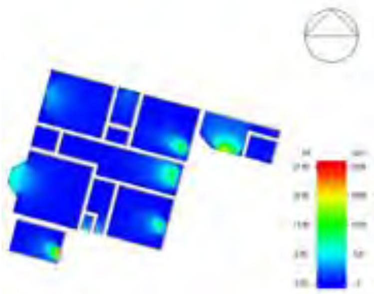
Open joints allow humidity to penetrate so lead to decay. Decayed join has to be removed and patch the proper elements. The weak joint must be maintained via pinning, glueing and cramping. There also evidence of woodworm affecting the attic timbers. The timber windows are old and worn, and the mastic pointing is defective in places. The glass to the first-floor bedroom window is cracked, and the glazing to the vestibule door is not kite marked as safety glass. The cavities among the masonry and the frame should be caulked or pointed with a suitable mastic.

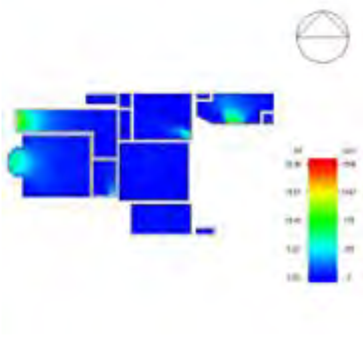
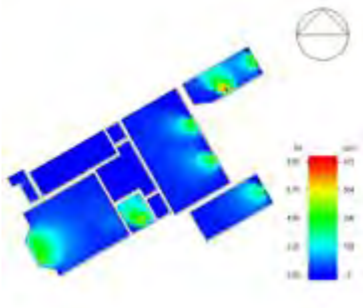
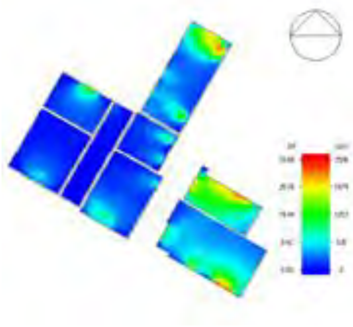
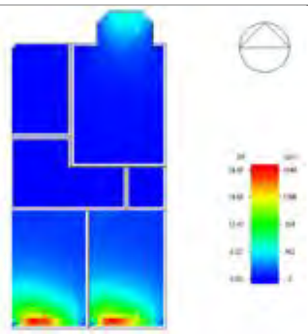
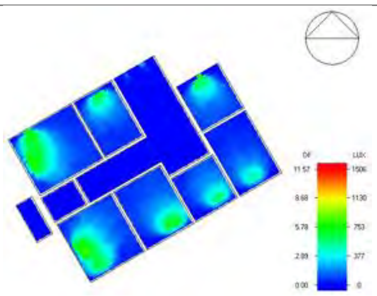
Case 11. The windows of a traditional house (age = 171)
The windows comprise a combination of the original single glazed case and sash units in timber frames and exchanging double glazing units in PVC-u frames. The front door to the property is of solid wood construction. External decorations comprise a painted finish to windows, doors and the external render. Double glazed units were noted to have failed within the property. Several windows were noted to be painted shut. Cracked glazing was noted in the dining room. One of the windows is racked. It occurs throughout times and causes to moisture and air infiltration that cracked joints. It is essential to repair it but first, have to find the root that leads to the rack.

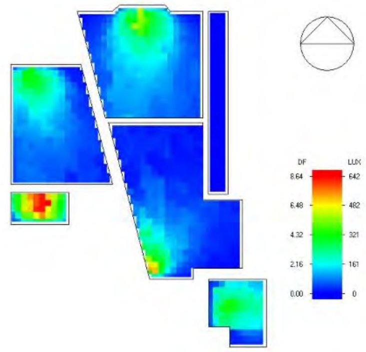
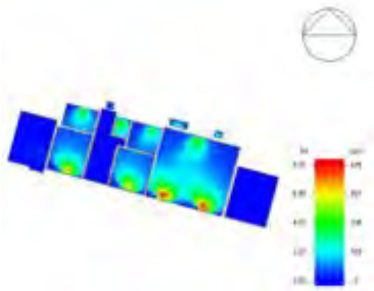
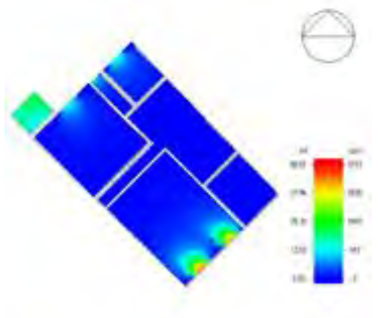
Case 12. The window of a traditional house (age = 223)
The proposal is to replace an existing window on the rear elevation, which has previously been split and serves two private rooms, with a single-glazed, timber sash and case window. The window configuration would be six over six. A new extension to an existing cast iron drainage pipe would be located below the window. The design and detailing of the window will match the adjacent window and will be an improvement on the existing, which is vertically split in half to serve two separate rooms. Install new 4-panel hardwood doors to suit existing openings. Door 826x2040 mm to en-suite.

Install a new timber single glazed sash and case window to match adjacent existing 12 pane windows. Window to incorporate a 12000 mm² permanent (total for the room being served) and be fitted with easy clean hinges and security measures by the recommendations in building standard 4.13. Remove the existing French window to shower room/bedroom and sash-and-case windows with working shutters, which have been draught-proofed by Ventrolla.

Table 6.22. The daylighting characteristic of the case studies.

Case study and age		Total area (m^2)	Total area above threshold (m^2)	% Area above a luminance threshold	LEED NC 2.2 Credit EQ 8.1 Status*	Daylighting visualisation
1	102	212	55.71	26	FAIL	
2	107	184	25.37	14	FAIL	
3	115	377	59.04	16	FAIL	
4	126	317	36.41	11	FAIL	

5	132	290	15.01	5	FAIL	
6	140	269	26.90	10	FAIL	
7	151	249	108.11	43	FAIL	
8	160	124	20.68	17	FAIL	
9	164	287	31.57	11	FAIL	

10	169	93	8.37	9	FAIL	
11	171	196	29.4	15	FAIL	
12	223	363	64.43	18	FAIL	

The results have been calculated according to the DesignBuilder program (354).

*EQ Credits 8.1 and 8.2 purposes to supply view and daylight of the outdoor environment for residences parts of the houses. In this method glazing factor is calculated according to:

Glazing Factor = 0.1 · (0.7/0.4) · 0.8 (Window/Floor) = 0.14 · (Window Area/Floor Area)

Regards to obtain the credit of daylighting, a minimum glazing ratio of 2% has to be obtained in the at least 75% of all residences parts of the houses. Regards to have a 2% glazing ratio, the following equation is required (355):

(Window Area) / (Floor Area) = 0.143

Table 6.22 demonstrates that none of the case studies meets the required factors of Leadership in Energy and Environmental Design - New construction (LEED - NC) (356) Credit EQ 8. Case study 7 has better condition and case studies 5, and 10 have the worst conditions. Therefore, all the case studies are in poor condition. Also, this condition is worse for the new and existing houses because according to the observation, the new and existing houses uses small and fewer windows rather than traditional houses.

6.4.2 Results and discussion

In this part, the results of all the windows of case studies that are modelled by Window program have assessed; the obtained U-values, SHGC, materials, all the conditions, and alternatives have considered suggesting the optimisations methods for repairing or replacement of windows to meet the required U-values. Also, some economics aspects have been assessed.

Table 6.23. Comparison of the main characteristic of the windows installed in the case studies.

Case study and age		Kind of window	Size (mm)	Kind of frame	Kind of glass	Kind of gap	Thickness (mm)	U-value of glazing sys (W/m²K)	SHGC	U-value of whole windows (W/m²K)	SHGC	Suggestion
1	102	Double	1.2× 1.5	Timber	Low-E	Argon	4-8-4	1.21	0.32	1.64	0.27	-
2	107	Double	0.6× 1.4	Timber	Low-E	Krypton	3-4-4	1.86	0.43	2.50	0.31	Repair
3	115	Single	0.8× 1.4	Timber	Low-E	-	5.7	3.26	0.23	2.73	0.19	Repair
4	126	Single	0.6× 1.8	Timber	Generic clear	-	5.7	**5.82**	**0.82**	**4.49**	**0.59**	**Replace**
	126*	Double	0.6× 1.8	Timber	Low-E	Vacuum air	3-0.2-3	1.03	0.67	1.72	0.49	-
5	132	Double	0.8× 1.8	Timber	Solarban	Air	3-3-3	2.18	0.35	2.49	0.28	Repair
6	140	Double	0.8× 2.1	PVC	Solarban	Xenon	3-3-3	1.06	0.18	1.50	0.15	-
7	151	Double	0.5× 1.9	PVC	Solarban	Vacuum air	4-0.2-3	0.50	0.16	1.49	0.13	-
	151	Single	1.5× 1.8	Timber	Low-E	-	5.7	3.22	0.32	2.74	0.27	Repair
8	160	Double	0.9× 1.8	Timber	Solarban	Argon	4-8-4	1.21	0.37	1.73	0.30	-
9	164	Double	0.9× 1.5	Timber	Low-E	Xenon	4-3-4	1.40	0.55	1.92	0.44	-
10	169	Double	1.2× 1.2	Timber	Generic clear	Air	3-3-3	3.77	0.76	3.50	0.58	Repair
	169	Single	0.6× 1.2	Timber	Generic clear	-	3	**5.91**	**0.86**	**4.68**	**0.62**	**Replace**
	169*	Double	0.6× 1.2	Timber	Low-E	Vacuum air	2-0.2-2	1.04	0.68	1.79	0.50	-
11	171	Double	0.8× 1.2	PVC	Solarban	Krypton	3-4-5	1.20	0.24	2.26	0.19	Repair
	171	Single	0.9× 1.4	Timber	Comfort clear	-	4	**5.76**	**0.76**	**4.66**	**0.58**	**Replace**
	171*	Double	0.9× 1.4	Timber	Low-E	Vacuum air	2-0.2-3	1.04	0.68	1.73	0.52	-
12	223	Single	0.9× 1.8	Timber	Generic clear	-	5.7	**5.82**	**0.82**	**4.71**	**0.64**	**Replace**
	223*	Double	0.9× 1.8	Timber	Low-E	Vacuum air	3-0.2-3	1.03	0.67	1.67	0.53	-

*Suggested replacement.

Some of the windows of the case study 4, 5 and 10 use secondary glazing, so their U-values are better than what the software calculated. Most of the single glazing windows are in poor condition, and it is strongly suggested to replace them because improving their condition and repairing do not make a significant impact on the thermal performance. The suggested double glazing windows for single glazed windows of case studies 4, 10, 11 and 12 are presented in the Appendix I. The single glazing windows of case studies 3 and 7 have replaced and are in acceptable condition with low-E glass, but they need improvement.

The double glazing windows of case studies 1, 6, 7, 8 and 9 are in good condition, but the double glazed windows of case studies 2, 5, 10 and 11 need more enhancement, because all the existing double glazing windows of case studies have been replaced from single glazed windows so, it is not recommended to replace them again, it is better to using draught proofing, shutter, blinds and heavy curtain or in some cases using secondary glazing is the best alternative. Typically, double glazing windows do not fit to the existing windows, therefore, in most of the cases replacement is essential, it costs around £800 per m^2; typically three triple glazed windows for £1720 compared to 'A' rated double glazing for £1495 (357)**.**
Another important point is that for example in the United States, according to the 0-10 levels of energy efficiency ratio (EER) star rating, 0.5 level increasing causes growth by 1.2% in the building price. Therefore, if replacing the single glazing costs around $10,000, this causes increasing the value of the $400,000 house by 2.4%, it means that double glazing pays for itself. The double glazing not only decrease the bills, but it also increases the value of the house. It also is correct for the EU countries but in the different ratio (358).

Table 6.24. The amount of carbon emissions of case studies windows after and before improvement and annually saving cost.

				Before improvement*			After improvement to the A^+ rate**		
Case study and age		Kind of window	Windows area (m^2)	Embodied carbon ($kgCO_2$)[1]	Equivalent CO_2 ($kgCO_2$-eq)[1]	Whole glazing cost (GBP)	Carbon emissions ($kgCO_2$)[2]	Carbon usage (kg CO_2)[2]	Annual savings (GBP/year) per typical window
1	102	Double	44.9	1145.6	1214.5	7,188	560	150	123.55
2	107	Double	21.5	548.1	580.3	4,089	700	190	154.44
3	115	Single	60.8	6083.0	775.6	6,083	590	160	129.68
4	126	Double	28.9	736.1	779.4	**5,485**	450	120	99.38
		Single		368.0	389.7	2,887	1040	280	**228.30**
5	132	Double	21.9	557.5	590.3	4,154	380	100	84.63
6	140	Double	32.1	819.3	867.5	5,141	400	110	89.05
7	151	Double	71.4	1799.1	1904.9	13,462	740	200	162.50
		Single		909.9	963.4	7,136	1110	300	244.42
8	160	Double	20.6	525.8	556.8	3,093	320	90	80.18
9	164	Double	26	596	631.1	4,625	400	110	87.72
10	169	Double	13.1	334	353.8	2,490	960	260	117.95
		Single		167.1	176.9	1,311	1420	390	174.36
11	171	Double	22.5	572.8	606.5	4,268	590	160	130.00
		Single		286.4	303.2	2,246	830	230	182.64
12	223	Double	36.1	919.9	974	6,854	720	200	102.06
		Single		459.9	487	3,607	1060	290	180.88

* The results have been calculated according to the DesignBuilder program (354) according to the ISO 13790 (9).

[1]The embodied carbon refers to CO_2 produced when destroying them; also, for wastes arrangement, as well as to generate and transportation the recent house materials. Carbon dioxide equivalent is a term for explaining various greenhouse gases in a standard module; it indicates the amount of CO_2 that would have the equivalent Global warming impact.

[2]Carbon usage is a metric for calculating the carbon gas gives out on a daily basis. CO_2 emission is a so-called greenhouse gas causing global warming, a gas that contributes to the greenhouse result by absorbing infrared radiation. Other greenhouse gases that might be giving out as a result of the activities are for example ozone and methane.

**The results have been calculated according to the myglazing.com website (359). The results were obtained according to the kinds of the building (detached, semi-detached, terraced and flat), the kinds of frames and glazing system, the thickness of gaps, the size of the windows and the heating fuel using.

According to the table, the embodied carbon of double glazing is high, so replacing the double glazing is not suggested and repairing the double glazing takes priority especially when considering the economic aspects. Regards to the single glazing the embodied carbon is less than double glazing, on the other hand, the carbon emissions and carbon usage of single glazing are too high. Therefore, replacing the single glazing in all cases is essential. In addition, if the economic aspects will be considered in regards to the table, by replacing the single glazing, it is possible to save on an average around £200 annually per windows. Then if the indicative cost of the whole glazing of each house will be considered, it shows that this price will be backed after around three years. It is correct for the case studies 4, 10, 11, and 12, where replacement is suggested. For example, in case study 4 that exist ten windows, after replacement the single glazing it is possible to save £2,283 annually, then after around two and a half years, the whole double glazing cost £5,485 will be backed. It is not clear that the estimated prices by the DesignBuilder program is included the wages of installation or not, but if the wages of labour will be added the payback year will not be more than three years.

In case study 10, the replacement saving cost is around £1050 annually, the double glazing cost in this house is £2.490, so the payback will not be more than three years. In case study 11, there are eight standard windows and two small windows above the doors; if we consider nine windows, the replacement saving cost is around £1.650, the double glazing cost for this house is £4268, again the payback will be around three years. In case study 12, there are five windows and one sunroom place at the back of the house with three wall windows that as a whole count as thirteen regular windows, the replacement saving cost is around £2,350, the double glazing costs around £6,850. Therefore, the payback will be around three years. The following table demonstrates the recommended solution that has been offered by assessors accredited by Elmhurst, an Approved Organization Appointed by Scottish Ministers.

Table 6.25. Recommended solutions for the case studies. Source: Assessors accredited by Elmhurst.

Case study	**Recommended measures**	**Indicative cost (£)**	**Typical saving per year (£/year)**	**Rating after improvement**		**Green deal***
				Energy	Environment	
3	Replace single glazed windows with low-E double glazed windows	£3.300 - £6.000	£264	C 78	C 71	
4	Secondary glazing to single glazed windows	£1.000 - £1.5000	£137	C 71	D 57	
7	Replace single glazed windows with low-E double glazed windows	£3.300 - £6.000	£205	F 31	E 47	
10	Replace single glazed windows with low-E double glazed windows	£3.300 - £6.000	£55	C 75	C 73	
11	Replace single glazed windows with low-E double glazed windows	£3.300 - £6.000	£104	C 74	C 70	

The information has been produced under the Energy Performance of Buildings (Scotland) Regulations 2008 from data lodged to the Scottish EPC register (110).

* Measures which have a green deal tick are likely to be eligible for Green Deal finance plans based on indicative costs. The subsidy also may be available for some measures, such as solid wall insulation. Additional support may also be available for certain households in receipt of means-tested benefits. Measures which have an orange tick may need additional finance.

The table demonstrates that adding secondary glazing has a significant impact on energy and environment improvement, and it incorporates the green deal. Also, it needs less initial cost rather than a replacement.

Regards to the possibility of extrapolating this results to other buildings; in this case for each different sample, the kinds of building, the locations and the cost are very important. As shown in Table 6.24various places with different weather conditions have different required U-values and SHGC, so the weather conditions have a significant impact on the U-value. The chapter, first worked on the structure of the windows separately; then the windows have analysed with the related software; finally, the windows of the case study have been assessed. As a whole, the chapter worked on the window elements as theoretically in the first part; as thermally and structurally in the second part also in some cases economically; and as a case study in the third part. Therefore, it is possible to extrapolate these outcomes to other buildings of the same type and same geographical area.

Table 6.26. The U-value of windows and doors awarded the Energy Star Program certification in the US (273).

Climate Zone	U-value (W/m^2K)	Equivalent European U-value*(W/m^2K)	SHGC
Mostly cooling	0.65	3.69	0.40
Heating and cooling	0.40	2.27	0.40
Cooling and heating	0.40	2.27	0.55
Mostly heating	0.35	1.99	Any

* Multiple American U-value by 5.68 to give European U-value in $W/m^2{\cdot}K$.

6.5 Conclusions

The window is the component with a more unfavourable thermal performance in comparison to the other parts of the house. The windows are responsible for 15-22% of the heat lost in the houses. Also, they have a tremendous and long course time influence in the house, with a lifespan between 20 and more than 50 years.

The solution for the single glazed window is the creation of a double glazed window with a gap among the two glasses thinner than the typical double glazed window. The heat transfer via the frames significantly decreased by exchanging the single glazed with slim profile double glazed. By applying draught proofing and secondary glazing, the heat lost decreased significantly. Draught proofing is a prevalence method to prevent the effect of the winds in the historic windows. The most heat lost reduction can be obtained by incorporating several elements such as curtains, shutters, and blinds applying more insulation layers.

The vacuum glazing is the most impressive alternative with the best thermal performance and slimmer profile. Selecting the kind of glazing system is very important because it has a significant effect on the U-values, then choosing the appropriate materials for frame and divider is essential too. Regards to the glazing system, the thickness and kinds of the gap have more impact on its U-values rather than the thickness and kinds of glasses.

CHAPTER 7. CONCLUSIONS

In this chapter, the main conclusions drawn from the research activities are summarised. Then, the main scientific contributions of this PhD Thesis are outlined, and finally, further work and future research perspectives are briefly presented.

7.1 Main outcomes

The main outcomes and conclusions disaggregated by chapters are presented below.

Chapter two

In the UK, building standards and regulations set the levels of thermal insulation required during the construction of new houses or the refurbishment of old ones. These are expressed as a U-value that should be obtained. The required U-value depends on the type of elements (wall, floor or roof), the type of building and its location.

U-value calculations are the basis for house energy assessment and house energy legislation and policy. To obtain a Near Zero Energy Building Renovation, renewable energies must be implemented. The selected solution will depend on the house characteristics and the climatic zone. There is a direct relation between the U-values of elements and the age of a property and its energy efficiency. The older the homes, the less the improvement/change on U-values. The thermal efficiency of the house elements is governed by the UK Building Regulations. It shows that the effect of national regulations has a significant influence with regard to zero carbon homes, as the U-values of elements of the houses built after 1985 were added with a higher slope.

In newer buildings, the trend of U-values increases with wall thickness; but in traditional structures, the trend of U-values decreases with wall thickness. The insulation layer has more effects on U-value rather than thickness in newer houses; with regard to traditional houses, it shows that the kind of material has more influence in thermal performance than in depth. The thermal performance of non-traditional timber walls is better than that of brick/block cavity walls, but the difference is minimal. For the buildings with the age of 30 to 79 years, the thermal performance of brick/block cavity walls is better than that of solid stone walls or the buildings of the age of 120 to 200 years, the thermal performance of solid stone walls is better than that of brick/block cavity walls. It just illustrates the effect of the kinds of materials and the thickness.

The maximum potential growth in energy efficiency is about the houses built between 1540 and 1814. The same issues were confirmed with regard to the Environment Impact rating. Therefore, the priority for renovation process accrues to the houses with age between 80 and 99 years, a way onward, according to energy cost and average saving cost, the traditional houses take precedence over others.

It is challenging to meet level 6 of the Code for Sustainable Homes just by renovating houses with adding insulation layers to the components; it is necessary to use new sustainable technologies. In addition, traditional houses require more investment, almost twice as much as newer homes. Nevertheless, there are still barriers including information and upfront costs which many of the developing policies are designed to address. In the longer term, it is essential to look at new, emerging technologies and a wider range of measures in order to meet the requirements of the 2050 timetable.

Massive dissemination and awareness, as well as social management, are needed to foster energy efficient rehabilitation. During the renovation process, buildings constructed between 1866 and 1915 should be boosted due to their huge stock, potential, need for restoration and lack of energy efficiency measures. It is also evident that both modelling and monitoring in traditional houses still require further enhancement to use as standardised tools for appraisement.

<u>Chapter three</u>

From the analysis of the energy performance of new houses in Spain and the UK, it can be concluded that timber construction is the best alternative for places with cold weather, the brick construction is the best alternative for places with hot weather, and both these kinds of construction are the better options for places with more moderate weather rather than metal construction. In addition, uninstalled pitched roofs are not accepted for the houses that are located in hot weather.

These suggested materials could be applied to other EU countries as the lowest U-values have been considered. But it should be checked according to the building regulations and standards of each country. Maybe in some countries such as a Spain, other parameters are more critical, and the required U-values are used to meet the other parameters. The required U–values in the UK are lower than in Spain, because of the colder weather and other issues. Generally, the required U–values in colder countries like Scandinavia countries are lower than in warmer countries like Croatia, Bosnia and some cities in Spain such as a Seville. As a whole, it is possible to consider these suggested materials as a preliminary approach for beginning the analysis.

At present, the U-values set by the UK Government are more restricted than before as the Government has set targets for diminishing carbon emission 80% by 2050. However, reaching the required U–values is possible just for new modern houses, and it is very difficult for existing houses and especially for the traditional houses as discussed previously, because their components need around 20-30 cm of insulation layer for reaching level 6 of zero carbon house. Also, it is necessary to consider that adding insulation layer is not possible for every kind of house. In addition, the costs of insulation materials and installation are very expensive. Therefore, using renewable technologies or a new generation of smart devices is essential in traditional houses.

The method of construction of brick/block, metal and timber frame is substantially different in how the elements are installing and in the external component. However, the construction of the roof and foundation are not different. Now in the EU, the trend of construction move toward green and energy efficient houses. Timber has the greenest features and knows as an eco-friendly material. However, it also depends on the climate condition. The most durable material is masonry material that needs lower maintenance rather than timber and metal materials. The most recycled material is metal, so, by applying the metal frame, some money can be saved.

Reaching the lower U-values by using the existed materials is very difficult. The only way is increasing the thickness of elements, which reduces the useful surface for the building users. If the national governments set low U-values, a new generation of technology and materials especially insulation material will be needed. It is possible to reach the lower U-values with new construction generation such as intelligent and prefabricated buildings.

Chapter four

The knowledge of energy performance of traditional houses has not yet been improved in an appropriate way. Also, there are not enough experimental data related to the traditional constructive solutions. Wall efficiency depends on the thermal conductivity of each layer constituting the wall which provides data about how heat flows through the components, and the heat capacity of the layers, that is related to physical heat storage. Overall performance depends on thickness, material type, and mass density of each layer.

The in-situ measurement of U-values is a useful tool which can aid in the assessment of the thermal performance of traditional house materials, particularly where calculation methods may suffer from deficiencies outcoming from the lack of knowledge of the modern buildups, and the thermal properties of conventional materials. As shown in the study, calculated values are usually higher than the in-situ measured ones; because U-value calculation tools only provide limited baseline data for some traditional buildings materials (e.g., DesignBuilder database presents just two options for stone types: sandstone and granite). Although the modelling of mortar joints in masonry is included in such tools, the modelling of a solid stone wall (i.e., with a centre packed with small stones and mortar) is not considered, and it has to be modelled as a multilayer build-up.

The in-situ measurements permit to better calibrate the thermal performance of traditional walls. The information constitutes a stable base for the correct diagnosis of energy performance in traditional houses, especially for the evaluation of thermal performance through the opaque elements. In addition, the conditions of operative measurement and the characteristics of the elements investigated strongly can impact on the accuracy of the in-situ U-values.

The results of the measurements performed in the twelve cases studies are generally lower than the comparable calculated values of the thermal transmittance. U-value calculations for the brick cavity wall construction with better-defined build-ups are closer to the in-situ measurement results. This acceptable achievement is related to the material with insulation layers; since the insulating elements seem to have thermal properties similar to those declared by the manufacturers. Moreover, it is essential to enhance the new energy simulation tools dedicated to traditional houses adding specific databases related to the thermophysical properties of house elements and more appropriate information referred to traditional construction techniques.

Chapter five

Energy-efficient systems and enhanced thermal performance maintain comfort, decrease carbon dioxide emissions and save on running costs. However, any alterations or changes to the house services in a traditional house require careful planning to ensure that the proposed work will be productive and beneficial. As a whole, the kinds and the ages of the houses have a little influence on the potential emissions of residences. For the houses of the same age, further general factors like materials, house location, the provision of adequate ventilation, furnishings and finishes, the state of repair and how a house is operated have more impact.

Several studies determined that there is a significant condensation of humidity in historic houses. In addition, damp exists in new houses because of inappropriate conditions of components also it is possible to happen anywhere because of improper preserving and cleaning. Condensation exists somewhere with no uniformity of temperatures in spaces. Maybe specific emissions condense by the time, for instance, in the dust. Nevertheless, this situation is not restricted to historic houses. Accurate attention is required to be allocated to situations of historic houses, especially ones that used lead paint materials, which are very hazardous.

During the 19th century, the thought was that the houses, should enhance a healthy life and not just avoid the illness; health issues had priority to another subject like energy efficiency. Nowadays the condition is different and takes more attention to carbon pollution and indoor environmental quality standards. There is a lack of information on health issues and indoor air quality subject; the disadvantage of packing construction that was applied to enhance the energy saving has not been evaluated appropriately. However, few studies show that renovation has adverse results which contain decreased lighting, overheating and indoor air quality.

It is essential to make an equivalency between CO_2 emissions reduction and residences healthy. A damp and cold building put health at risk. Besides the rates of ventilation determined by new standards are not adequate to prevent disease. A notable number of residents in the UK tolerate breathing diseases, depression, and allergies. The recent studies demonstrate that radiant heat is healthier than convective one because it supplies comfortable situations at low indoor temperatures with low ventilate heat loss. For the renovation of the traditional house, the best option is radiant heating, which is efficient and guarantees the health of residences. Moreover, the rates of air change in radiant heating are higher than those determined now, which improves the health of residences.

One of the methods to enhance indoor air quality would be to prevent determining elements which give out dangerous chemicals and avoid the transferring of humidity. Experience from different European countries offers a labelling method which evaluates the elements of the house regards to the influence on the health that decrease illness link to the house. The types and kinds of lights and illuminations rates supplied are essential to healthy living. Daylighting is healthier than artificial ones; direct sunlight can be useful for health. Although the new standards for lighting in the UK for houses consider some advantages of sunlight and daylight, they are not compulsive. Regards to enhance the insulation sheets and to reduce the risk of overheating; there are fewer spaces for solar usage; a lot of old houses were well planned for health according to the natural lighting, heating and ventilation. The trouble is renovating them to the new standards of energy efficiency which enhances and preserve the health issues.

Supplying sufficient moisture and ventilation arrangement is a complicated subject and needs a knowledgeable answer. Mainly it is essential for the elements applied in historical houses not to limit the humidity equivalence in the house, as it has a negative effect on the housing element and causes an indoor environment unhealthy. While decreasing the ventilation rate and infiltration can involve lower energy bills; an excessive decrease will damage the capability of a house to supply sufficient fresh air. More investigation on this subject in Scotland helps to determine the values and required skills to create the best methods. The Scottish Government does not claim that all the recommendation are suitable for traditional houses that were constructed for radiant warming and natural ventilation. Also, if the renovation pursues the new regulation of ventilation and airtightness programs, it may result in proving damaging to residences and the houses. The finding of the chapter shows that the renovation of traditional houses needs a sympathetic approach. Also, refurbishment should enhance the inherent environmental performance features ideally.

All the case studies were analysed, and several improvement recommendations were suggested. The wall insulations were suggested for all case studies. The priority is enhancing the house fabric, then replace the boiler and glazing units. The most cost-effective recommendation is to install draught proofing, with an indicative cost of £80-120, and a typical annual saving of £200-400. Using renewable technologies such as solar photovoltaic panels and solar water heating are essential for all the houses to reach zero carbon houses level.

Chapter six

The windows are responsible for 15-22% of the heat lost in the houses, even though it will differ significantly from house to house, based on the number, orientation and size of openings of the exterior wall zone. In plenty of traditional houses, windows are minor than the wall spaces, in such a manner the cost of double glazed windows rarely will be recovered via energy savings considering the current lifespan of the insulated glazing units.

Enhancing the thermal performance of house elements is an essential aspect to make an energy efficient house. The window is the housing element with a more unfavourable thermal performance in comparison to the other parts. Generally, the replacement of single glazed windows placed in traditional houses is thought out to be unsuitable for preservation reasons. However, there are several methods to enhance the thermal performance of single glazing windows such as exchange them with slim profile double glazed ones, justified secondary glazed, applying shutters and curtain and adding draught proofing. The old window thermal performance can be enhanced via draught-proofing or significantly secondary glazed. More advantages can be simply obtained from shutters, closing curtains and blinds, methods which can provide similar energy savings than double glazed.

The subsequent solution is the creation of a double glazed window with a gap among the two glasses thinner than the typical double glazed window. Slim profile double glazed windows have a lower thermal performance than the common ones. However, their thermal performance is considerably better than the single glazed. In addition, this kind of windows can be suitable in almost all of the current houses because of its thickness that let the existing windows to be maintained and preserved.

The vacuum glazing is the most impressive alternative with the best thermal performance and slimmer profile. The studies demonstrate that single glazed with secondary glazing is approximately as efficient as vacuum glazed windows. The performance of the glazing depends on the gas type such as Xenon, Krypton and Argon and the Low-E emissivity. The best impressive alternative is the Pilkington Legacy vacuum glazing with a narrow width that has well thermal performance. The heat transfer via the frames significantly decreased by exchanging the single glazed with slim profile double glazed.

Because of their energy saving potential, it is imperative to choose the appropriate windows, because they have a great and long course time influence in the house, with a lifespan between 20 and more than 50 years. By applying draught proofing and secondary glazing, the heat lost decreased significantly. However, it is essential to consider enough ventilation and the risk of condensation. For this reason, it is better to close the window tightly in cool weather because the condensation can cause decay and mould.

Draught proofing is a prevalence method to prevent the effect of the winds in the historic windows. The most heat lost reduction can be obtained by incorporating several elements such as curtains, shutters, and blinds applying more insulation layers. The most effective coverage for windows frames was rigid beadboard insulation, and the most efficient material was the movable beadboard insulation. The shutter is the most recommended traditional alternative for enhancement; more improvement can be achieved via insulated shutters. Moreover, enhanced designs of the blind have a great effect on the reduction of the heat lost. The best solutions are achieved by combining several options, such as secondary glazing or shutters along with blind or curtains. It was a traditional method that let fitting the house conditions according to the weather. Also, the new roller blind with Low-E foil is an efficient solution. Secondary glazing has a similar effect as blinds and shutter, but secondary glazing is efficient throughout the day.

Moreover, the structure of the windows and the influence of each parameter on the whole U-values of the window were also studied. Selecting the kind of glazing system is very important because it has a significant effect on the U-values, then choosing the appropriate materials for frame and divider is important too. The rest of the parameters have a lower effect on the U-values, but it is essential to consider all of them especially when the houses have many windows. Regards to the glazing system, the thickness and kinds of the gap have more impact on its U-values rather than the thickness and kinds of glasses. Moreover, the colour of the glasses does not influence the U-value. As a whole, it is clear that the kind of glass and gas have a significant effect on the U-values rather than their thickness and other parameters.

From the assessment study of the windows elements in several case studies, it can be concluded that it is essential to replace the single glazing windows as their poor thermal condition, dominant carbon emissions and its major cost savings in the case of replacement. Also, as an economic aspect, the payback of this replacement is estimated in three years. In the case of double glazing, it is suggested to repair them because of their significant embodied carbon and higher economic cost of their replacement. According to the LEED requirements for new construction (LEED NC 2.2 Credit EQ 8.1), the daylighting of all the case studies is in poor condition, although most of them have big windows and around ten windows. A possible solution could be to use a clear glass without dark colour, as the glass colour does not influence the U-value, but it is an important factor for daylighting. The condition of daylighting in new houses is very crucial because of the reduction in size and number of windows in these houses. In addition, it is possible to extrapolate the results of this study for the buildings of the same kind and same geographical area, because all the windows elements were studied as individual elements from the structural, thermal, and in some cases from the economical point of view.

7.2 Scientific contributions

The summary of the main contributions of this PhD Thesis to the state-of-the-art is presented below.

- A novel study of the relationship between the age of the house and the U-values of elements and its energy efficiency. There is no scientific paper about the exact relation of the house age and component U-values calculated by energy software. The results of this study are outcomes from a total of one hundred Scottish houses used as case studies located in one climate with the least variable conditions, so they are more valuable and reliable.
- A comparative analysis of energy performance based on two different energy simulation tools considering three kinds of construction in a typical new house located in six different cities (Edinburgh, Leeds, Pembrokeshire, Ávila, Almería and Zaragoza) of two countries (Spain and UK) with different kinds of weather. The main contribution comprises the suggestion of appropriate materials for each group for moving toward energy efficient houses. For cities with the same weather, it is possible to use the results of this chapter and analysing the economic parameters to make a decision.
- An in-situ measurement study and subsequent comparison with U-values calculated by a software tool in a total of twelve Scottish houses used as case studies. The in-situ measurement of U-values has allowed the assessment of the actual thermal performance of traditional house materials, particularly where calculation methods may suffer from deficiencies out coming from the lack of knowledge of the modern buildups, and the thermal properties of conventional materials. The study constitutes a stable base for the correct diagnosis of energy performance in traditional houses, especially for the evaluation of thermal performance through the opaque elements.
- A complete state-of.-the-art of different issues affecting the indoor environmental quality and users' health in buildings, such as the refurbishment works, the indoor air quality, the house services, etc. The study illustrates how it is possible to put sustainable

development into practice when upgrading house services in the traditional house stock. A holistic and interdisciplinary approach based on an appreciation and understanding of the highly individual nature of many older houses is exposed, reflecting the unique manner in which they have been developed over time; the materials and methods of construction; the actual performance; and the formal recognition and protection offered by legislation.

- Analysis of some subject regards to the healthy building, such as the contaminations materials, ventilation, thermal mass, heating, orientation and lighting in a total of twelve Scottish houses used as case studies. The study addressed some of the fundamental concerns and problems in regards to the healthy subjects. Some solutions have been proposed for improving indoor air quality, house service, repairing and replacement, and reducing the movement of moisture.
- A state-of-the-art of some parameters (such as the kind of windows, repair or replacement, glass quality, frames and kind of them, windows painting) regards to the energy efficiency of the windows. In addition, other factors like heat transfer, ventilation, condensation, noise insulation and ultraviolet protection were analysed. Moreover, future window technologies (e.g. zero energy windows, integrate surface for arranging, dynamic glazing, phase change materials, semi-transmitted solar cell and highly insulating windows such as a vacuum glazing) were shortly discussed.
- Assessment of the U-value and Solar Heat Gain Coefficient (SHGC) and the economic cost of 131 windows, 20 glazing systems and 12 case studies by using specific software. The results of this study can be used as underlying data for analysing, but it is essential to consider the climate and economic aspects in each area.
- Analysis of the influence of the windows on the whole house energy efficiency considering a total of twelve Scottish houses used as case studies. According to the results, some solutions were suggested for improving the case studies performance, and it is possible to consider them for another case studies with the same climate conditions.

7.3 Further work and perspectives

Since energy efficiency in residential buildings is a multidisciplinary, broad and complex subject, many further activities can be proposed to continue the research started with this PhD Thesis. Further research activities and perspectives are presented below.

- Analyse the possibility of adding insulation layers and using renewable technologies in traditional houses in different EU countries from both the technical and the economic point of view.
- Use another energy software programs for rechecking the thermal performance of houses. In addition, doing in-situ U-value measurement following the methodology presented in this PhD Thesis for a higher number of valuable houses would reduce the uncertainty.
- Analyse in detail the carbon footprint and economic issues of different building materials for new houses located in representative cities of the EU-28 countries.

Besides, since a simple 100m^2 one-floor house has been considered as a case study, further work should be done with different kind of houses (detached, semi-detached houses, blocks of flats, etc.), different geometry and shape factors, different size, etc.

- Comparative studies of U-values of house elements with different energy software programs and analysis of the differences with respect to in-situ U-values measures.
- Study on the carbon footprint of the new technologies used for healthy houses.
- Develop a survey about the occupant's satisfaction regards the indoor air quality and the conditions of the house. This would provide very valuable information, which could help designers at the design stage.
- Design and develop a monitoring program of indoor air quality issues in different building types and climates. This would allow studies on the negative impact of modern materials or technologies that are used for the traditional houses. Also, the influence of traditional materials on indoor air quality and health could be assessed. In the case of refurbishment, pre- and post-intervention monitoring work would be very useful.
- Measure the influence of some subjects like draught-proofing, secondary glazing, shutters, blinds, etc. by means of in-situ U-value measures in different window types and compare with the U-values calculated by the software.
- Design and monitoring of pilot buildings using new technologies for energy efficient windows. This would allow obtaining feedback from users, which it is essential because users make decisions to use the new technologies and invest, so they have to trust the results of new technologies; therefore, their opinions have a significant impact on the designing stage.
- Comparative analysis of using different software tools to assess the energy performance of windows, considering more materials for the glass, frame and dividers.

CAPÍTULO 7. CONCLUSIONES

En este capítulo, se resumen las principales conclusiones extraídas de las actividades de investigación. Luego, se resumen las principales contribuciones científicas de esta tesis doctoral y, finalmente, se presentan brevemente los trabajos y las perspectivas de investigación futuras.

7.1 Principales resultados

A continuación se presentan los principales resultados y conclusiones desglosados por capítulos.

Capítulo dos

Las normas y regulaciones de construcción en el Reino Unido, establecen los niveles de aislamiento térmico requerido durante la construcción de nuevas viviendas o la renovación de viviendas existentes. La exigencia se expresa principalmente en un valor de U que debe obtenerse. El valor de U requerido depende del tipo de elemento (fachada, suelo o cubierta), el tipo de edificio y su ubicación.

Los cálculos del valor de U son la base de la evaluación energética de la vivienda, la legislación y la política energética del sector residencial. No obstante, para conseguir que la rehabilitación de un edificio permita alcanzar un nivel de energía casi cero, es necesaria la integración de energías renovables. La solución seleccionada dependerá de las características de la vivienda y de la zona climática. Existe una correlación directa entre los valores de U de los elementos, la antigüedad de una propiedad y su eficiencia energética. Conforme más antiguas son las casas, se producen menores cambios en los valores de U. La eficiencia térmica de los elementos de las viviendas se rige por las normas de construcción del Reino Unido. Su efecto tiene una influencia significativa en la consecución de los hogares con cero emisiones de carbono. Asimismo se observa que los valores de U de los elementos de las casas construidas después de 1985 muestran un decrecimiento con una mayor pendiente.

En los edificios más nuevos, la tendencia de los valores de U es aumentar con el espesor del muro. Sin embargo, en las viviendas tradicionales, la tendencia de los valores de U es disminuir con el espesor del muro. La capa de aislamiento tiene más efectos en el valor de U que el espesor del muro, y en las casas tradicionales, se observa que el tipo de material tiene más influencia en el comportamiento térmico que en el espesor. El comportamiento térmico de los muros de madera no tradicionales es mejor que el de los muros realizados con fábrica de ladrillo/bloque, pero la diferencia es poco significativa. Para los edificios con una antigüedad de entre 30 y 79 años, el comportamiento térmico de los muros con fábrica de ladrillo/bloque es mejor que el de los muros de piedra sólida, mientras que en edificios con una antigüedad de 120 a 200 años, el comportamiento térmico de los muros de piedra sólida es mejor que el de los muros de ladrillo/bloque de cavidades. Todo esto demuestra el efecto de los tipos de materiales y su espesor en el valor de U.

El máximo potencial de crecimiento en la eficiencia energética se encuentra en las viviendas construidas entre 1540 y 1814. Esto mismo es aplicable también a la calificación de impacto ambiental de las viviendas. La prioridad en el proceso de rehabilitación energética correspondería a las viviendas con una antigüedad entre 80 y 99 años, si se consideran los costes económicos asociados a la energía y los ahorros económicos obtenidos. De este modo, las viviendas tradicionales tendrían prioridad sobre el resto de viviendas.
Es muy complicado cumplir con el nivel 6 del Código para Hogares Sostenibles simplemente renovando las viviendas mediante la agregación de capas de aislamiento a sus componentes, por lo que es necesario utilizar nuevas tecnologías renovables. Además, se observa que las viviendas tradicionales requieren más inversión, casi el doble que las viviendas más nuevas. Sin embargo, todavía existen barreras, como la falta de información y los costes iniciales, que muchas de las políticas en desarrollo están abordando. A más largo plazo, es esencial considerar las nuevas tecnologías emergentes y una gama más amplia de medidas para cumplir con los requisitos en el horizonte de 2050.
La difusión y la concienciación generalizada, así como la gestión social, son necesarias para fomentar una rehabilitación energética eficiente. Debería impulsarse el proceso de rehabilitación de los edificios construidos entre 1866 y 1915, debido a su enorme stock, potencial, necesidad de renovación y la falta de implementación de medidas de eficiencia energética. También es evidente que tanto el modelado como la monitorización de viviendas tradicionales aún requieren de mejoras metodológicas adicionales para su uso como herramientas estandarizadas de evaluación.

<u>Capítulo tres</u>

Del análisis del comportamiento energético de las viviendas nuevas en España y el Reino Unido, se puede concluir que la construcción de madera es la mejor alternativa para lugares con clima frío, la construcción de ladrillo es la mejor opción para los lugares con clima cálido, y ambos tipos de construcción son mejores opciones para lugares con clima más moderado en detrimento de la construcción con metal. Además, las cubiertas inclinadas no son adecuadas para las viviendas que se encuentran en climas cálidos.
Estas recomendaciones podrían extrapolarse a otros países de la UE ya que se han considerado valores muy bajos de U. No obstante, esto debería verificarse de acuerdo con las normas y estándares de construcción de cada país. En algunos países como España, hay otros parámetros críticos, si bien los valores de U requeridos deben considerarse para poder cumplir con los otros parámetros. Los valores de U requeridos en el Reino Unido son más bajos que en España, debido al clima más frío. En general, los valores de U requeridos en los países más fríos, como los países escandinavos, son más bajos que en los países más cálidos como Croacia, Bosnia y algunas ciudades de España, como Sevilla. En general, es posible considerar los materiales recomendados como una aproximación preliminar para comenzar el análisis.
Actualmente los valores de U establecidos por el gobierno del Reino Unido son más estrictos que en el pasado, ya que el gobierno ha establecido objetivos para disminuir las emisiones de carbono en un 80% para 2050. Sin embargo, alcanzar los valores de U requeridos es viable solo para las viviendas nuevas, siendo muy difícil para las viviendas existentes y especialmente para las viviendas tradicionales, como se mencionó anteriormente, ya que sus componentes

necesitan alrededor de 20-30 cm de capa de aislamiento térmico para alcanzar el nivel 6 de los edificios de carbono cero. Además, es necesario tener en cuenta que la agregación de una capa de aislamiento no es posible en todos los tipos de vivienda. Adicionalmente, los costes de los materiales aislantes y su instalación son muy elevados. Por lo tanto, el uso de tecnologías renovables y/o una nueva generación de dispositivos inteligentes son esenciales en las viviendas tradicionales.

Los métodos de construcción de muros de ladrillo/bloque, metal y madera son sustancialmente diferentes en cómo se instalan los elementos y en el componente exterior. Sin embargo, la construcción de la cubierta y del forjado no son diferentes. La tendencia actual de la construcción en la UE se orienta hacia las casas ecológicas y energéticamente eficientes. La madera tiene las características más verdes y es reconocida como un material ecológico. Sin embargo, su uso depende de las condiciones climáticas. La solución más duradera es la compuesta por fábricas de ladrillo/bloque, que necesita un menor mantenimiento en comparación con la madera y los materiales metálicos. El material más reciclado es el metal, por lo que al instalar marcos de metal se pueden obtener ahorros económicos asociados al uso de menos materia prima.

Alcanzar los valores más bajos de U exigidos por la normativa utilizando los materiales existentes resulta muy difícil. La única forma es aumentar el espesor de los elementos, lo que reduce la superficie útil para los usuarios del edificio. Si los gobiernos nacionales establecen valores de U más bajos, se necesitará una nueva generación de materiales, especialmente de materiales de aislamiento térmico. También es posible alcanzar los valores de U más bajos con nuevos tipos de construcciones, como los edificios inteligentes y los edificios prefabricados.

Capítulo cuatro

El conocimiento del comportamiento energético de las casas tradicionales es aún escaso. Además, no hay suficientes datos experimentales relacionados con el uso de soluciones constructivas tradicionales. La eficiencia de un muro depende de la conductividad térmica de cada capa que lo constituye, que proporciona datos sobre cómo fluye el calor a través de sus componentes, además de la capacidad térmica de las capas, que está relacionada con el almacenamiento físico del calor. El comportamiento general depende de su espesor, el tipo de material y la densidad de cada capa.

La medición in-situ de los valores de U es una herramienta útil que puede ayudar en la evaluación del comportamiento térmico de los materiales tradicionales de la vivienda, especialmente cuando los métodos de cálculo pueden presentar deficiencias derivadas de la falta de conocimiento de las soluciones constructivas modernas y de las propiedades térmicas de los materiales convencionales. Como se muestra en el estudio, los valores calculados de U suelen ser más altos que los medidos in-situ; porque las herramientas de cálculo del valor de U solo proporcionan datos de referencia limitados para algunos materiales de edificios tradicionales (por ejemplo, la base de datos de materiales del software DesignBuilder incluye solo dos opciones para los tipos de piedra: arenisca y granito). Aunque el modelado de las capas de mortero usadas en mampostería está incluido en tales herramientas, el modelado de un muro de piedra sólida (es decir, constituido por piedras pequeñas y mortero) no se considera, y tiene que ser modelado como una agrupación multicapa.

Las mediciones in-situ permiten conocer mejor el comportamiento térmico de las paredes tradicionales. La información obtenida constituye una base para el correcto diagnóstico del comportamiento energético en las casas tradicionales, especialmente para la evaluación del comportamiento térmico de los elementos opacos. Conviene destacar que las condiciones operativas de medición y las propias características de los elementos investigados pueden tener un gran impacto en la precisión de los valores medidos de U.

Excepto en un caso de estudio, los resultados de las mediciones de la transmitancia térmica realizadas en los doce casos son generalmente más bajos que los correspondientes valores calculados. Los cálculos de los valores de U para paredes construidas a base de ladrillo, con estructuras mejor definidas, están más cerca de los resultados de las mediciones in-situ. Este hecho se observa en soluciones que incluyen capas de aislamiento; ya que los elementos aislantes parecen tener propiedades térmicas similares a las declaradas por los fabricantes. Además, resulta esencial mejorar las nuevas herramientas de simulación energética que se usen en viviendas tradicionales, agregando bases de datos específicas relacionadas con las propiedades termo-físicas de los elementos de la vivienda e información más apropiada referente a las técnicas tradicionales de construcción.

Capítulo cinco

Las instalaciones energéticamente eficientes y la mejora del comportamiento térmico de las viviendas permiten mantener el confort, disminuir las emisiones de dióxido de carbono y ahorrar en costes de operación. Sin embargo, cualquier alteración o modificación en una casa tradicional requiere una planificación cuidadosa para garantizar que el trabajo propuesto sea productivo y beneficioso. En general, la tipología y la antigüedad de estas casas tienen poca influencia en sus emisiones potenciales. Para las casas de la misma antigüedad, existen otros parámetros generales adicionales que tienen más impacto, como por ejemplo, los materiales, la ubicación de la casa, la adecuación del nivel de ventilación, el mobiliario y los acabados, el grado de deterioro y la forma en que se usa la casa.

Varios estudios han determinado que existe una significativa condensación de humedad en las casas históricas. Además, la humedad existe también en las casas nuevas debido a las condiciones inadecuadas de sus componentes, y también puede producirse en cualquier lugar como consecuencia de una conservación y una limpieza inadecuadas. Generalmente la condensación se produce en lugares donde no haya una uniformidad de temperaturas. Algunas emisiones específicas contaminantes interiores de la vivienda se condensan en el momento, por ejemplo, en el polvo. A pesar de que esta situación no se limita a casas históricas, se debe prestar especial atención a las casas históricas que utilizan materiales de pintura con plomo, ya que son muy peligrosos.

Durante el siglo 19 se pensó que las viviendas deberían favorecer una vida saludable, y no solo evitar las enfermedades. Las cuestiones relacionadas con la salud tenían prioridad sobre la eficiencia energética. Hoy en día, la situación es diferente y se requiere más atención sobre las emisiones de carbono y los estándares de calidad ambiental en interiores. Existe una falta de información sobre temas relacionados con la salud y la calidad del aire interior. Las desventajas de las técnicas constructivas aplicadas para incrementar el ahorro de energía no se han evaluado adecuadamente. Sin embargo, unos pocos estudios demuestran que la renovación puede tener

resultados adversos que conlleven una disminución de la iluminación, el sobrecalentamiento y el deterioro de la calidad del aire interior.
Es esencial hacer un balance entre la reducción de emisiones de CO_2 y la consecución de viviendas saludables. Un edificio húmedo y frío pone en riesgo la salud. Además las tasas de ventilación establecidas por los nuevos estándares no son adecuadas para prevenir las enfermedades. Un número notable de residentes en el Reino Unido experimenta enfermedades respiratorias, depresión y alergias. Estudios recientes demuestran que el calor radiante es más saludable que el convectivo, ya que permite alcanzar una situación de confort térmico a bajas temperaturas interiores con un bajo nivel de pérdidas de calor por ventilación. Por tanto, la mejor opción para la renovación de las viviendas tradicionales es la calefacción radiante, que es eficiente y garantiza la salud de los ocupantes. Además, las ratios de renovación del aire en la calefacción radiante suelen ser más altas, lo que mejora las condiciones de salud de las viviendas.
Una de las soluciones para mejorar la calidad del aire interior sería no utilizar elementos que produzcan compuestos químicos peligrosos y evitar la transferencia de humedad. La experiencia de diferentes países europeos ofrece un método de etiquetado que evalúa los elementos de la vivienda en relación con su influencia sobre la salud y la disminución de las enfermedades. Los tipos de lámparas e iluminación existentes son esenciales para conseguir una vivienda saludable. La luz del día es más saludable que la luz artificial y la luz solar directa puede ser beneficiosa para la salud. Aunque, los nuevos estándares de iluminación en el Reino Unido para las viviendas consideran algunas ventajas de la luz solar y la luz del día, éstos no son obligatorios. Debido a la mejora en los aislamientos y a la reducción del riesgo de sobrecalentamiento, quedan menos espacios para el aprovechamiento solar. Muchas casas antiguas se diseñaron adecuadamente para garantizar la salud de los ocupantes, teniendo en cuenta aspectos como la iluminación natural, la calefacción y la ventilación. El problema surge al renovarlas a los nuevos estándares de eficiencia energética, de un modo que se consiga mejorar y preservar los aspectos relacionados con la salud.
Conseguir un nivel de humedad y ventilación suficiente es un tema complicado y requiere de una respuesta bien informada. Es esencial que los elementos utilizados en casas históricas no limiten la humedad en la casa, ya que esto tiene un efecto negativo en los elementos de la vivienda, causando un ambiente interior poco saludable. Aunque la disminución de la tasa de ventilación y de las infiltraciones puede reducir la factura energética de la vivienda; una disminución excesiva reducirá la capacidad de la casa para suministrar suficiente aire fresco. Una mayor investigación sobre este tema, centrada en las casas tradicionales de Escocia, ayudará en el planteamiento de mejores métodos y buenas prácticas. De hecho, el gobierno escocés afirma que no todas sus recomendaciones son adecuadas para las casas tradicionales que fueron diseñadas con calentamiento radiante y ventilación natural. Además, si la renovación persigue el cumplimiento de las nuevas regulaciones sobre ventilación y estanqueidad, puede resultar perjudicial para las viviendas. La conclusión de este capítulo es que la renovación de las casas tradicionales necesita un enfoque específico. También, la renovación debería mejorar las características inherentes de desempeño ambiental de las casas. Se analizaron todos los casos de estudios y se sugirieron diversas recomendaciones de mejora. El aislamiento de la fachada fue sugerido en todos los casos de estudio. La prioridad es mejorar primero la parte opaca de la envolvente térmica de la vivienda, y reemplazar posteriormente la

caldera y las ventanas. La recomendación más rentable es instalar elementos para mejorar la estanqueidad, con un coste indicativo de £80-120 y un ahorro anual típico de £200-400. El uso de tecnologías renovables como los paneles solares fotovoltaicos y los captadores solares térmicos son esenciales para que todas las viviendas puedan alcanzar el nivel de cero emisiones de carbono.

Capítulo seis

Las ventanas son responsables del 15-22% del calor perdido en las viviendas, aunque esta cifra difiere significativamente de una casa a otra, según el número, la orientación y el tamaño de las aberturas en la pared. En muchas casas tradicionales, las ventanas son menores que la parte opaca de las paredes, de modo que el coste de las ventanas con doble acristalamiento rara vez se recuperará a través del ahorro de energía, teniendo en cuenta la vida útil actual de las unidades de vidrio aislante.

Mejorar el comportamiento térmico de los elementos de la casa es un aspecto esencial para conseguir una vivienda energéticamente eficiente. La ventana es el elemento de la vivienda con un comportamiento térmico más desfavorable en comparación con las otras partes. En general, la sustitución de ventanas de un solo cristal instaladas en casas tradicionales no resulta adecuada por razones de conservación. Sin embargo, existen varios métodos para mejorar el comportamiento térmico de las ventanas de acristalamiento simple, como cambiarlas por las de doble acristalamiento de perfil delgado, instalar contraventanas por el interior, instalar persianas y cortinas y agregar elementos para la mejora de la estanqueidad. Se pueden obtener más ventajas de las contraventanas, cortinas y persianas, pudiendo proporcionar un ahorro de energía similar al de las ventanas de doble acristalamiento.

Otra solución es el uso de una ventana de doble acristalamiento con un espacio entre los dos vidrios más delgado que la típica ventana de doble acristalamiento. Las ventanas de doble acristalamiento de perfil delgado tienen un comportamiento térmico inferior al de las ventanas de doble vidrio convencionales. Sin embargo, su comportamiento térmico es mucho mejor que el del acristalamiento simple. Además, este tipo de vidrios pueden ser adecuados en casi todas las viviendas actuales gracias a su pequeño espesor, que permite mantener y preservar las ventanas existentes.

El acristalamiento al vacío es la alternativa más prometedora proporcionando el mejor comportamiento térmico con un perfil más delgado. No obstante, los estudios demuestran que el acristalamiento simple con un acristalamiento secundario añadido (contraventana) es casi tan eficiente como las ventanas acristaladas al vacío. El comportamiento del acristalamiento doble depende del tipo de gas incorporado, como Xenon, Krypton y Argon y del tratamiento bajo emisivo. La mejor alternativa es el acristalamiento al vacío Pilkington Legacy con un perfil estrecho y un buen comportamiento térmico. Además, la transferencia de calor a través del marco disminuye significativamente al sustituir el vidrio simple por un doble vidrio con perfil delgado.

Debido a su potencial de ahorro de energía, es imperativo elegir las ventanas más apropiadas, ya que tienen una gran influencia durante el periodo de uso de la vivienda, con una vida útil de entre 20 y 50 años, o más. Mediante la instalación de elementos para la mejora de la estanqueidad y de acristalamiento secundario (contraventanas), la pérdida de calor disminuye significativamente. Sin embargo, es esencial tener en cuenta un nivel de ventilación suficiente y los riesgos de condensación. Por esta razón, es mejor cerrar las ventanas herméticamente cuando hace frío, ya que la condensación puede producir su deterioro y generar moho.

La mejora de la estanqueidad es el método principal para evitar el efecto del viento en las ventanas de los edificios históricos. La mayor reducción en las pérdidas de calor se puede obtener incorporando varios elementos, como cortinas y persianas, y aplicando más capas de aislamiento. La cobertura más efectiva para los marcos de ventanas son los paneles rígidos de aislamiento y los paneles móviles. La persiana es la alternativa tradicional más recomendada para la mejora de las ventanas, pudiendo lograrse un mejor resultado por medio de persianas aisladas. La nueva persiana enrollable con lámina de baja emisividad es también una solución eficiente. Además, los diseños mejorados de las persianas tienen un gran efecto en la reducción de las pérdidas de calor. La mejor solución se logra combinando varias opciones, como el acristalamiento secundario, persianas y cortinas. Esto era un método tradicional que permitía ajustar las condiciones de la casa según el clima. El acristalamiento secundario tiene un efecto similar al de las persianas, si bien el acristalamiento secundario es eficiente durante todo el día. Además, también se ha estudiado la estructura de las ventanas y la influencia de cada parámetro en el valor de U de las ventanas. La selección del tipo de sistema de acristalamiento es muy importante porque tiene un efecto significativo en los valores de U, seguidamente la elección de los materiales adecuados para el marco y el divisor son también importantes. Los restantes parámetros tienen un menor efecto en los valores de U, pero es esencial considerarlos todos, especialmente cuando las casas tienen muchas ventanas. Con respecto al sistema de acristalamiento, el espesor y los tipos de cámara tienen un mayor impacto en los valores de U que el espesor y los tipos de vidrios. Además, el color de los vidrios no influye en el valor de U. En general, se concluye que el tipo de vidrio y gas tiene un efecto significativo en los valores de U más que su espesor y otros parámetros.

A partir del estudio de evaluación de los elementos de las ventanas en varios casos de estudio, se puede concluir que es prioritario reemplazar las ventanas de acristalamiento simple debido a su deficiente comportamiento térmico, las emisiones de carbono dominantes asociadas y su mayor potencial de ahorro en el caso de ser reemplazadas. Además, desde el punto de vista económico, el reembolso de este reemplazo se estima en tres años. En el caso del doble acristalamiento, se recomienda su reparación debido a la mayor cantidad de carbono incorporado y al mayor coste económico asociado a su reemplazo. Según los requisitos establecidos en el estándar LEED para nuevas construcciones (LEED NC 2.2 Crédito EQ 8.1), la iluminación diurna de todos los casos de estudio es deficiente, aunque la mayoría de ellos tienen ventanas grandes y alrededor de diez ventanas. Una posible solución podría ser usar un vidrio transparente no oscuro, ya que el color del vidrio no influye en el valor de U, pero es un factor importante para la iluminación diurna. La condición de la iluminación diurna es también un aspecto muy importante en las viviendas nuevas debido a la habitual reducción del tamaño y del número de ventanas. Finalmente, hay que reseñar que es posible extrapolar los resultados de este estudio a edificios del mismo tipo y la misma área geográfica puesto que todos los elementos de las ventanas se estudiaron como elementos individuales desde los puntos de vista estructural y térmico, y en algunos casos, desde el punto de vista económico.

7.2 Contribuciones científicas

El resumen de las principales contribuciones de esta tesis doctoral al estado del arte se presenta a continuación.

- Un estudio novedoso de la relación entre la antigüedad de las viviendas, los valores de U de sus elementos y su eficiencia energética. Actualmente no hay ningún artículo científico publicado sobre la relación exacta que existe entre la antigüedad de las viviendas y los valores de U de sus componentes calculados mediante software. Los resultados de este estudio proceden de un total de cien casas escocesas utilizadas como casos de estudio ubicados en climas que presentan unas mínimas variaciones en sus condiciones, por lo que son más valiosos y fiables.
- Un análisis comparativo del comportamiento energético basado en dos herramientas diferentes de simulación energética considerando tres tipos de construcción para una casa nueva típica ubicada en seis ciudades distintas (Edimburgo, Leeds, Pembrokeshire, Ávila, Almería y Zaragoza) de dos países (España y Reino Unido) con diferentes tipos de clima. La contribución principal ha incluido la recomendación de materiales apropiados para cada caso analizado, de modo que sea posible avanzar hacia viviendas energéticamente eficientes. Es posible usar los resultados de este capítulo y analizar los parámetros económicos para la toma de decisiones en viviendas nuevas ubicadas en otras ciudades con climas similares a los analizados.
- Un estudio de medición in-situ y una comparación posterior con los valores de U calculados mediante software en un total de doce casas escocesas utilizadas como casos de estudio. La medición in-situ de los valores de U ha permitido evaluar el comportamiento térmico real de los materiales de las casas tradicionales, especialmente en casos en los que los métodos de cálculo pueden llevar a resultados deficientes derivados de la falta de conocimiento de las soluciones constructivas actuales y las propiedades térmicas de los materiales convencionales. El estudio constituye una base para el correcto diagnóstico del comportamiento energético en las casas tradicionales, especialmente para la evaluación del comportamiento térmico de los elementos opacos.
- Un completo estado del arte de diferentes aspectos que afectan a la calidad ambiental interior y a la salud de los usuarios de los edificios, como por ejemplo, las obras de rehabilitación, la calidad del aire interior, los servicios de la casa, etc. El estudio ha ilustrado cómo es posible implementar en la práctica la sostenibilidad al renovar las viviendas tradicionales. Se ha planteado un enfoque holístico e interdisciplinar basado en una valoración y comprensión de las particularidades y especificidades que presentan muchas viviendas antiguas, que es un reflejo de la manera en que se han desarrollado a lo largo del tiempo; analizando los materiales y métodos de construcción utilizados; las diferencias entre el comportamiento real y previsto; y el reconocimiento y protección formal que ofrece la legislación.
- Análisis de diversos aspectos relacionados con la construcción saludable, tales como los materiales contaminantes, la masa térmica, la ventilación, la orientación, la

iluminación y la calefacción, en un total de doce casas escocesas utilizadas como casos de estudio. El estudio ha abordado algunas de las preocupaciones y problemas fundamentales con respecto a la construcción saludable y ha propuesto algunas soluciones para mejorar la calidad del aire interior y el uso de la vivienda, para la reparación y el reemplazo de componentes, y para la reducción de la humedad.

- Un estado del arte de algunos parámetros (como el tipo de ventanas, las necesidades de reparación o reemplazo, la calidad del vidrio, los tipos de marcos y la pintura de las ventanas) relacionados con la eficiencia energética de las ventanas. Además, se han analizado otros factores como la transferencia de calor, la infiltración, la condensación, el aislamiento frente al ruido y la protección ultravioleta. Además, se han discutido brevemente las tecnologías de ventanas futuras (por ejemplo, ventanas de energía cero, ventanas integradas, acristalamientos dinámicos, materiales de cambio de fase, ventanas con células solares semitransparentes y ventanas altamente aislantes, como los acristalamientos al vacío).
- Evaluación del valor de U, del coeficiente de ganancia de calor solar (SHGC, por sus siglas en inglés) y del coste económico de 131 tipos de ventanas, 20 sistemas de acristalamiento y 12 casos de estudio, mediante software especializado. Los resultados de este estudio pueden utilizarse como datos preliminares para el análisis, pero es esencial considerar siempre los aspectos climáticos y económicos en cada área geográfica.
- Análisis de la influencia de las ventanas en la eficiencia energética de la vivienda, considerando un total de doce casas escocesas utilizadas como casos de estudio. A partir de los resultados, se han propuesto algunas soluciones para mejorar el comportamiento energético de los casos de estudios, que pueden ser consideradas para otros casos de estudio que tengan las mismas condiciones climáticas.

7.3 Trabajo y perspectivas futuras

Puesto que la eficiencia energética en edificios residenciales es un tema multidisciplinar, amplio y complejo, se pueden proponer muchas líneas de trabajo futuras que permitan continuar la investigación iniciada con esta tesis doctoral. A continuación se presentan las actividades de investigación y perspectivas de trabajo futuras.

- Analizar la posibilidad de agregar capas de aislamiento y utilizar tecnologías renovables en casas tradicionales en diferentes países de la UE, tanto desde el punto de vista técnico como económico.
- Utilizar otros programas de simulación energética para verificar el comportamiento térmico de las viviendas. Además, realizar mediciones in-situ del valor de U, siguiendo la metodología presentada en esta tesis, en un mayor número de viviendas, reduciría la incertidumbre de los resultados.
- Analizar en detalle la huella de carbono y los costes económicos de diferentes materiales de construcción para nuevas viviendas ubicadas en ciudades representativas de los países de la UE-28. Además, puesto que como caso de estudio se ha optado únicamente por una vivienda simple de 100 m^2 de una sola planta, se puede trabajar

con diferentes tipos de casas (casas separadas, adosadas, bloques de pisos, etc.), diferentes geometrías y factores de forma, diferentes tamaños, etc.

- Realizar estudios comparativos de los valores de U de los elementos de las viviendas calculados mediante distintas herramientas de software y analizar las diferencias con respecto a las medidas in-situ de los valores de U.
- Estudiar la huella de carbono de las nuevas tecnologías utilizadas para garantizar viviendas saludables.
- Desarrollar una encuesta sobre la satisfacción de los usuarios con respecto a la calidad del aire interior y las condiciones de la vivienda. Esto proporcionaría información muy valiosa, que podría ayudar a los arquitectos en la etapa de diseño.
- Diseñar y desarrollar un programa de monitoreo de los problemas de calidad del aire interior en diferentes tipos de edificios y climas. Esto permitiría estudiar el impacto negativo de los materiales y tecnologías modernas que se utilizan en las casas tradicionales. Además, se podría evaluar la influencia de los materiales tradicionales en la calidad del aire interior y la salud. En el caso de obras de renovación, un trabajo de monitoreo previo y posterior a la intervención sería de gran utilidad.
- Evaluar la influencia de algunos aspectos como la estanqueidad, el acristalamiento secundario, las contraventanas, las persianas, etc. mediante mediciones in-situ del valor de U en diferentes tipos de ventanas, comparándolas posteriormente con los valores de U calculados mediante software.
- Diseño y monitoreo en edificios piloto que utilicen nuevas tecnologías de ventanas eficientes. Esto permitiría obtener retroalimentación de los usuarios, lo cual es esencial ya que son los usuarios los que deciden e invierten en nuevas tecnologías siempre que los resultados sean satisfactorios. Por lo tanto, sus opiniones tienen un impacto muy significativo en la etapa de diseño.
- Realizar un análisis comparativo del uso de diferentes herramientas de software para evaluar el comportamiento energético de las ventanas, considerando más materiales para el vidrio, el marco y los separadores.

Publications related to the PhD Thesis

Journal publications

1. Fahimeh Rezvani, Ignacio Zabalza Bribián. Calculation and comparative analysis of thermal transmittance (U-value) of Scottish houses from the last centuries. Indoor and built environment Journal (JCR indexed). Sage Publication. *Accepted on 15 August 2018. First published online: 13 September 2018.* doi: 10.1177/1420326X18798885

2. Fahimeh Rezvani, Ignacio Zabalza Bribián. In-situ thermal transmittance measurement for evaluating differences between actual house thermal performance and modelled one by energy simulation software. Informes de la construcción (JCR indexed). *Under review.*

Conferences

3. Fahimeh Rezvani, Ignacio Zabalza Bribián. Design, analysis and modelling the window elements by LBNL software. 12th International Energy Conference on Innovative Systems in Energy-Water-Environment Nexus. 19-20 June 2018. Tehran, Iran. (BEST PAPER AWARD).

4. Fahimeh Rezvani, Ignacio Zabalza Bribián. The future energy-efficient technology of the windows and their thermal optimisation. 12th International Energy Conference on Innovative Systems in Energy-Water-Environment Nexus. 19-20 June 2018. Tehran, Iran.

5. Fahimeh Rezvani, Ignacio Zabalza Bribián. Measurement and comparative evaluation of thermal transmittance of a hundred houses. 12th International Energy Conference on Innovative Systems in Energy-Water-Environment Nexus. 19-20 June 2018. Tehran, Iran.

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APPENDIXES

Appendix A. Templates of 100 case studies
Appendix B. Analysing the required information to work by software
Appendix C. Results of Design Builder Software
Appendix D. Results of HULC software
Appendix E. The characteristic and full details of 12 case studies of activity 4&5 and 6
Appendix F. In situ measurement values of the wall in case 4.
Appendix G. The RIBA Plan of Work
Appendix H. Results of LNBL software
Appendix I. Results of LNBL software for case studies
Appendix J. Data sources

Appendix A. Templates of 100 case studies

Appendix A

Case 1. A House Built in 2015

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of cavity masonry, with a timber framed inner leaf. The external finish is of render, with synthetic stone features.	0.319	Increase 11 cm Insulation
	Flat -	-
	Pitched 0.208	Increase 18 cm Insulation
Floor at ground level appears to be of a floating design, with timber set upon .concrete	0.345	Increase 23 cm Insulation
Internal Walls have a plasterboard finish	0.51	
Windows are fully double glazed. The windows, which are in casement and tilt and turn styles, are encased within PVC.		

* As a basis for a theory of possibility

Description

The subjects form a detached house over two storeys.

The accommodation comprises:
Ground floor: vestibule, hall, living room, kitchen / dining room, utility room.
First floor: upper hall, 5 bedrooms, 2 en-suite shower rooms, family bathroom.

Weather dry and sunny.

Heating and hot water

The property has full gas central heating. A Logic Heat boiler, located within the garage, serves panel radiators throughout the property and, in conjunction with an immersion system, provides hot water. An unvented hot water cylinder is located within the utility room cupboard.

Gross internal floor area (m²) 186 m²

Address

NORTH BERWICK EH39 4SD

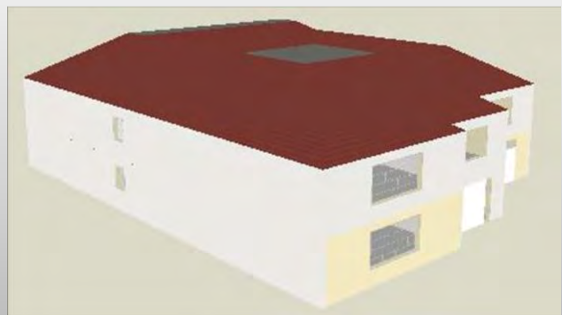
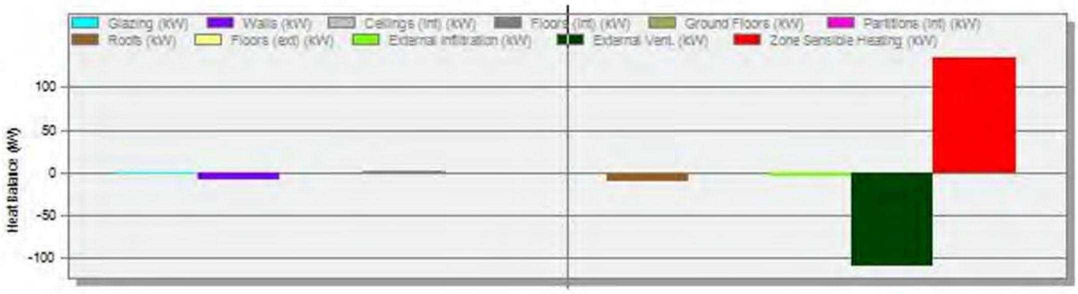


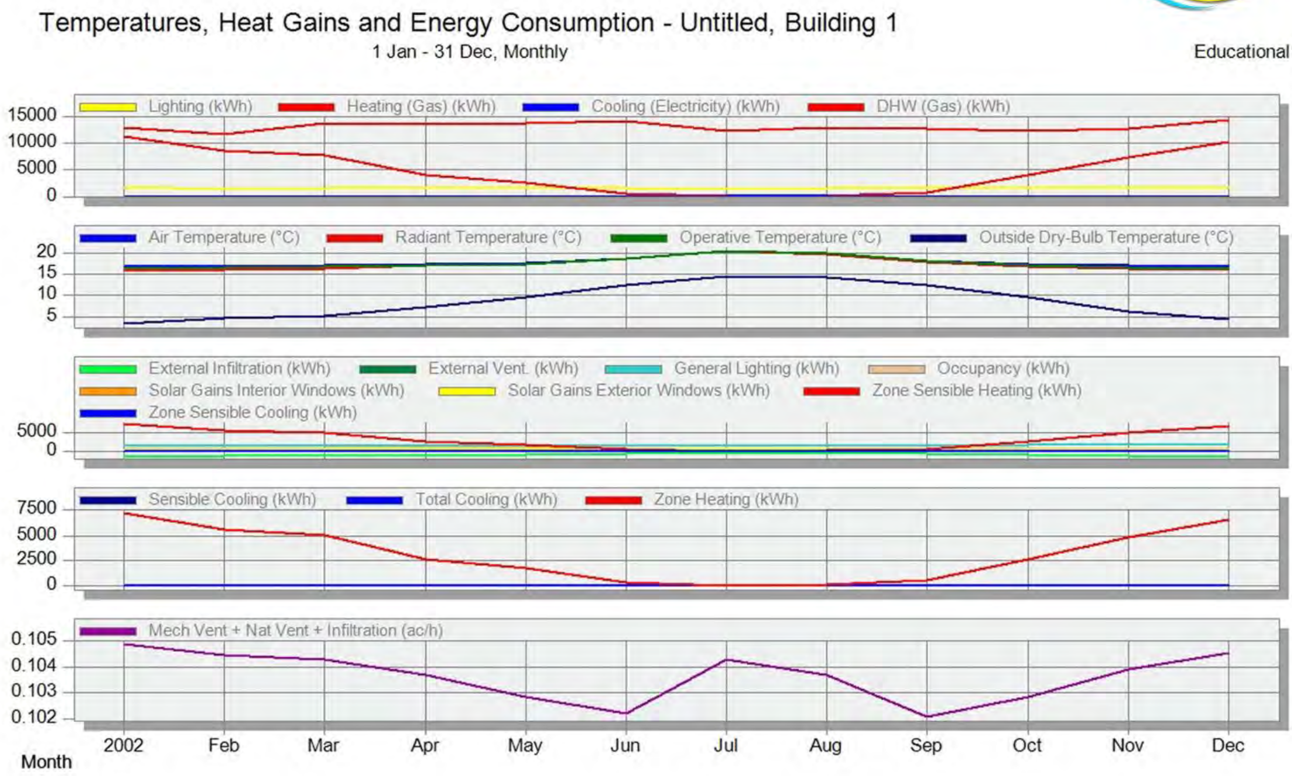
Figure A1. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.95
Operative Temperature (°C)	16.97
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.81
Walls (kW)	-7.58
Ceilings (int) (kW)	-0.78
Floors (int) (kW)	0.78
Ground Floors (kW)	0.35
Partitions (int) (kW)	0.00
Roofs (kW)	-10.88
Floors (ext) (kW)	-0.66
External Infiltration (kW)	-3.67
External Vent. (kW)	-110.22
Zone Sensible Heating (kW)	135.28

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 169.080 (kW)				
Ground Floor Total Design Heating Capacity = 69.550 (kW)				
Sitting Room	16.68	12.65	**15.81**	120.3117
Vestibule	16.45	1.86	**2.32**	145.0865
Hall	17.77	5.54	**6.92**	102.7704
Garage	16.79	10.68	**13.36**	119.4980
Service	17.52	3.04	**3.80**	107.5593
Landing	17.81	1.39	**1.73**	102.8827
Kitchen DiningRoom	17.40	15.91	**19.89**	107.2815
Utility Room	17.25	3.75	**4.69**	114.4209
Service	17.39	0.82	**1.03**	115.1225
First Floor Total Design Heating Capacity = 63.570 (kW)				
Master BedRoom	17.16	10.70	**13.37**	104.8944
Service	17.12	2.57	**3.21**	111.8658
Double BedRoom	17.13	5.78	**7.22**	107.6136
Hall	17.67	7.43	**9.28**	97.8497
Store	17.70	1.21	**1.51**	99.1012
Service	17.37	3.55	**4.43**	103.7358
Double BedRoom	17.28	8.41	**10.51**	103.6657
BedRoom	17.44	3.66	**4.57**	102.5185
Double BedRoom	17.27	5.09	**6.36**	104.8389
Service	17.45	2.49	**3.11**	103.3760
Roof 1 Total Design Heating Capacity = 15.720 (kW)				
Zone 1	16.08	12.57	**15.72**	77.6001
Roof 2 Total Design Heating Capacity = 19.670 (kW)				
Zone 1	16.50	15.74	**19.67**	60.5280
Roof Entrance Total Design Heating Capacity = 0.570 (kW)				
Zone 1	17.08	0.46	**0.57**	85.4304

Figure A2. The heating design simulation and data of the house.



Lighting (kWh)	1700.38	1436.20	1587.14	1529.45	1519.35	1512.28	1401.24	1495.44	1485.61	1553.50	1611.34	1822.59
Heating (Gas) (kWh)	11240.82	8638.82	7773.76	4035.85	2672.24	599.90	6.46	187.67	829.73	4111.66	7478.18	10229.69
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.01	0.00	0.00	0.00	0.00
DHW (Gas) (kWh)	13050.92	11696.53	13759.29	13543.94	13759.29	14252.31	12342.56	13050.92	12835.58	12342.56	12835.58	14467.65
Air Temperature (°C)	16.76	16.90	17.08	17.44	17.61	18.73	20.53	19.90	18.17	17.41	17.05	16.89
Radiant Temperature (°C)	15.82	16.06	16.37	17.01	17.26	18.58	20.47	19.81	17.99	16.95	16.32	15.99
Operative Temperature (°C)	16.29	16.48	16.73	17.23	17.44	18.65	20.50	19.85	18.08	17.18	16.69	16.44
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1513.31	-1247.78	-1336.96	-1124.43	-880.12	-673.57	-637.79	-608.49	-631.30	-876.44	-1177.28	-1411.77
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-17.53	-8.75	0.00	0.00	0.00	0.00
General Lighting (kWh)	1700.38	1436.20	1587.14	1529.45	1519.35	1512.28	1401.24	1495.44	1485.61	1553.50	1611.34	1822.59
Occupancy (kWh)	667.29	598.04	702.72	688.83	695.99	690.62	545.77	594.74	638.32	629.59	655.91	739.71
Solar Gains Interior Windows (kWh)	0.86	1.57	2.11	2.15	2.51	2.61	2.63	2.33	2.32	1.84	1.02	0.66
Solar Gains Exterior Windows (kWh)	171.23	293.93	415.90	429.17	496.94	509.92	521.09	463.78	445.84	345.21	203.01	134.87
Zone Sensible Heating (kWh)	7245.72	5568.37	5010.66	2601.12	1720.93	385.93	4.17	120.83	534.35	2650.23	4819.15	6597.20
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.12	-0.01	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.12	-0.01	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.16	-0.02	0.00	0.00	0.00	0.00
Zone Heating (kWh)	7306.53	5615.23	5052.94	2623.30	1736.96	389.93	4.20	121.98	539.32	2672.58	4860.82	6649.30
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Figure A3. The simulation detailed results of the house.

Case 2. A House Built in 2014

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of timber framed construction externally clad in block work with a roughcast cladding.	0.320	Increase 11 cm Insulation
	Flat -	-
	Pitched 0.215	Increase 19 cm Insulation
Floor The flooring at ground level is solid concrete. The flooring at first floor level is suspended timber joists.	0.371	Increase 24 cm Insulation
Internal Wall have a plasterboard finish.	0.531	
Windows The external windows are of a u-PVC framed design fitted with hermetically sealed double-glazed panes.		

* As a basis for a theory of possibility

Description

Two storey detached villa. Ground Floor: Entrance Vestibule, Hall, Lounge, Kitchen/Dining Room, Utility Room and WC Compartment. First Floor: Two Bedrooms with En-Suite Shower Rooms with WC, Three further Bedrooms and Bathroom hot water. An unvented hot water cylinder is located within the utility room cupboard.

Weather Dry.

Heating and hot water

Central heating takes the form of a gas fired, wall mounted boiler in the garage serving pressed steel radiators throughout the property. The radiators are fitted with individual thermostatic valves. Domestic hot water is also provided by the central heating boiler via an insulated hot water cylinder, which is located in the utility room.

Gross internal floor area (m²) 170.25 m^2

Address

EDINBURGH EH10 6TG

Figure A4. The software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.06
Operative Temperature (°C)	16.53
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.65
Walls (kW)	-3.60
Ceilings (int) (kW)	-0.40
Floors (int) (kW)	0.05
Ground Floors (kW)	0.11
Partitions (int) (kW)	0.00
Roofs (kW)	-2.15
External Infiltration (kW)	-0.52
External Vent. (kW)	-15.70
Zone Sensible Heating (kW)	23.75

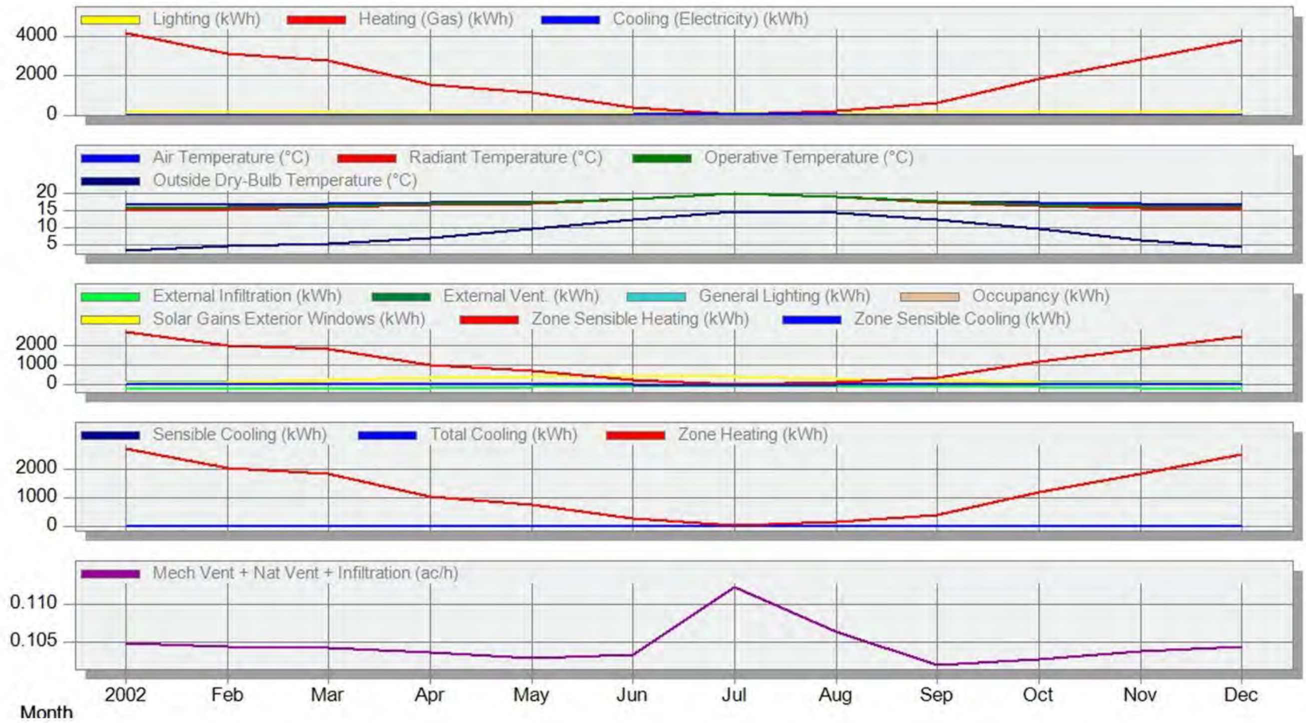
Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 29.690 (kW)				
Ground Floor Total Design Heating Capacity = 14.480 (kW)				
Kitchen DiningRoom	16.81	2.75	**3.44**	148.4599
Utility Room	16.67	0.98	**1.22**	172.3105
Hall	17.59	1.59	**1.99**	125.1316
Garage	16.15	2.39	**2.98**	180.0399
Vestibule	16.37	0.40	**0.50**	254.3626
Sitting Room	15.85	2.85	**3.56**	187.5822
Service	17.15	0.63	**0.79**	150.1755
First Floor Total Design Heating Capacity = 15.210 (kW)				
Service	16.97	0.64	**0.80**	152.7162
Double BedRoom	16.75	1.27	**1.59**	154.3907
BedRoom	17.07	1.38	**1.73**	137.2115
Hall	17.39	1.59	**1.98**	124.9328
Double BedRoom	16.77	0.91	**1.14**	161.0102
Service	17.17	0.52	**0.66**	146.4951
Service	15.33	0.62	**0.77**	390.3488
Double BedRoom	16.71	1.46	**1.82**	153.5766
Master BedRoom	14.58	3.77	**4.72**	248.7550
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.49	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.23	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.94	0.00	**0.00**	0.0000

Figure A5. The heating design simulation and data of the house.

New Result Set - Untitled, Building 1

1 Jan - 31 Dec, Monthly

Educational



Lighting (kWh)	172.21	139.13	134.49	106.29	96.59	86.27	95.01	105.93	120.95	151.17	158.13	174.82
Heating (Gas) (kWh)	4171.51	3114.61	2791.66	1568.39	1137.06	386.94	39.18	201.97	601.43	1815.16	2811.68	3853.42
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	2.30	7.34	2.21	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.46	16.64	16.82	17.19	17.36	18.31	19.90	19.10	17.69	17.12	16.81	16.52
Radiant Temperature (°C)	14.99	15.38	15.78	16.57	16.89	18.15	19.93	19.02	17.37	16.34	15.71	15.13
Operative Temperature (°C)	15.73	16.01	16.30	16.88	17.13	18.23	19.92	19.06	17.53	16.73	16.26	15.82
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-208.80	-172.36	-184.69	-155.50	-120.92	-89.94	-82.26	-74.25	-81.86	-118.97	-162.45	-193.21
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.81	-11.11	-3.63	0.00	0.00	0.00	0.00
General Lighting (kWh)	172.21	139.13	134.49	106.29	96.59	86.27	95.01	105.93	120.95	151.17	158.13	174.82
Occupancy (kWh)	92.77	83.52	94.64	91.86	94.35	90.80	81.07	86.19	89.52	90.70	90.33	96.83
Solar Gains Exterior Windows (kWh)	89.47	160.18	280.96	369.71	401.07	403.19	411.16	339.95	247.99	152.33	105.74	61.15
Zone Sensible Heating (kWh)	2694.23	2011.77	1803.09	1012.92	734.42	249.95	25.29	130.41	388.44	1172.86	1815.99	2489.04
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-3.74	-10.87	-2.95	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-3.80	-10.99	-2.98	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-3.84	-12.26	-3.69	0.00	0.00	0.00	0.00
Zone Heating (kWh)	2711.48	2024.50	1814.58	1019.45	739.09	251.51	25.47	131.28	390.93	1179.85	1827.59	2504.73
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.10	0.10	0.10	0.10

Figure A6. The simulation detailed results of the house.

Case 3. A House Built in 2013

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of concrete block with render finish on a structural timber frame.	0.327	Increase 11 cm Insulation
	Flat 0.232	Increase 19 cm Insulation
	Pitched 0.210	Increase 20 cm Insulation
Floors are of concrete at ground floor level and suspended timber joists with timber board overlay at upper level.	0.350	Increase 24 cm Insulation
Internal Walls are of concrete block with plaster finish and timber stud partitioning.	0.552	
Windows are double glazed set within timber frames with aluminum finish.		

* As a basis for a theory of possibility

Description

The subject form a two story detached, modern villa with annex flat and double garage all set within garden grounds.
Ground Floor: Vestibule, Hallway, Living room, Dining room/bedroom four, Kitchen/family room, Utility room and shower room.
First Floor: Three Bedroom, ensuite shower room and bathroom.
Annex Flat: Living room/Kitchen, Bedroom and bathroom.

Weather Dry but dull

Heating and hot water

Benefit from full gas fired central heating system, has under floor heating at ground level with radiators serving the first floor accommodation and also the annex flat.

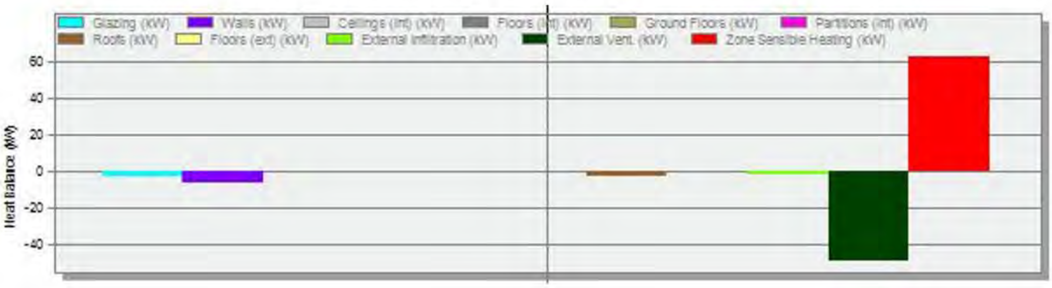
Water for domestic purposes is heated by the same gas fired boilers.

Gross internal floor area (m²) 294 m^2 **approx.**

Address

EDINBURGH, EH20 9SZ

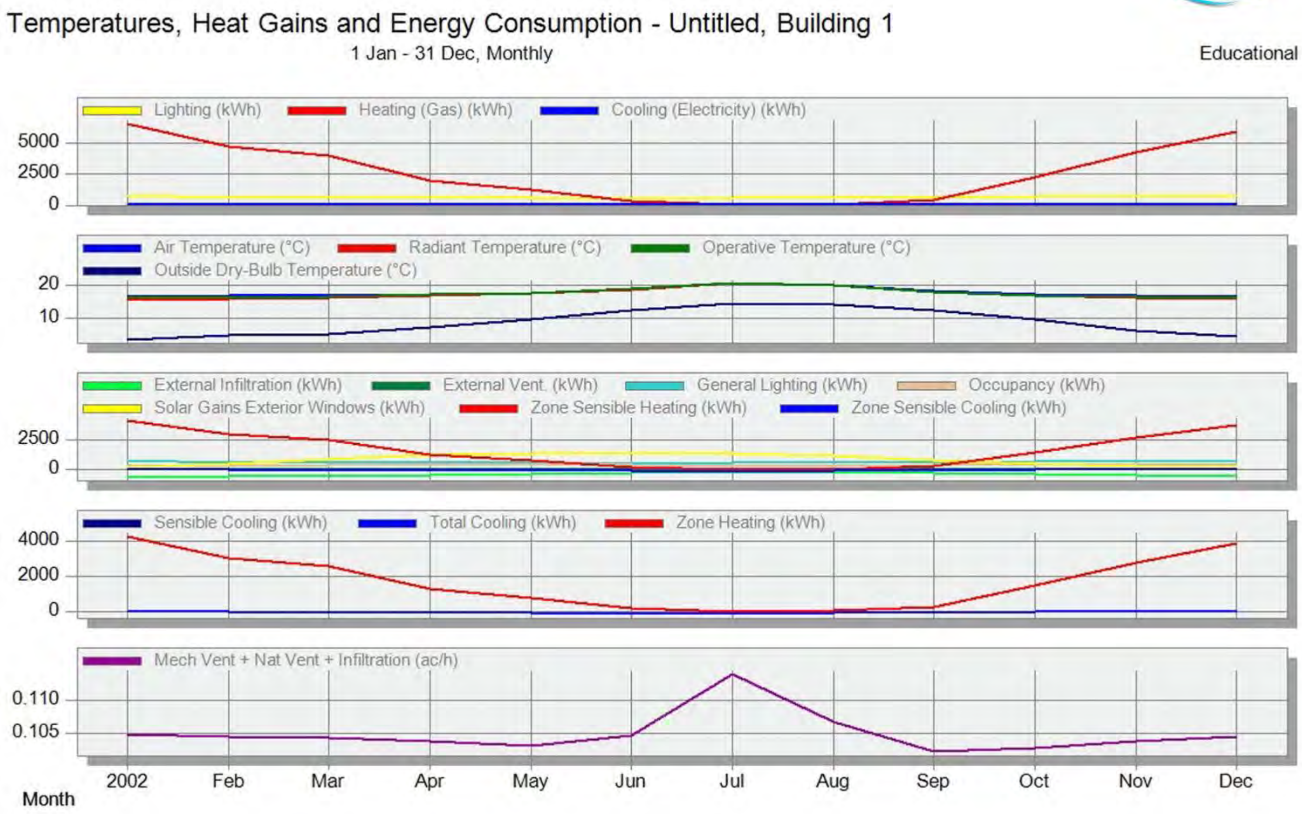
Figure A7. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.78
Operative Temperature (°C)	16.89
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.12
Walls (kW)	-6.47
Ceilings (int) (kW)	0.00
Floors (int) (kW)	0.00
Ground Floors (kW)	0.37
Partitions (int) (kW)	0.00
Roofs (kW)	-2.70
Floors (ext) (kW)	-0.13
External Infiltration (kW)	-1.65
External Vent. (kW)	-49.51
Zone Sensible Heating (kW)	63.17

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 78.960 (kW)				
Ground Floor Total Design Heating Capacity = 15.980 (kW)				
Service	17.26	1.79	**2.23**	114.4079
Bed Room	17.29	2.32	**2.90**	112.8521
Kitchen	16.68	8.68	**10.85**	121.9858
Ground Floor Total Design Heating Capacity = 29.450 (kW)				
Bed Room	16.49	5.61	**7.02**	129.5297
Bed Room	17.77	1.09	**1.37**	103.8090
Hall	17.79	1.08	**1.35**	104.2608
Service	17.60	1.68	**2.10**	106.7219
Service	17.57	1.13	**1.41**	108.6775
Vestibule	16.97	1.61	**2.01**	124.8757
Bed Room	15.87	4.63	**5.78**	149.5584
Master BedRoom	16.67	6.73	**8.41**	123.4017
FirstFloor Roof Total Design Heating Capacity = 12.220 (kW)				
Bed Room	16.87	6.48	**8.10**	90.8493
Bed Room	17.13	2.04	**2.55**	99.1516
Service	17.16	1.26	**1.57**	80.3340
First Floor Total Design Heating Capacity = 5.060 (kW)				
Bed Room	16.11	4.05	**5.06**	138.2851
First Floor Roof Total Design Heating Capacity = 15.300 (kW)				
Family Room	17.02	4.21	**5.26**	83.8180
Service	17.22	0.35	**0.44**	38.2826
Service	17.36	1.42	**1.78**	79.0425
Service	17.34	2.11	**2.63**	81.8007
Landing	17.45	0.75	**0.93**	72.1428
Bed Room	17.02	3.41	**4.26**	82.9444

Figure A8. The heating design simulation and data of the house.



Lighting (kWh)	747.08	639.10	660.03	577.42	559.08	525.71	552.42	584.59	616.72	698.00	705.92	756.74
Heating (Gas) (kWh)	6525.00	4673.80	3971.16	1949.61	1197.67	316.20	7.42	81.71	406.14	2273.70	4209.56	5925.71
Cooling (Electricity) (kWh)	2.95	9.41	26.87	45.80	51.81	66.10	87.70	61.42	31.84	9.95	5.25	1.59
Air Temperature (°C)	16.76	16.93	17.11	17.51	17.82	19.04	20.87	20.20	18.28	17.39	17.08	16.82
Radiant Temperature (°C)	15.66	16.01	16.37	17.11	17.54	18.92	20.84	20.12	18.10	16.86	16.26	15.79
Operative Temperature (°C)	16.21	16.47	16.74	17.31	17.68	18.98	20.85	20.16	18.19	17.12	16.67	16.31
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-672.11	-555.87	-596.52	-506.13	-403.93	-317.80	-304.65	-285.65	-285.70	-387.88	-524.23	-623.02
External Vent. (kWh)	-0.06	-0.36	-0.82	-1.34	-1.22	-6.88	-37.11	-11.54	-0.95	-0.55	-0.14	-0.17
General Lighting (kWh)	747.08	639.10	660.03	577.42	559.08	525.71	552.42	584.59	616.72	698.00	705.92	756.74
Occupancy (kWh)	384.18	345.92	391.61	378.78	384.85	362.69	316.86	335.91	361.34	375.15	374.08	401.01
Solar Gains Exterior Windows (kWh)	244.17	478.11	930.19	1235.74	1332.14	1346.07	1392.92	1133.39	819.81	486.79	286.03	162.64
Zone Sensible Heating (kWh)	4207.11	3013.99	2560.94	1257.53	772.63	203.91	4.79	52.67	261.91	1467.57	2715.40	3821.09
Zone Sensible Cooling (kWh)	-4.89	-15.67	-44.72	-76.24	-86.22	-110.10	-143.01	-101.51	-52.92	-16.51	-8.72	-2.64
Sensible Cooling (kWh)	-4.93	-15.72	-44.88	-76.48	-86.52	-110.38	-143.51	-101.90	-53.17	-16.61	-8.77	-2.65
Total Cooling (kWh)	-4.93	-15.72	-44.88	-76.48	-86.52	-110.39	-146.45	-102.56	-53.18	-16.61	-8.77	-2.65
Zone Heating (kWh)	4241.25	3037.97	2581.26	1267.25	778.49	205.53	4.82	53.11	263.99	1477.91	2736.22	3851.71
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.10	0.10	0.10	0.10

Figure A9. The simulation detailed results of the house.

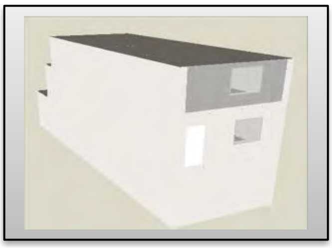
Case 4. A House Built in 2013

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are a non- traditional "fast build" construction which utilises pre-fabricated concrete panels with a metal lath and render finish.	0.333	Increase 12 cm Insulation
	Flat 0.230	Increase 19 cm Insulation
	Pitched -	-
Floor have fitted floor coverings.	0.357	Increase 24 cm Insulation
Internal Walls have plaster finishes	0.578	
Windows are double glazed.		

* As a basis for a theory of possibility

Description

A three storey mid terraced villa.
Lower Ground Floor: Two bedrooms and bathroom.
Ground Floor: Bedroom, kitchen/breakfast room, shower room and utility room.
First Floor: Living room and master bedroom with en-suite shower room. Balcony areas are present to the rear elevation



Weather Dry but Overcast

Heating and hot water

We understand the property benefits from geothermal heating which services an underfloor heating system. The property benefits from a hot water system. There is an electric fire in the living room.

Gross internal floor area (m²) 187 m² **approx.**

Address

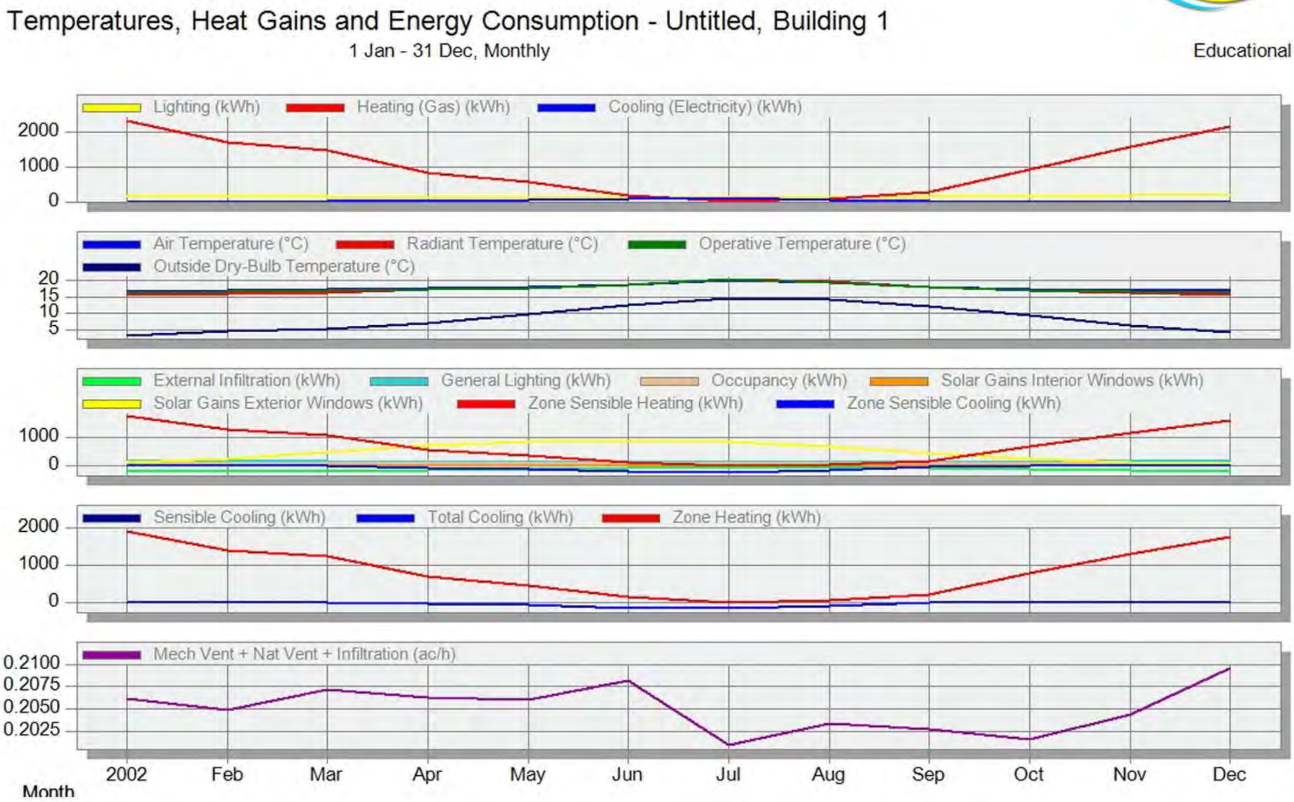
EDINBURGH EH13 0LG

Figure A10. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.79
Operative Temperature (°C)	16.90
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.09
Walls (kW)	-3.29
Ceilings (int) (kW)	-0.09
Floors (int) (kW)	0.09
Ground Floors (kW)	0.04
Partitions (int) (kW)	0.00
Roofs (kW)	-0.44
External Infiltration (kW)	-0.47
External Vent. (kW)	-1.26
Zone Sensible Heating (kW)	6.48

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 8.110 (kW)				
Lower Floor Total Design Heating Capacity = 2.970 (kW)				
Service	17.35	0.18	**0.23**	32.2662
Bed Room	17.26	0.47	**0.59**	27.7742
Hall	17.45	0.25	**0.31**	26.8302
Service	17.39	0.09	**0.12**	37.6047
Vestibule	16.97	0.13	**0.16**	90.3816
Lower Terrace	17.13	0.72	**0.89**	132.1248
Bed Room	17.00	0.53	**0.67**	37.1220
Ground Floor Total Design Heating Capacity = 2.280 (kW)				
Hall	17.04	0.45	**0.57**	42.1941
Dining Room	17.02	0.37	**0.46**	36.0014
Service	17.32	0.11	**0.14**	34.6311
Landing	17.64	0.06	**0.08**	20.0221
Service	17.31	0.10	**0.12**	39.4745
Kitchen	16.77	0.73	**0.91**	40.2288
First Floor Total Design Heating Capacity = 2.860 (kW)				
Service	17.06	0.16	**0.19**	41.2847
Landing	17.16	0.16	**0.20**	32.1881
Bed Room	15.95	0.91	**1.13**	69.5902
Living Room	16.32	1.07	**1.34**	48.0332

Figure A11. The heating design simulation and data of the house.



Lighting (kWh)	177.27	148.45	150.07	125.51	120.23	111.45	117.49	125.92	135.96	159.91	165.10	179.24
Heating (Gas) (kWh)	2322.80	1698.20	1491.45	834.78	554.17	163.59	6.94	71.32	267.35	942.05	1574.14	2148.52
Cooling (Electricity) (kWh)	0.00	0.00	1.51	19.57	44.28	90.24	97.79	51.81	6.51	0.00	0.00	0.00
Air Temperature (°C)	16.69	16.89	17.10	17.53	17.81	18.69	20.13	19.40	17.97	17.35	17.03	16.75
Radiant Temperature (°C)	15.57	15.97	16.39	17.16	17.61	18.75	20.31	19.46	17.83	16.80	16.18	15.68
Operative Temperature (°C)	16.13	16.43	16.75	17.34	17.71	18.72	20.22	19.43	17.90	17.07	16.61	16.22
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-190.31	-157.63	-169.63	-144.23	-115.32	-86.59	-77.58	-71.48	-77.72	-109.88	-148.40	-176.35
General Lighting (kWh)	177.27	148.45	150.07	125.51	120.23	111.45	117.49	125.92	135.96	159.91	165.10	179.24
Occupancy (kWh)	96.36	86.74	98.13	94.96	96.91	93.62	84.13	88.99	92.44	94.15	93.83	100.58
Solar Gains Interior Windows (kWh)	0.84	2.01	4.19	6.24	7.48	8.06	7.42	5.93	3.87	2.18	1.02	0.59
Solar Gains Exterior Windows (kWh)	110.97	240.50	477.45	690.61	817.16	872.37	814.04	652.39	435.68	252.55	133.14	77.27
Zone Sensible Heating (kWh)	1723.79	1242.36	1068.17	570.74	375.04	107.68	5.73	47.76	175.74	672.34	1148.68	1584.10
Zone Sensible Cooling (kWh)	0.00	-1.02	-9.47	-52.55	-99.97	-200.67	-226.74	-136.18	-39.36	-2.73	-0.50	0.00
Sensible Cooling (kWh)	0.00	0.00	-2.52	-32.68	-73.85	-150.39	-160.32	-84.44	-10.72	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	-2.52	-32.68	-73.94	-150.70	-163.31	-86.53	-10.88	0.00	0.00	0.00
Zone Heating (kWh)	1927.92	1409.51	1237.90	692.87	459.96	135.78	5.76	59.20	221.90	781.90	1306.54	1783.27
Mech Vent + Nat Vent + Infiltration (ac/h)	0.21	0.20	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20	0.21

Figure A12. The simulation detailed results of the house.

Case 5. A House Built in 2013

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of cavity brick/block construction rendered externally with cast stone and brick finishes.	0.323	Increase 13 cm Insulation
	Flat -	-
	Pitched 0.220	Increase 21 cm Insulation
Floors at ground floor level are suspended timber construction; at first floor level are fitted floor coverings throughout.	0.363	Increase 24 cm Insulation
Internal Wall are plasterboard.	0.579	
Windows u-PVC double glazed units.		

* As a basis for a theory of possibility

Description

Detached two storey house.

Ground Floor: Entrance Vestibule & Hallway, Living room, Sitting room, Kitchen/Dining room, Dining room, Utility Room and WC.

First Floor: Hallway, Landing, 4 Bedrooms, 2 with En Suite facilities, and Bathroom.

Weather Overcast

Heating and hot water

Gas fired boiler serving radiators throughout the property.

Hot water assumed supplied via the central heating system and hot water, circulating tank located at first floor Hallway cupboard.

Gross internal floor area (m²) 208 m² **approx.**

Address

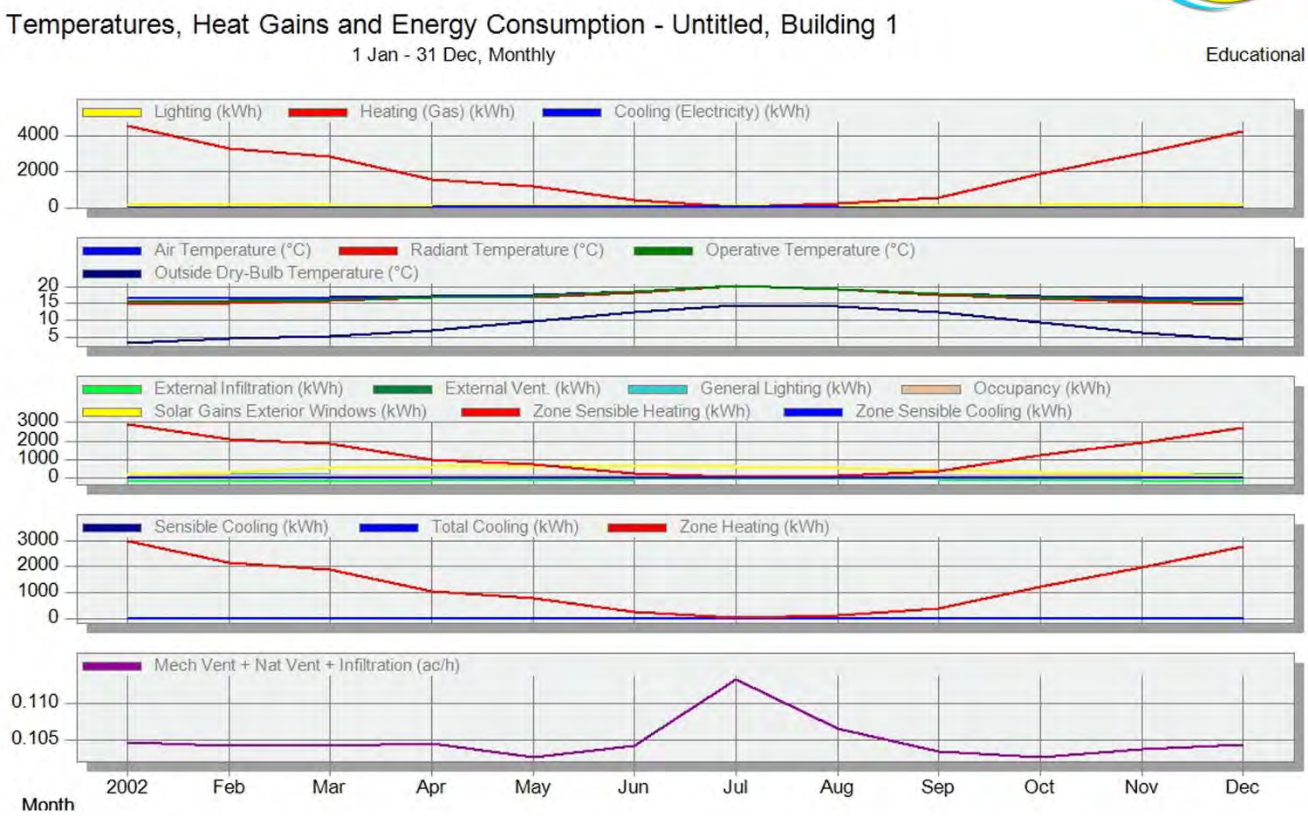
EDINBURGH EH12 8WS

Figure A13. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.72
Operative Temperature (°C)	16.36
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.48
Walls (kW)	-3.80
Ceilings (int) (kW)	-0.46
Floors (int) (kW)	0.06
Ground Floors (kW)	0.12
Partitions (int) (kW)	-0.00
Roofs (kW)	-2.22
External Infiltration (kW)	-0.54
External Vent. (kW)	-16.09
Zone Sensible Heating (kW)	25.33

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 31.670 (kW)				
Ground Floor Total Design Heating Capacity = 15.630 (kW)				
Lounge	16.00	3.22	**4.02**	164.4793
Vestibule	15.74	0.76	**0.95**	237.6344
Family Room	15.48	2.38	**2.98**	196.7304
Hall	17.54	1.29	**1.62**	116.8586
Kitchen BreakFastArea	17.03	2.19	**2.74**	130.2931
Utility Room	16.69	0.47	**0.59**	173.5155
Dining Room	16.44	1.85	**2.32**	153.6347
Service	17.08	0.33	**0.41**	156.6139
First Floor Total Design Heating Capacity = 16.040 (kW)				
Master BedRoom	16.12	3.04	**3.80**	154.9739
Service	16.72	0.52	**0.65**	162.3050
Bed Room	14.02	3.31	**4.14**	273.6746
Hall	17.26	1.34	**1.67**	120.7217
Bed Room	16.83	2.19	**2.74**	130.4296
Service	16.78	0.43	**0.54**	160.6464
Bed Room	16.68	1.67	**2.08**	138.0609
Service	16.93	0.34	**0.42**	160.1990
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.68	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.73	0.00	**0.00**	0.0000
Roof 3 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.22	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.71	0.00	**0.00**	0.0000

Figure A14. The heating design simulation and data of the house.



Lighting (kWh)	185.77	147.14	137.97	101.29	87.53	75.27	85.16	99.26	120.57	158.64	168.69	188.49
Heating (Gas) (kWh)	4593.13	3329.31	2873.21	1584.32	1168.04	390.49	38.36	197.74	549.47	1895.58	3050.59	4276.84
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.41	0.11	3.63	13.16	5.03	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.38	16.60	16.85	17.28	17.42	18.43	20.17	19.30	17.86	17.14	16.78	16.41
Radiant Temperature (°C)	14.79	15.29	15.81	16.68	16.96	18.29	20.22	19.24	17.59	16.34	15.61	14.91
Operative Temperature (°C)	15.59	15.94	16.33	16.98	17.19	18.36	20.19	19.27	17.72	16.74	16.19	15.66
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-212.57	-175.97	-189.67	-160.64	-124.75	-93.96	-88.45	-79.28	-86.42	-122.13	-165.82	-196.25
External Vent. (kWh)	0.00	0.00	0.00	-1.46	0.00	-2.19	-12.35	-3.85	-1.74	0.00	0.00	0.00
General Lighting (kWh)	185.77	147.14	137.97	101.29	87.53	75.27	85.16	99.26	120.57	158.64	168.69	188.49
Occupancy (kWh)	104.22	93.79	106.07	102.83	105.74	101.41	89.92	95.77	100.02	101.86	101.41	108.78
Solar Gains Exterior Windows (kWh)	188.33	311.27	528.29	617.38	629.24	606.82	632.50	553.90	445.96	302.51	216.53	125.64
Zone Sensible Heating (kWh)	2966.41	2150.17	1855.68	1023.28	754.43	252.22	24.76	127.60	354.71	1224.82	1970.18	2762.11
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	-0.68	-0.17	-5.92	-20.50	-7.14	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	-0.69	-0.18	-6.00	-20.68	-7.19	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	-0.69	-0.18	-6.06	-21.98	-8.40	0.00	0.00	0.00	0.00
Zone Heating (kWh)	2985.53	2164.05	1867.58	1029.81	759.23	253.82	24.93	128.53	357.15	1232.13	1982.89	2779.95
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.10	0.10	0.10	0.10

Figure A15. The simulation detailed results of the house.

Case 6. A House Built in 2011

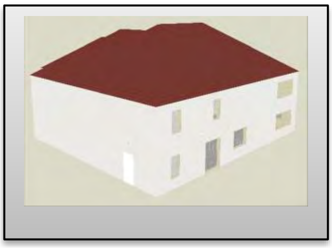
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are built of load bearing timber frame with a masonry.	0.344	Increase 12 cm Insulation
	Flat -	-
	Pitched 0.219	Increase 21 cm Insulation
Floor is of solid masonry and ground floor and suspended timber at first floor.	0.385	Increase 25 cm Insulation
Internal Walls have a plasterboard finish. **Windows** are of PVC double glazed style. The external doors are of PVC material.	0.682	

* As a basis for a theory of possibility

Description

Two detached villa. Ground Floor: Entrance hall, living room, kitchen/dining room, family room, utility room and WC compartment.

First Floor: Master bedroom and en-suite shower room, bedroom and en-suite shower room, two bedrooms and bathroom.



Weather dry and overcast

Heating and hot water

The property has a gas fired boiler which appears to serve the central heating system and hot water supply. An electric immersion heater has also been fitted.

Gross internal floor area (m²) 174 m^2

Address

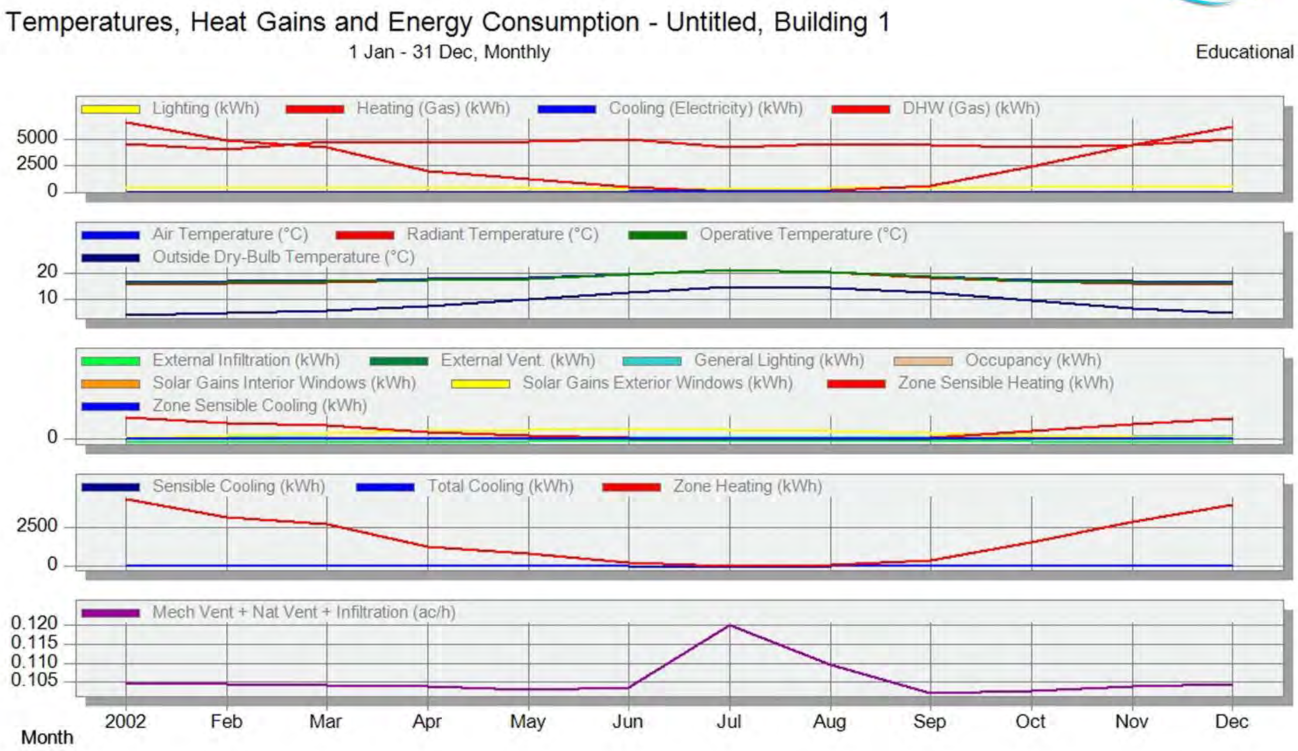
CATELBOCK CLOSE
KIRKLISTON EH29 9FF

Figure A16. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.46
Operative Temperature (°C)	16.73
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.01
Walls (kW)	-7.52
Ceilings (int) (kW)	-1.18
Floors (int) (kW)	-0.09
Ground Floors (kW)	0.40
Partitions (int) (kW)	0.00
Roofs (kW)	-1.59
External Infiltration (kW)	-1.53
External Vent. (kW)	-45.81
Zone Sensible Heating (kW)	60.16

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 75.210 (kW)				
Ground Floor Total Design Heating Capacity = 41.890 (kW)				
Utility Room	16.70	1.17	**1.46**	141.9735
Family Room	16.99	2.90	**3.62**	123.1818
Hall	17.52	4.51	**5.63**	107.8134
Lounge	15.14	11.20	**14.00**	160.7959
Dining Room	17.12	9.95	**12.44**	113.1645
Vestibule	13.50	2.72	**3.40**	313.9868
Service	16.89	1.07	**1.34**	133.6840
First Floor Total Design Heating Capacity = 33.320 (kW)				
Bed Room	16.81	2.13	**2.66**	124.2101
Bed Room	16.83	8.06	**10.08**	111.3784
Hall	17.44	2.84	**3.55**	103.1810
Bed Room	16.94	1.43	**1.79**	121.9257
CupBoard	17.46	0.46	**0.58**	111.4747
Service	17.22	2.08	**2.60**	108.8537
Service	16.90	1.18	**1.48**	123.7921
CupBoard	17.53	0.19	**0.24**	110.4291
Service	16.99	2.30	**2.88**	117.9838
Bed Room	16.96	5.54	**6.92**	110.9185
CupBoard	17.48	0.43	**0.54**	111.6777
Main Roof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.12	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.46	0.00	**0.00**	0.0000

Figure A17. The heating design simulation and data of the house.



Lighting (kWh)	532.42	408.25	399.39	354.21	326.05	307.05	302.38	344.26	387.09	448.27	485.72	574.99
Heating (Gas) (kWh)	6593.01	4854.08	4163.42	1995.33	1227.73	433.78	71.77	212.64	566.34	2426.63	4371.24	6138.55
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.04	3.50	0.52	0.00	0.00	0.00	0.00
DHW (Gas) (kWh)	4487.30	4021.62	4730.86	4656.82	4730.86	4900.38	4243.75	4487.30	4413.26	4243.75	4413.26	4974.42
Air Temperature (°C)	16.68	16.87	17.17	17.83	18.20	19.64	21.63	20.81	18.71	17.45	16.98	16.78
Radiant Temperature (°C)	15.53	15.93	16.47	17.53	18.04	19.63	21.74	20.84	18.61	16.96	16.14	15.67
Operative Temperature (°C)	16.10	16.40	16.82	17.68	18.12	19.64	21.69	20.83	18.66	17.20	16.56	16.22
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-618.66	-512.27	-554.83	-482.05	-390.80	-320.82	-317.79	-293.28	-283.76	-361.74	-481.28	-575.70
External Vent. (kWh)	0.00	0.00	0.00	-0.08	0.00	-3.50	-58.03	-15.93	-0.15	0.00	0.00	0.00
General Lighting (kWh)	532.42	408.25	399.39	354.21	326.05	307.05	302.38	344.26	387.09	448.27	485.72	574.99
Occupancy (kWh)	229.46	205.46	240.57	232.92	233.55	228.29	178.22	196.27	215.20	216.17	225.42	254.38
Solar Gains Interior Windows (kWh)	1.80	3.41	6.34	8.27	9.24	9.38	9.47	7.78	5.65	3.40	2.13	1.21
Solar Gains Exterior Windows (kWh)	387.81	705.51	1276.81	1626.83	1789.51	1801.20	1839.45	1514.08	1121.09	691.39	456.09	260.54
Zone Sensible Heating (kWh)	4251.92	3129.47	2684.52	1285.75	790.82	279.17	46.15	136.98	365.01	1564.75	2817.96	3959.70
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.07	-4.93	-0.63	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.07	-4.99	-0.63	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.07	-5.84	-0.87	0.00	0.00	0.00	0.00
Zone Heating (kWh)	4285.46	3155.15	2706.22	1296.96	798.02	281.96	46.65	138.22	368.12	1577.31	2841.31	3990.06
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.10	0.12	0.11	0.10	0.10	0.10	0.10

Figure A18. The simulation detailed results of the house.

Case 7. A House Built in 2010

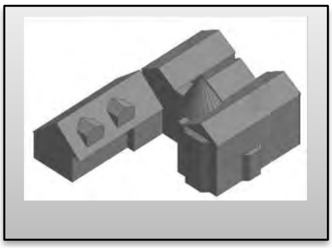
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Wall are 360mm thick and appear to be of traditional cavity brickwork	0.353	Increase 13 cm Insulation
	Flat 0.241	Increase 22 cm Insulation
	Pitched 0.221	Increase 22 cm Insulation
Floor The ground floor appears to be of solid concrete with cement screed overlay.	0.309	Increase 24 cm Insulation
Internal Wall are plasterboard lined stud frame.	0.709	
Windows are mostly timber frame double glazed tilt.		

* As a basis for a theory of possibility

Description

Detached house. Ground floor - Entrance and hallway, cloak roam, laundry, sitting room, dining room, kitchen/family room including breakfasting area, bedroom 5/office.

First floor - Landing, master bedroom with dressing room, fitted wardrobe room and en-suite bathroom.



Weather Dry and bright.

Heating and hot water

Space heating is provided by a gas fired wet central heating system.

In an eaves store at top floor level there is a Worcester 40cdi Greenstar condensing boiler which heats water fed through under floor pipes throughout the property.

Gross internal floor area (m²) 458 m^2

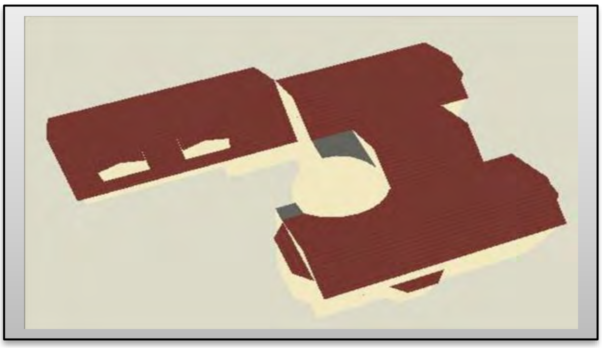
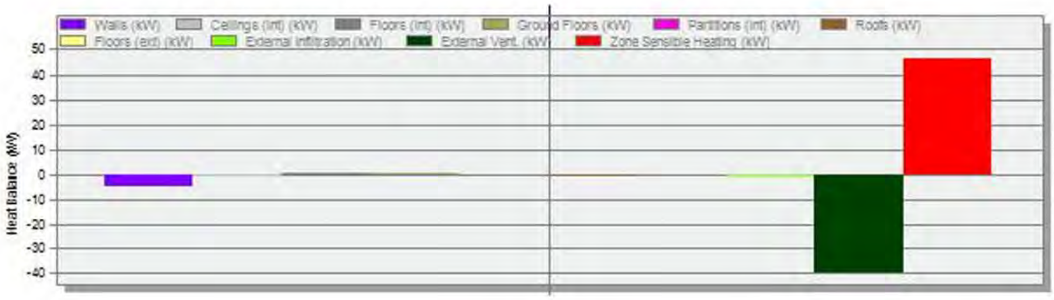


Figure A19. The software visualization of the house.

Address

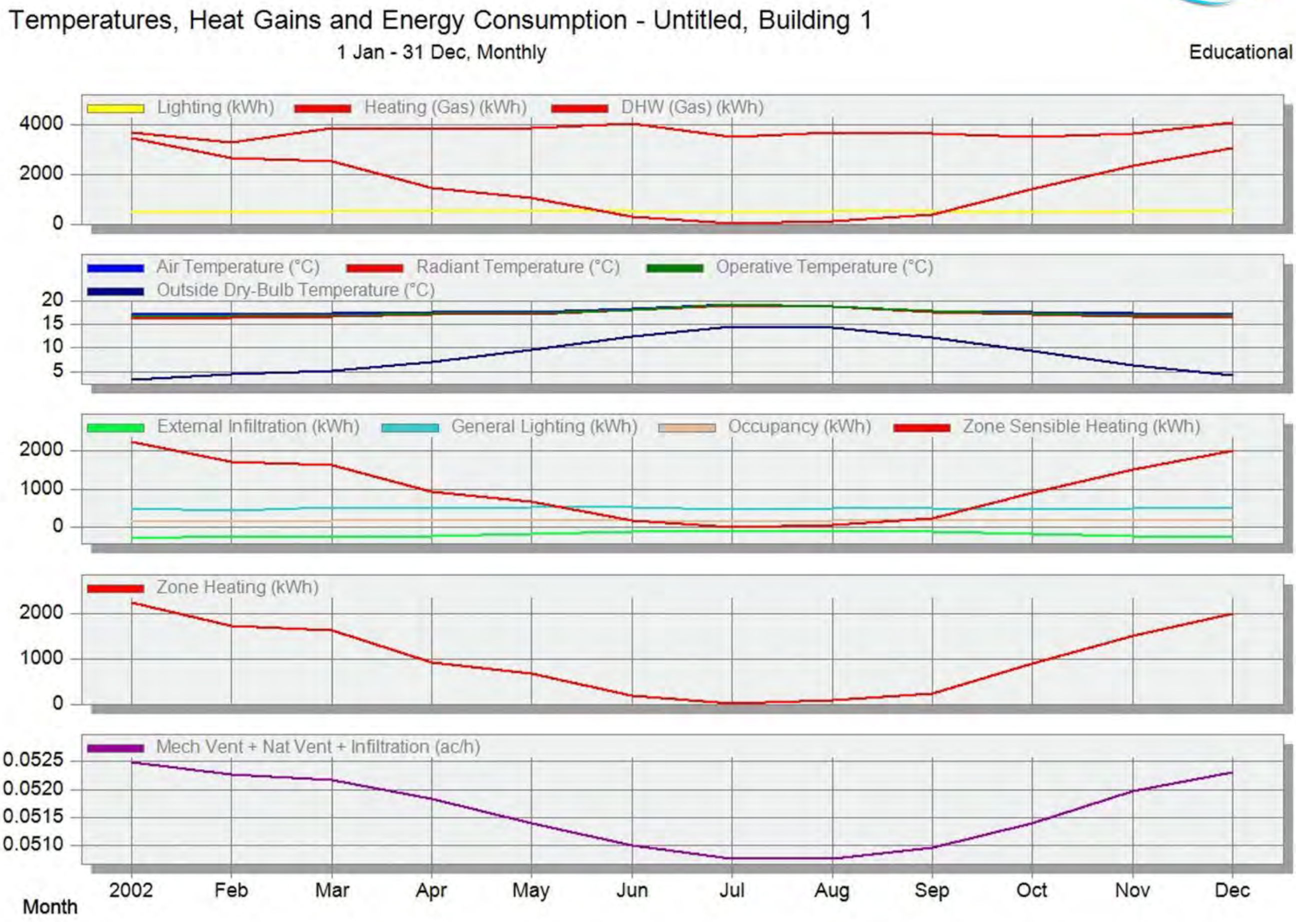
EDINBURGH EH4 3RH



Air Temperature (°C)	18.00
Radiant Temperature (°C)	16.37
Operative Temperature (°C)	17.18
Outside Dry-Bulb Temperature (°C)	-5.60
Walls (kW)	-4.84
Ceilings (int) (kW)	-0.81
Floors (int) (kW)	0.27
Ground Floors (kW)	0.27
Partitions (int) (kW)	0.00
Roofs (kW)	-1.15
Floors (ext) (kW)	-0.08
External Infiltration (kW)	-0.66
External Vent. (kW)	-39.84
Zone Sensible Heating (kW)	46.84

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 58.540 (kW)				
Ground Floor Total Design Heating Capacity = 31.270 (kW)				
Vestibule	17.19	0.42	**0.52**	152.2049
Family Room	17.16	2.44	**3.04**	133.5429
Dining Hall	17.53	3.53	**4.42**	122.7252
Drawing Room	17.18	3.19	**3.98**	131.2482
Study Room	17.49	1.95	**2.44**	124.7940
Kitchen BreakfastArea	17.18	3.95	**4.94**	130.2511
Utility Room	17.57	0.86	**1.07**	126.0223
Cloak Room	17.77	0.27	**0.34**	121.9877
Service	17.50	0.27	**0.33**	137.3645
Triple Garage	17.05	6.87	**8.58**	131.4892
Flat Hall	17.20	0.52	**0.66**	148.1068
Service	17.42	0.26	**0.33**	142.5737
Boot Room	17.29	0.50	**0.62**	143.8975
First Floor Total Design Heating Capacity = 21.350 (kW)				
Lounge SittingArea	17.29	4.97	**6.21**	124.7068
Master BedRoom	16.97	2.54	**3.18**	135.2108
Service	17.21	0.50	**0.62**	142.0035
Bed Room	17.01	1.93	**2.41**	137.2977
Dressing Room	17.36	0.92	**1.15**	129.3992
Service	17.38	0.92	**1.14**	128.7251
Bed Room	16.99	2.09	**2.62**	138.0975
Service	17.39	0.37	**0.47**	137.7556
Service	17.12	1.60	**2.00**	134.4105
Bed Room	17.31	1.24	**1.55**	129.0107

Figure A20. The heating design simulation and data of the house.



Lighting (kWh)	502.55	451.80	518.92	507.46	518.92	523.83	486.18	502.55	491.09	486.18	491.09	535.29
Heating (Gas) (kWh)	3448.09	2658.81	2501.38	1428.79	1041.70	281.53	12.57	125.62	367.24	1386.30	2322.09	3073.35
DHW (Gas) (kWh)	3675.84	3294.37	3875.35	3814.70	3875.35	4014.21	3476.32	3675.84	3615.18	3476.32	3615.18	4074.86
Air Temperature (°C)	17.09	17.17	17.28	17.51	17.62	18.25	19.24	18.82	17.91	17.49	17.28	17.20
Radiant Temperature (°C)	16.28	16.45	16.63	17.04	17.22	18.02	19.10	18.64	17.66	17.03	16.64	16.44
Operative Temperature (°C)	16.68	16.81	16.95	17.28	17.42	18.14	19.17	18.73	17.78	17.26	16.96	16.82
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-277.86	-228.66	-243.91	-203.47	-158.24	-112.34	-90.49	-88.29	-107.80	-158.50	-215.48	-259.30
General Lighting (kWh)	502.55	451.80	518.92	507.46	518.92	523.83	486.18	502.55	491.09	486.18	491.09	535.29
Occupancy (kWh)	187.95	168.45	198.03	194.53	196.81	199.63	164.64	177.43	182.16	177.50	184.78	208.36
Zone Sensible Heating (kWh)	2227.33	1717.71	1616.45	923.86	673.51	182.05	8.14	81.14	237.24	896.58	1500.39	1986.09
Zone Heating (kWh)	2241.26	1728.22	1625.90	928.71	677.11	183.00	8.17	81.65	238.71	901.10	1509.36	1997.68
Mech Vent + Nat Vent + Infiltration (ac/h)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Figure A21. The simulation detailed results of the house.

Case 8. A House Built in 2009

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are 360mm thick and appear to be of traditional cavity brickwork	0.353	Increase 13 cm Insulation
	Flat 0.241	Increase 22 cm Insulation
	Pitched 0.221	Increase 22 cm Insulation
Floor The ground floor appears to be of solid concrete with cement screed overlay.	0.309	Increase 24 cm Insulation
Internal Walls are plasterboard lined stud frame.	0.709	
Windows are mostly timber frame double glazed tilt and turn or sash and case style.		

* As a basis for a theory of possibility

Description

Detached house. Ground floor - Entrance and hallway, cloak roam, laundry, sitting room, dining room, kitchen/family room including breakfasting area, bedroom 5/office.

First floor - Landing, master bedroom with dressing room, fitted wardrobe room and en-suite bathroom.

Weather Dry and bright.

Heating and hot water

Space heating is provided by a gas fired wet central heating system.

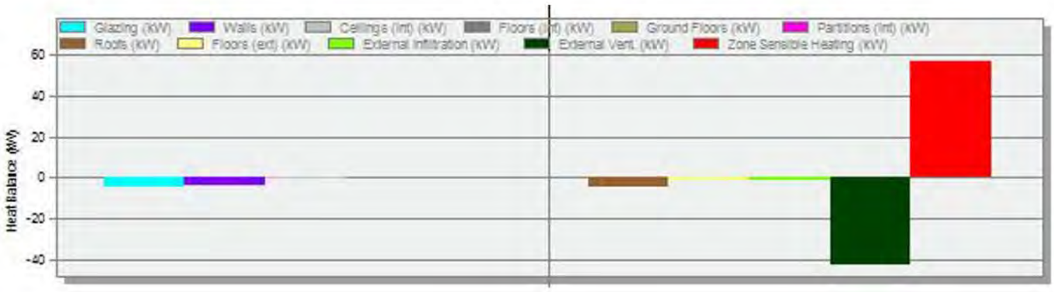
In an eaves store at top floor level there is a Worcester 40cdi Greenstar condensing boiler which heats water fed through under floor pipes throughout the property.

Gross internal floor area (m²) 458 m^2

Address

EDINBURGH EH4 3RH

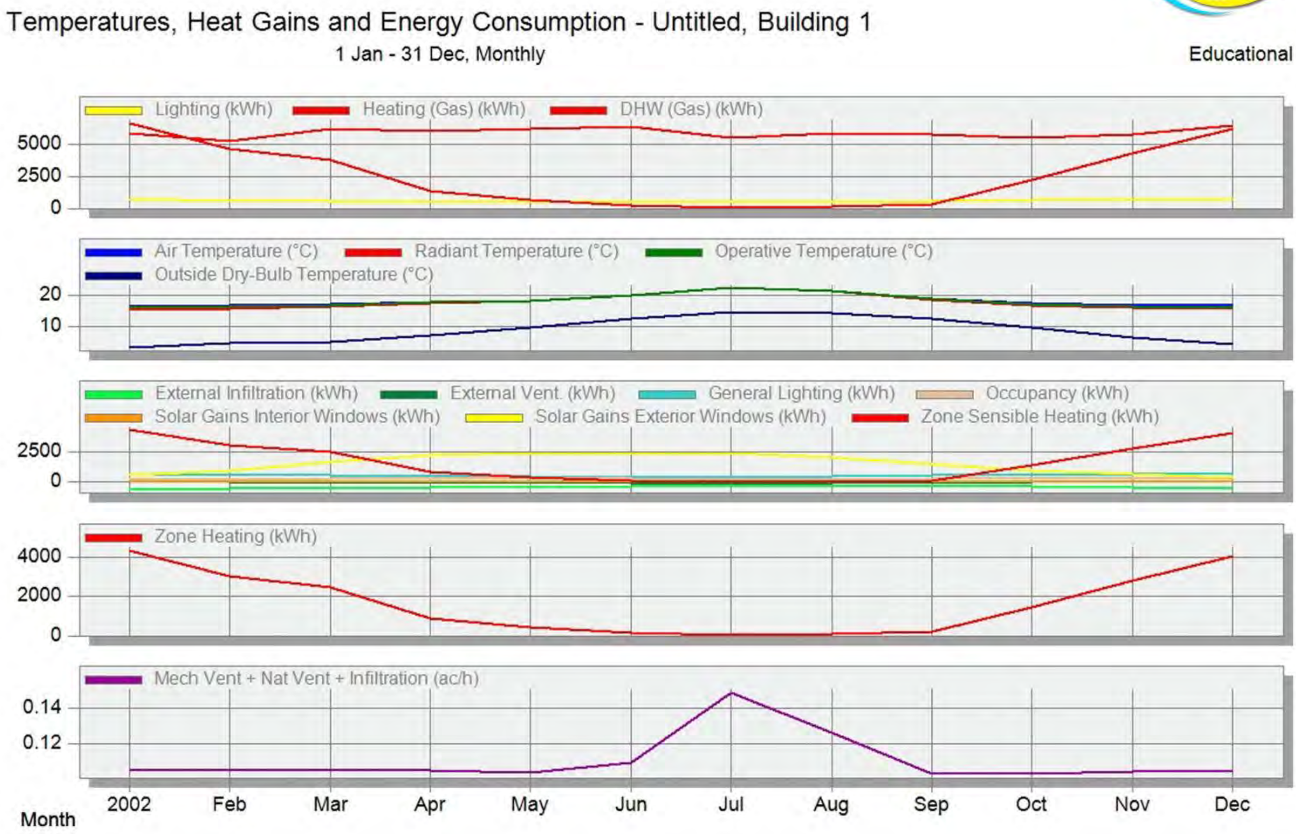
Figure A22. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.53
Operative Temperature (°C)	16.77
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-4.38
Walls (kW)	-3.55
Ceilings (int) (kW)	-0.13
Floors (int) (kW)	0.13
Ground Floors (kW)	0.23
Partitions (int) (kW)	0.00
Roofs (kW)	-4.30
Floors (ext) (kW)	-1.22
External Infiltration (kW)	-1.42
External Vent. (kW)	-42.51
Zone Sensible Heating (kW)	56.98

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 71.210 (kW)				
Block 1 Total Design Heating Capacity = 40.840 (kW)				
Zone 3	16.84	7.81	**9.76**	119.8825
Zone 9	16.98	1.59	**1.98**	123.9309
Zone 2	16.37	4.56	**5.70**	136.9617
Zone 5	17.12	5.24	**6.55**	124.7926
Zone 4	16.55	1.74	**2.18**	140.9006
Zone 6	17.30	0.63	**0.79**	123.0194
Zone 7	17.31	1.02	**1.27**	117.8975
Zone 8	17.46	1.28	**1.60**	110.4666
Zone 10	16.80	5.58	**6.98**	121.2940
Zone 1	17.07	3.23	**4.03**	117.5115
Block 3 Total Design Heating Capacity = 4.070 (kW)				
Zone 1	16.88	3.26	**4.07**	89.2219
Block 2 Total Design Heating Capacity = 8.490 (kW)				
Zone 1	16.90	6.79	**8.49**	92.3275
Roof 1 Total Design Heating Capacity = 8.590 (kW)				
Zone 1	16.68	6.87	**8.59**	58.7187
Roof 2 Total Design Heating Capacity = 4.010 (kW)				
Zone 1	16.44	3.21	**4.01**	50.2306
Roof 3 Total Design Heating Capacity = 4.890 (kW)				
Zone 1	16.58	3.91	**4.89**	49.8540
Block 4 Total Design Heating Capacity = 0.160 (kW)				
Zone 1	16.60	0.13	**0.16**	296.5355
Block 5 Total Design Heating Capacity = 0.160 (kW)				
Zone 1	16.60	0.13	**0.16**	297.3370

Figure A23. The heating design simulation and data of the house.



Lighting (kWh)	719.94	576.17	574.80	506.56	472.38	444.46	436.77	495.50	553.52	628.07	668.00	773.70
Heating (Gas) (kWh)	6649.16	4695.16	3811.58	1387.74	653.46	182.80	45.15	93.19	273.44	2211.70	4350.96	6199.92
DHW (Gas) (kWh)	5879.52	5269.36	6198.65	6101.63	6198.65	6420.76	5560.40	5879.52	5782.51	5560.40	5782.51	6517.77
Air Temperature (°C)	16.53	16.76	17.12	17.86	18.28	20.11	22.27	21.23	18.77	17.35	16.88	16.65
Radiant Temperature (°C)	15.39	15.85	16.44	17.62	18.18	20.09	22.37	21.25	18.68	16.87	16.04	15.55
Operative Temperature (°C)	15.96	16.30	16.78	17.74	18.23	20.10	22.32	21.24	18.73	17.11	16.46	16.10
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-574.77	-477.26	-518.97	-454.85	-371.35	-318.98	-326.76	-296.97	-270.62	-337.19	-448.38	-534.88
External Vent. (kWh)	0.00	0.00	-0.76	-4.26	-2.43	-19.81	-152.72	-54.56	-2.10	0.00	0.00	0.00
General Lighting (kWh)	719.94	576.17	574.80	506.56	472.38	444.46	436.77	495.50	553.52	628.07	668.00	773.70
Occupancy (kWh)	300.50	269.06	314.15	303.07	302.89	290.43	224.64	249.52	279.61	283.24	295.13	333.12
Solar Gains Interior Windows (kWh)	0.60	1.02	1.74	2.13	2.21	2.14	2.26	1.93	1.50	0.96	0.70	0.40
Solar Gains Exterior Windows (kWh)	549.08	973.35	1707.02	2194.60	2368.24	2361.63	2439.62	2015.75	1491.29	926.58	645.60	371.52
Zone Sensible Heating (kWh)	4298.95	3036.15	2465.36	896.99	421.65	117.77	29.10	60.00	176.42	1430.80	2813.47	4009.43
Zone Heating (kWh)	4321.95	3051.86	2477.53	902.03	424.75	118.82	29.35	60.57	177.74	1437.61	2828.12	4029.95
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.11	0.15	0.13	0.10	0.10	0.10	0.10

Figure A24. The simulation detailed results of the house.

Case 9. A House Built in 2008

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of timber frame construction.	0.363	Increase 12 cm Insulation
	Flat -	-
	Pitched 0.231	Increase 24 cm Insulation
Floors are is solid concrete construction.	0.355	Increase 24 cm Insulation
Internal Walls are of timber studwork framed construction.	0.727	
Windows are timber double glazed.		

* As a basis for a theory of possibility

Description

The subject comprise a two story detached house. Ground Floor: Entrance Hall and Lobby, Hall, Living room, Dining room/bedroom four, Kitchen/family room, Utility room and Cloaroom.

First Floor: Four Bedroom, En suite shower room and bathroom.

Weather Dry

Heating and hot water

The property is heated by gas fired boiler. Hating to the rooms is provided by water filled radiators.

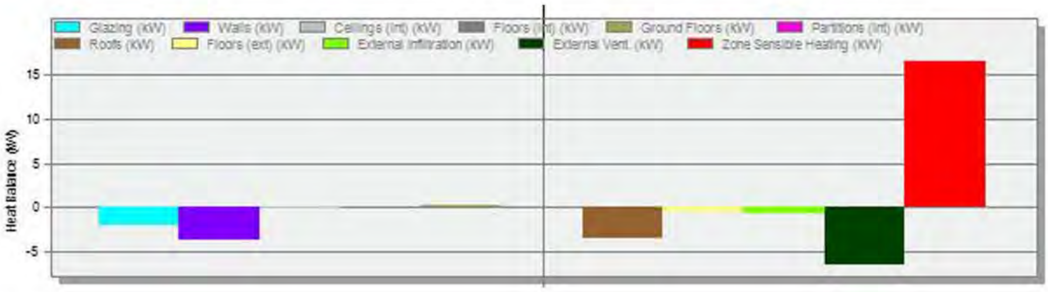
Local heating is provided by a gas fire. Hot water is stored in a storage tank.

Gross internal floor area (m²) 240 m^2

Address

DALKEITH, MIDLOTHIAN,
EH22 1JF

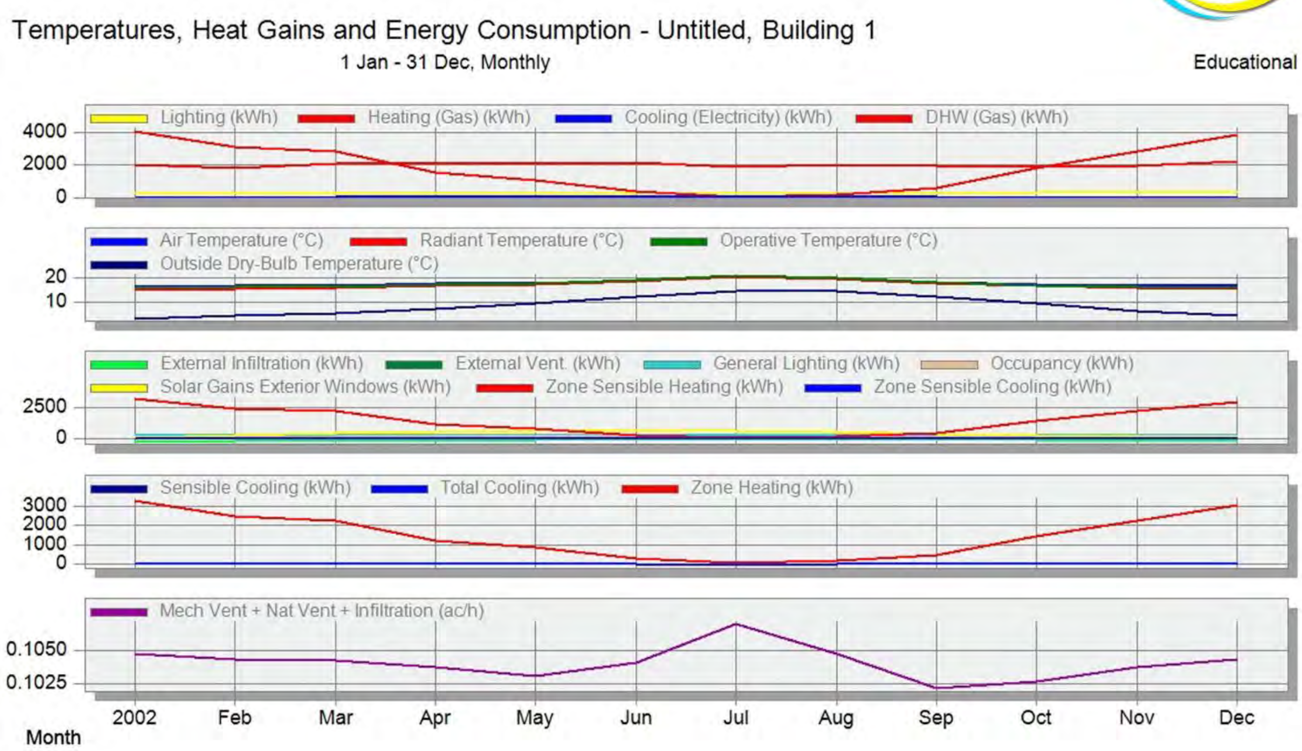
Figure A25. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.23
Operative Temperature (°C)	16.61
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.91
Walls (kW)	-3.62
Ceilings (int) (kW)	-0.14
Floors (int) (kW)	-0.01
Ground Floors (kW)	0.21
Partitions (int) (kW)	0.00
Roofs (kW)	-3.50
Floors (ext) (kW)	-0.53
External Infiltration (kW)	-0.65
External Vent. (kW)	-6.51
Zone Sensible Heating (kW)	16.58

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Sitting Room	16.59	1.48	**1.85**	68.1944
Hall	15.59	2.17	**2.71**	163.7377
Kitchen BreakfastRoo...	16.83	1.57	**1.97**	69.2373
Store	16.48	0.37	**0.46**	144.0775
Family Room	16.70	1.33	**1.66**	75.2884
Utility Room	16.77	0.42	**0.53**	97.1051
Vestibule	14.77	0.68	**0.85**	355.9742
Service	17.33	0.13	**0.16**	70.4426
Dining Room	16.62	1.25	**1.56**	81.7330
Bed Room	17.07	0.53	**0.66**	71.1292
Garage Total Design Heating Capacity = 3.400 (kW)				
Garage	15.85	2.72	**3.40**	100.8715
Roof 1 Total Design Heating Capacity = 2.140 (kW)				
Zone 1	16.50	1.71	**2.14**	35.4664
First Floor Roof Total Design Heating Capacity = 2.170 (kW)				
Service	17.22	0.07	**0.09**	23.4414
Master BedRoom	17.04	0.43	**0.54**	28.8401
Bed Room	17.10	0.23	**0.29**	24.5301
Service	17.17	0.09	**0.12**	28.6148
Bed Room	16.95	0.21	**0.26**	27.1974
Service	17.42	0.09	**0.11**	18.6289
Hall	17.39	0.25	**0.31**	32.4499
Landing	17.48	0.09	**0.11**	21.3438
Bed Room	16.72	0.28	**0.34**	11.4110
Roof Garage Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.01	0.00	**0.00**	0.0000
Window Roof Total Design Heating Capacity = 0.170 (kW)				
Zone 1	16.78	0.14	**0.17**	625.4047
Window Roof Total Design Heating Capacity = 0.160 (kW)				
Zone 1	16.78	0.13	**0.16**	611.3410

Figure A26. The heating design simulation and data of the house.



Lighting (kWh)	312.16	261.41	275.52	251.84	244.13	236.33	225.30	247.75	261.27	281.44	295.25	334.38
Heating (Gas) (kWh)	4069.67	3101.50	2808.56	1520.83	1064.38	362.34	45.56	190.09	565.06	1778.95	2833.32	3800.23
Cooling (Electricity) (kWh)	0.00	0.00	1.00	3.29	4.78	16.71	28.46	13.07	0.82	0.00	0.00	0.00
DHW (Gas) (kWh)	1985.42	1779.38	2093.18	2060.42	2093.18	2168.19	1877.66	1985.42	1952.66	1877.66	1952.66	2200.95
Air Temperature (°C)	16.39	16.59	16.87	17.39	17.64	18.88	20.54	19.68	18.02	17.20	16.78	16.56
Radiant Temperature (°C)	15.04	15.42	15.86	16.77	17.16	18.66	20.47	19.53	17.68	16.47	15.72	15.27
Operative Temperature (°C)	15.71	16.01	16.37	17.08	17.40	18.77	20.50	19.60	17.85	16.84	16.25	15.92
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-257.37	-212.77	-229.74	-195.41	-152.75	-117.03	-107.84	-97.50	-104.30	-148.12	-200.12	-240.17
External Vent. (kWh)	0.00	0.00	-0.19	-0.39	-0.72	-3.27	-8.03	-3.79	-0.44	0.00	0.00	0.00
General Lighting (kWh)	312.16	261.41	275.52	251.84	244.13	236.33	225.30	247.75	261.27	281.44	295.25	334.38
Occupancy (kWh)	124.73	111.65	130.85	127.67	128.75	127.88	102.23	112.23	119.42	117.25	122.25	138.17
Solar Gains Exterior Windows (kWh)	107.91	217.77	413.57	548.62	606.58	618.51	634.60	512.51	369.11	215.96	129.87	71.62
Zone Sensible Heating (kWh)	3239.97	2469.46	2236.61	1211.45	847.81	288.67	36.27	151.50	450.45	1417.54	2256.05	3026.41
Zone Sensible Cooling (kWh)	0.00	0.00	-1.40	-4.60	-6.68	-23.26	-38.52	-16.83	-1.15	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	-1.40	-4.61	-6.69	-23.31	-38.62	-16.87	-1.15	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	-1.40	-4.61	-6.70	-23.39	-39.84	-18.30	-1.15	0.00	0.00	0.00
Zone Heating (kWh)	3255.74	2481.20	2246.85	1216.67	851.51	289.87	36.45	152.07	452.05	1423.16	2266.66	3040.18
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.10	0.11	0.10	0.10	0.10	0.10	0.10

Figure A27. The simulation detailed results of the house.

Case 10. A House Built in 2008

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone dry lined internally.	0.358	Increase 13 cm Insulation
	Flat -	-
	Pitched 0.253	Increase 24 cm Insulation
Floors are is solid concrete construction.	0.364	Increase 24 cm Insulation
Internal Walls are plasterboard.	0.742	
Windows are timber double glazed.		

* As a basis for a theory of possibility

Description

The subjects comprise a detached 3 storey dwelling house, known as a Huf Haus, with single storey attached accommodation within a refurbished cottage style dwelling house.

Weather Dry

Heating and hot water

Geo thermal heating from ground source pump system underfloor.

Electric underfloor heating to Livingroom/Kitchen/Diningroom.

Gross internal floor area (m²) 278 m^2

Address

WEST LINTON EH46 7AP

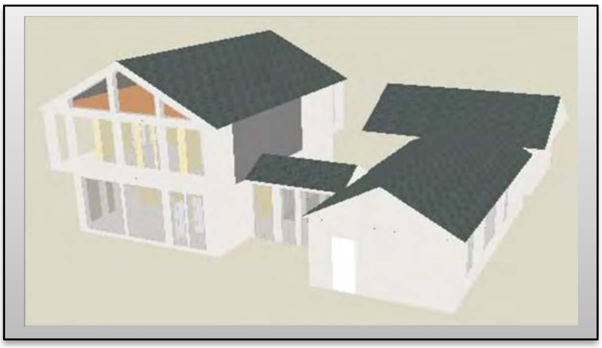
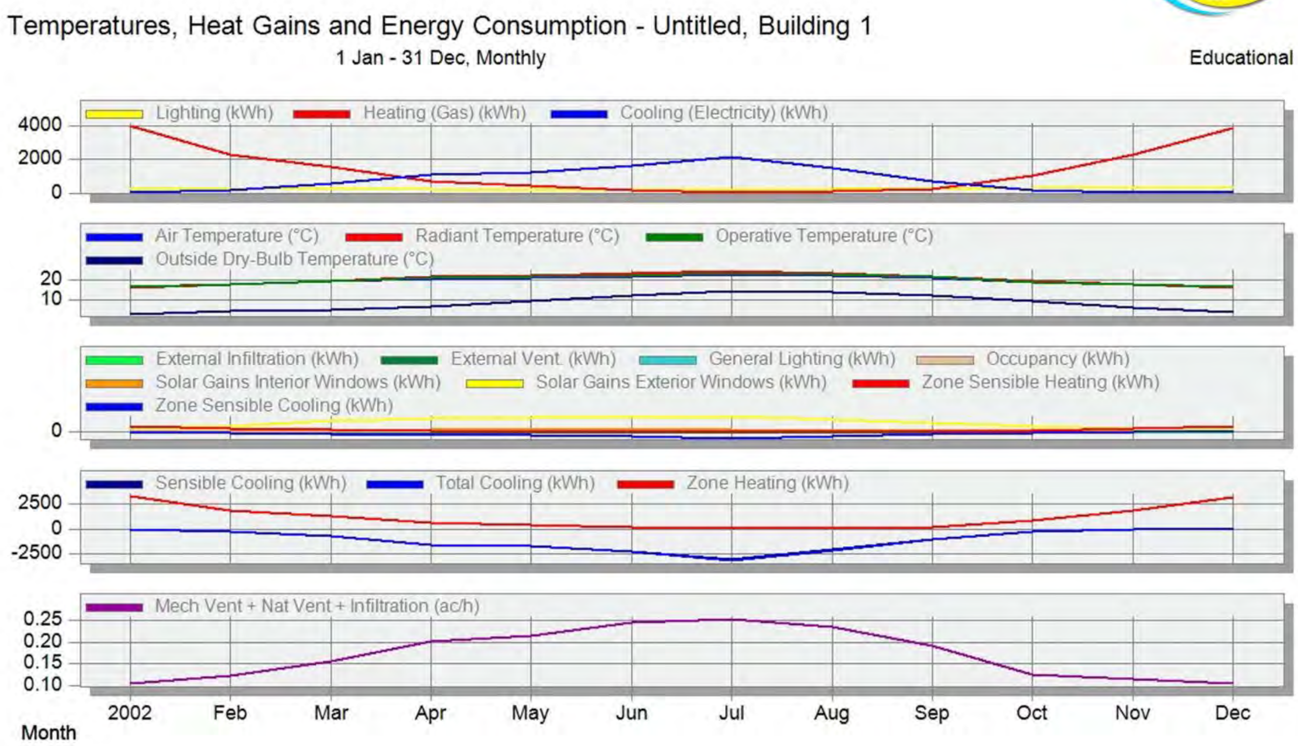


Figure A28. The software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.83
Operative Temperature (°C)	16.92
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-8.68
Walls (kW)	-2.90
Ceilings (int) (kW)	-0.98
Floors (int) (kW)	0.04
Ground Floors (kW)	0.14
Partitions (int) (kW)	-0.01
Floors (ext) (kW)	-0.24
External Infiltration (kW)	-0.98
External Vent. (kW)	-9.80
Zone Sensible Heating (kW)	23.37

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 29.200 (kW)				
Ground Floor Total Design Heating Capacity = 14.430 (kW)				
Sitting Room	16.87	2.28	**2.85**	58.9273
Study Room	15.56	1.56	**1.95**	107.4034
Service	15.94	0.42	**0.52**	158.4335
Balcony	17.26	1.62	**2.02**	234.2429
Hall	14.87	1.68	**2.10**	153.3437
Kitchen LivingRoom ...	16.29	3.99	**4.99**	73.3321
Lower Ground Floor Total Design Heating Capacity = 2.890 (kW)				
Hall	17.90	0.50	**0.63**	40.4573
Service	17.91	0.20	**0.25**	40.6773
Utility Room	17.88	0.46	**0.57**	40.8318
Double BedRoom	17.92	0.58	**0.72**	40.0045
Double BedRoom	17.92	0.58	**0.72**	40.0071
First Floor Total Design Heating Capacity = 10.460 (kW)				
Balcony	16.93	5.46	**6.82**	201.7568
Service	17.23	0.39	**0.49**	57.1041
Hall	17.38	0.66	**0.82**	51.5640
Service	17.26	0.29	**0.37**	57.0449
Double BedRoom	17.46	0.89	**1.12**	44.9486
Double BedRoom	17.45	0.68	**0.84**	45.9957
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.90	0.00	**0.00**	0.0000
Roof 3 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-2.27	0.00	**0.00**	0.0000
Roof 4 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	0.06	0.00	**0.00**	0.0000
Store Shed Total Design Heating Capacity = 1.420 (kW)				
Store Shed	16.29	1.14	**1.42**	94.9456

Figure A29. The heating design simulation and data of the house.



Lighting (kWh)	325.56	265.87	259.34	203.32	186.46	168.14	181.87	200.93	228.76	283.41	300.28	328.39
Heating (Gas) (kWh)	3996.57	2282.83	1552.89	704.00	442.93	161.59	28.56	85.43	225.50	1056.35	2313.54	3893.79
Cooling (Electricity) (kWh)	8.88	155.47	533.51	1100.03	1218.31	1620.26	2188.96	1486.94	727.28	173.71	66.27	1.07
Air Temperature (°C)	17.15	18.11	19.40	20.79	21.23	22.09	23.05	22.35	21.30	19.27	18.01	16.98
Radiant Temperature (°C)	16.54	18.03	19.86	21.75	22.28	23.32	24.41	23.43	22.04	19.43	17.78	16.32
Operative Temperature (°C)	16.84	18.07	19.63	21.27	21.75	22.70	23.73	22.89	21.67	19.35	17.89	16.65
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-410.83	-361.21	-419.97	-391.64	-336.21	-272.16	-242.44	-230.02	-252.42	-283.66	-337.61	-375.23
External Vent. (kWh)	-4.00	-77.90	-244.93	-417.45	-419.35	-417.79	-384.66	-335.72	-265.09	-86.03	-41.69	-5.17
General Lighting (kWh)	325.56	265.87	259.34	203.32	186.46	168.14	181.87	200.93	228.76	283.41	300.28	328.39
Occupancy (kWh)	182.98	158.38	170.55	156.75	157.80	151.34	140.09	147.09	151.53	166.58	173.21	191.57
Solar Gains Interior Windows (kWh)	290.41	504.60	872.16	1076.69	1132.29	1119.00	1198.61	973.34	746.83	476.28	341.88	192.86
Solar Gains Exterior Windows (kWh)	1778.34	3201.18	5672.49	7151.87	7538.42	7483.98	7809.13	6471.44	4868.99	3084.84	2083.19	1192.34
Zone Sensible Heating (kWh)	3178.57	1814.52	1233.29	559.02	351.72	128.36	22.70	67.89	179.20	840.17	1839.60	3096.87
Zone Sensible Cooling (kWh)	-12.08	-215.99	-740.63	-1528.28	-1691.68	-2250.67	-2987.65	-2016.57	-1003.70	-238.92	-91.56	-1.48
Sensible Cooling (kWh)	-12.43	-217.66	-746.91	-1540.04	-1704.32	-2262.97	-3007.66	-2030.38	-1013.42	-242.65	-92.78	-1.50
Total Cooling (kWh)	-12.43	-217.66	-746.91	-1540.04	-1705.63	-2268.37	-3064.54	-2081.71	-1018.19	-243.20	-92.78	-1.50
Zone Heating (kWh)	3197.26	1826.27	1242.32	563.20	354.35	129.27	22.85	68.34	180.40	845.08	1850.83	3115.03
Mech Vent + Nat Vent + Infiltration (ac/h)	0.11	0.12	0.16	0.20	0.21	0.25	0.25	0.23	0.19	0.13	0.11	0.11

Figure A30. The simulation detailed results of the house.

Case 11. A House Built in 2006

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of load bearing timber frame construction with a masonry external leaf finished with render and facing brick.	0.375	Increase 14 cm Insulation
	Flat 0.252	Increase 20 cm Insulation
	Pitched 0.211	Increase 24 cm Insulation
Floor is of suspended timber construction with fitted coverings throughout.	0.314	Increase 24 cm Insulation
Internal Wall are of plasterboard construction.	0.767	
Windows are original double glazed type.		

* As a basis for a theory of possibility

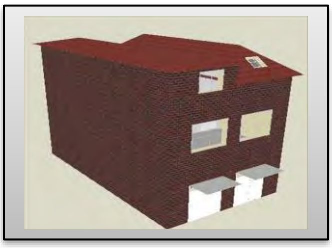
Description

The property comprises a 3 storey terraced townhouse

Ground floor: Entrance hall way, Kitchen/Dining room and WC apartment.

First floor: Living room, Bedroom, Study room and Bathroom.

Second floor: Master Bedroom with En suite Shower room, 2 further Bedrooms and separate WC.



Weather Dry and Clear

Heating and hot water

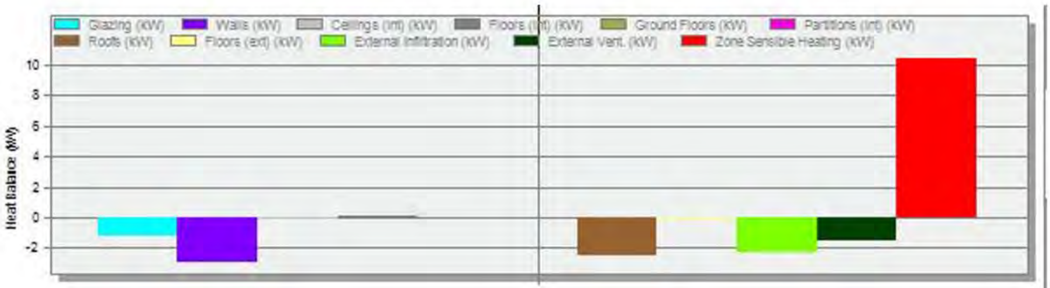
Space heating is provided by a gas fired radiator central heating installation. The boiler is located within Kitchen. Hot water is stored within an insulated tank within second floor landing cupboard.

Gross internal floor area (m²) 144 m² approx.

Address

EDINBURGH, EH14 1TJ

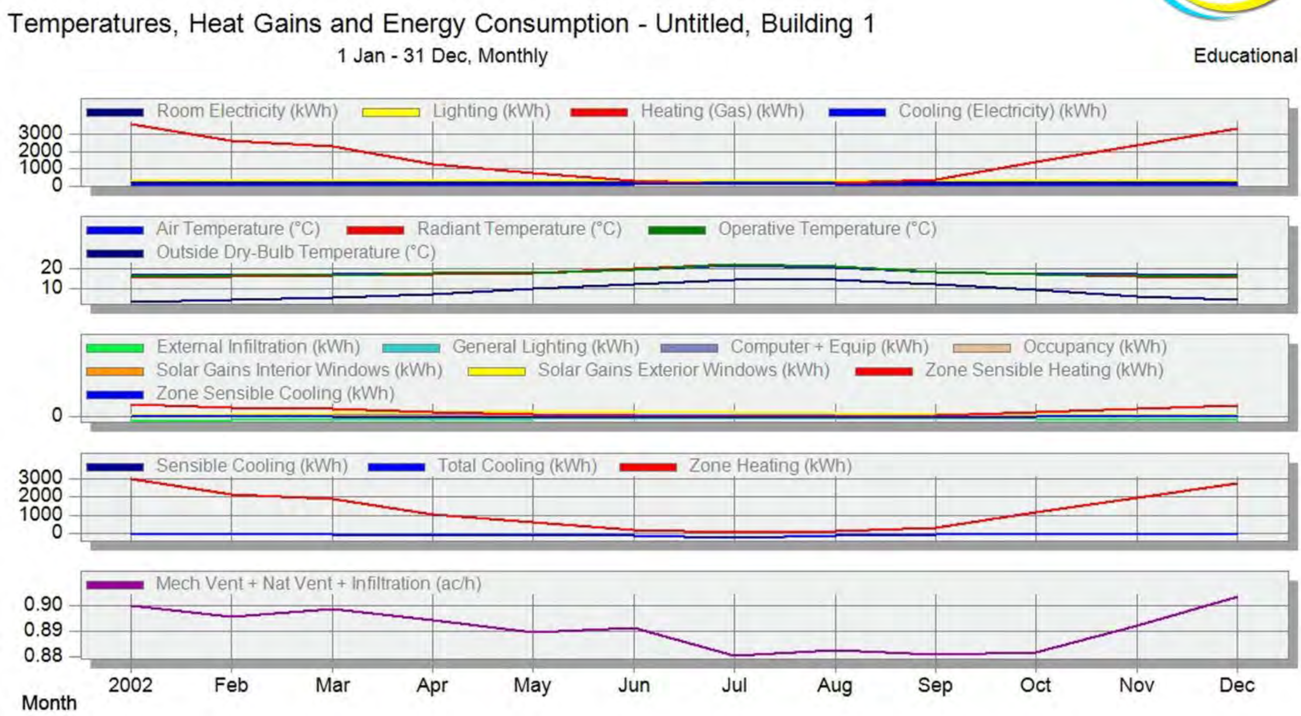
Figure A31. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.53
Operative Temperature (°C)	16.77
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.20
Walls (kW)	-2.96
Ceilings (int) (kW)	-0.07
Floors (int) (kW)	0.07
Ground Floors (kW)	0.04
Partitions (int) (kW)	0.00
Roofs (kW)	-2.47
Floors (ext) (kW)	-0.08
External Infiltration (kW)	-2.31
External Vent. (kW)	-1.47
Zone Sensible Heating (kW)	10.44

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 13.060 (kW)				
Ground Floor Total Design Heating Capacity = 4.160 (kW)				
Hall Landing	17.29	0.49	**0.62**	47.8543
Kitchen DiningRoom	16.47	1.20	**1.50**	74.7456
Garage	16.34	0.89	**1.11**	86.4514
Vestibule	15.90	0.58	**0.73**	406.0228
CupBoard	17.40	0.06	**0.07**	76.1076
Service	17.21	0.10	**0.13**	75.5220
First Floor Total Design Heating Capacity = 3.020 (kW)				
Hall Landing	17.32	0.31	**0.39**	47.6376
Service	17.25	0.22	**0.28**	54.0115
Double BedRoom	16.83	0.59	**0.74**	66.1277
BedRoom	16.94	0.34	**0.43**	72.1185
Sitting Room	16.65	0.94	**1.18**	66.4675
Second Floor Total Design Heating Capacity = 1.300 (kW)				
Hall	17.40	0.07	**0.08**	53.1287
Double BedRoom	16.86	0.37	**0.46**	57.3100
Service	17.32	0.07	**0.09**	56.2726
Master BedRoom	16.84	0.54	**0.67**	56.1281
Roof 2 Total Design Heating Capacity = 3.110 (kW)				
Zone 1	12.87	2.48	**3.11**	529.0548
Second Floor Total Design Heating Capacity = 0.720 (kW)				
Service	17.18	0.12	**0.15**	36.9892
Hall Landing	17.34	0.30	**0.37**	28.0292
Double BedRoom	17.13	0.16	**0.20**	36.0627
Roof 1 Total Design Heating Capacity = 0.750 (kW)				
Zone 1	17.00	0.60	**0.75**	28.7603

Figure A32. The heating design simulation and data of the house.



Room Electricity (kWh)	196.86	177.81	196.86	190.51	196.86	190.51	196.86	196.86	190.51	196.86	190.51	196.86
Lighting (kWh)	289.06	260.86	290.82	282.01	290.82	283.77	287.30	289.06	280.25	287.30	280.25	292.58
Heating (Gas) (kWh)	3581.66	2604.72	2303.79	1263.94	751.44	278.66	110.14	170.49	387.87	1383.70	2375.77	3320.56
Cooling (Electricity) (kWh)	0.88	13.37	27.01	57.34	49.34	75.53	127.33	77.05	31.55	7.95	6.22	0.73
Air Temperature (°C)	16.64	16.84	17.05	17.52	17.91	19.53	21.73	20.67	18.49	17.36	16.99	16.70
Radiant Temperature (°C)	15.58	16.01	16.47	17.37	17.91	19.74	22.05	20.87	18.52	16.92	16.24	15.68
Operative Temperature (°C)	16.11	16.43	16.76	17.45	17.91	19.64	21.89	20.77	18.51	17.14	16.62	16.19
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-932.60	-773.03	-830.33	-706.64	-565.21	-466.48	-475.82	-423.42	-406.54	-541.11	-729.12	-863.64
General Lighting (kWh)	289.06	260.86	290.82	282.01	290.82	283.77	287.30	289.06	280.25	287.30	280.25	292.58
Computer + Equip (kWh)	196.86	177.81	196.86	190.51	196.86	190.51	196.86	196.86	190.51	196.86	190.51	196.86
Occupancy (kWh)	92.17	82.95	93.90	90.79	92.06	85.26	72.72	78.85	86.15	89.90	89.72	96.21
Solar Gains Interior Windows (kWh)	2.61	4.47	7.55	9.78	10.23	9.92	10.37	9.01	6.66	4.27	3.05	1.81
Solar Gains Exterior Windows (kWh)	254.02	427.65	721.04	935.24	995.75	976.57	1029.24	853.92	630.36	398.13	299.48	173.74
Zone Sensible Heating (kWh)	2736.27	1969.48	1722.72	927.14	555.61	212.89	87.43	133.88	292.82	1034.88	1793.48	2525.80
Zone Sensible Cooling (kWh)	-1.86	-25.15	-61.34	-140.38	-147.14	-216.49	-308.57	-213.01	-119.30	-30.88	-15.78	-2.27
Sensible Cooling (kWh)	-1.48	-22.33	-45.11	-95.76	-82.37	-126.04	-209.71	-125.84	-52.62	-13.26	-10.39	-1.22
Total Cooling (kWh)	-1.48	-22.33	-45.11	-95.76	-82.40	-126.14	-212.64	-128.68	-52.69	-13.27	-10.39	-1.22
Zone Heating (kWh)	2972.77	2161.92	1912.14	1049.07	623.69	231.29	91.41	141.51	321.93	1148.47	1971.89	2756.07
Mech Vent + Nat Vent + Infiltration (ac/h)	0.90	0.90	0.90	0.89	0.89	0.89	0.88	0.88	0.88	0.88	0.89	0.90

Figure A33. The simulation detailed results of the house.

Case 12. A House Built in 2006

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional cavity concrete block rendered externally with white paint finish and incorporating hardwood timber cladding and in part facing brick.	0.386	Increase 14 cm Insulation
	Flat 0.266	Increase 21 cm Insulation
	Pitched 0.246	Increase 24 cm Insulation
Floors are solid assumed concrete screed.	0.365	Increase 24 cm Insulation
Internal Walls are Plasterboard construction.	0.749	
Windows are Original metal double glazed windows.		

* As a basis for a theory of possibility

Description

Detached two storey dwelling house.

Ground Floor: Entrance Vestibule and Hall, Living room, Dining room, Sitting room, Kitchen, Utility Room, Bedroom/Study and Cloakroom.

First Floor: Master Bedroom with En-Suite, Three Bedrooms, Bathroom and En-Suite.

Weather Dry

Heating and hot water

Gas fired wall mounted fanned flue condensing boiler to underfloor heating pipes. Zoned thermostat system. Hot water distribution system with hot water cylinder fed from central heating boiler. The boiler is located within the garage.

Gross internal floor area (m²) 221 m^2 **approx.**

Address

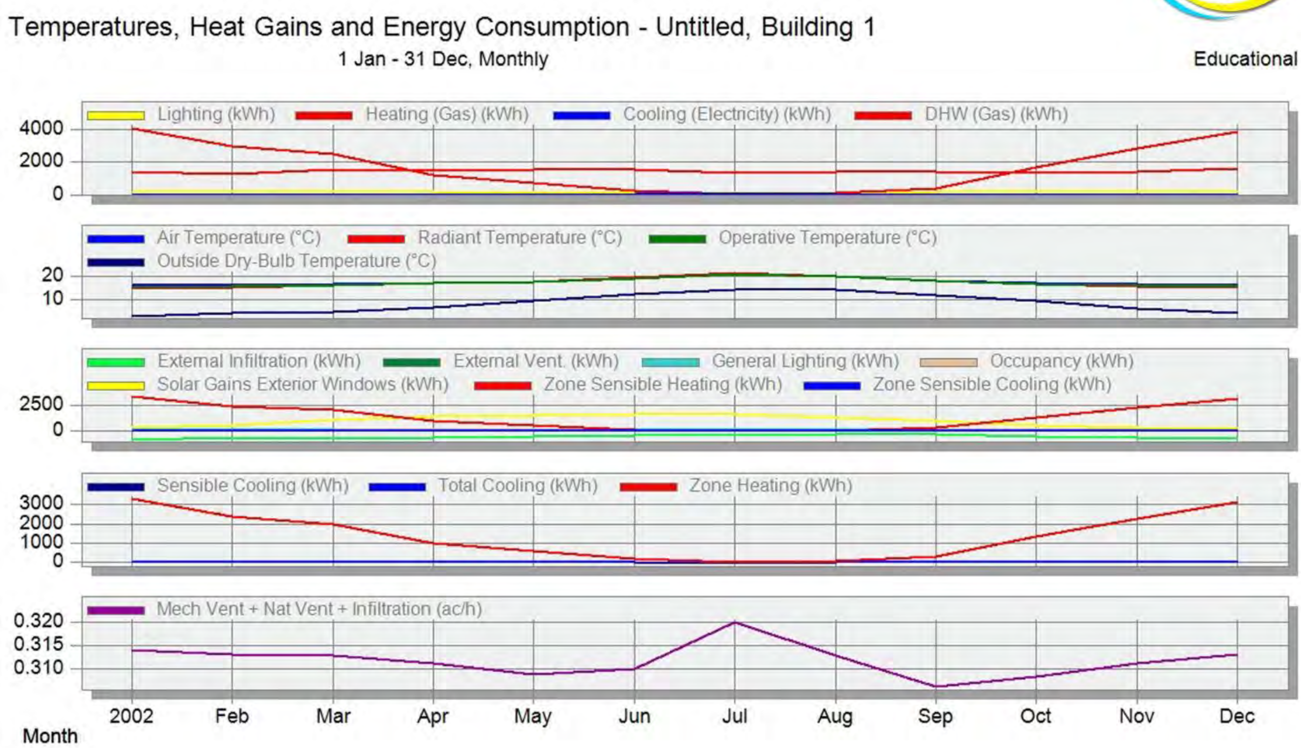
EDINBURGH EH4 6QT

Figure A34. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.18
Operative Temperature (°C)	16.59
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.34
Walls (kW)	-4.55
Ceilings (int) (kW)	-1.45
Floors (int) (kW)	0.26
Ground Floors (kW)	0.16
Partitions (int) (kW)	0.00
Roofs (kW)	-0.18
External Infiltration (kW)	-1.97
External Vent. (kW)	-6.57
Zone Sensible Heating (kW)	16.53

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 20.660 (kW)				
Ground Floor Total Design Heating Capacity = 12.200 (kW)				
Garage	16.15	2.07	**2.58**	98.1171
Kitchen	17.00	1.06	**1.33**	73.4448
Dining Room	16.61	0.96	**1.20**	91.4925
Sitting Room	16.67	1.04	**1.30**	89.4056
Utility Room	17.07	0.38	**0.47**	83.2105
Vestibule	17.10	0.38	**0.47**	81.9480
Hall	17.39	0.97	**1.22**	64.7660
Study Room	17.12	0.56	**0.70**	75.3960
Service	17.52	0.26	**0.33**	70.4005
Lounge	16.31	2.08	**2.60**	92.7043
First Floor Total Design Heating Capacity = 8.460 (kW)				
Bed Room	16.07	0.93	**1.16**	103.9459
Landing	16.70	0.79	**0.99**	78.7475
Service	16.67	0.41	**0.52**	85.2271
Service	15.98	0.87	**1.08**	109.3808
Hall	17.27	0.44	**0.55**	58.6439
Bed Room	16.04	1.22	**1.53**	96.7519
Bed Room	16.04	0.94	**1.17**	105.0643
Bed Room	16.57	0.73	**0.92**	78.9223
Service	16.51	0.43	**0.54**	95.2977
Roof Garage Total Design Heating Capacity = 0.000 (kW)				
Zone 1	2.66	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	0.61	0.00	**0.00**	0.0000
Roof Lounge Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.17	0.00	**0.00**	0.0000

Figure A35. The heating design simulation and data of the house.



Lighting (kWh)	198.57	159.68	161.66	139.47	127.25	120.44	115.38	132.94	150.11	170.01	182.12	212.47
Heating (Gas) (kWh)	4109.04	2968.09	2510.55	1219.74	737.75	208.16	10.85	79.09	376.56	1648.38	2850.07	3898.25
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	2.96	11.27	1.24	0.00	0.00	0.00	0.00
DHW (Gas) (kWh)	1430.69	1282.22	1508.34	1484.74	1508.34	1562.39	1353.04	1430.69	1407.08	1353.04	1407.08	1586.00
Air Temperature (°C)	16.27	16.55	16.91	17.51	17.88	19.30	21.08	20.05	18.12	17.18	16.67	16.43
Radiant Temperature (°C)	15.00	15.54	16.20	17.30	17.83	19.47	21.36	20.24	18.11	16.63	15.72	15.17
Operative Temperature (°C)	15.64	16.04	16.55	17.41	17.85	19.39	21.22	20.14	18.11	16.91	16.19	15.80
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-776.46	-645.55	-702.39	-605.37	-487.30	-396.98	-379.68	-336.59	-333.34	-452.77	-604.66	-723.90
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-3.93	-21.34	-7.14	0.00	0.00	0.00	0.00
General Lighting (kWh)	198.57	159.68	161.66	139.47	127.25	120.44	115.38	132.94	150.11	170.01	182.12	212.47
Occupancy (kWh)	90.00	80.64	94.58	92.42	92.90	91.40	72.61	80.58	86.98	85.10	88.49	99.76
Solar Gains Exterior Windows (kWh)	294.67	592.19	1111.55	1429.76	1563.93	1595.03	1584.71	1321.73	976.31	600.38	349.66	195.10
Zone Sensible Heating (kWh)	3270.04	2362.77	1999.22	971.89	587.78	165.87	8.63	63.03	300.25	1313.76	2269.08	3103.44
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-4.07	-14.42	-1.39	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-4.10	-14.49	-1.41	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-4.15	-15.78	-1.73	0.00	0.00	0.00	0.00
Zone Heating (kWh)	3287.23	2374.47	2008.44	975.79	590.20	166.53	8.68	63.27	301.25	1318.70	2280.06	3118.60
Mech Vent + Nat Vent + Infiltration (ac/h)	0.31	0.31	0.31	0.31	0.31	0.31	0.32	0.31	0.31	0.31	0.31	0.31

Figure A36. The simulation detailed results of the house.

Case 13. A House Built in 2006

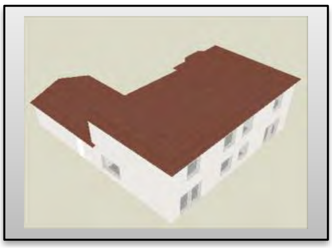
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are Cavity construction the inner leaf of load bearing timber outer of rendered masonry.	0.392	Increase 14 cm Insulation
	Flat -	-
	Pitched 0.301	Increase 26 cm Insulation
Floor are solid construction at ground level and suspended timber at upper floor level.	0.401	Increase 25 cm Insulation
Internal Walls are Plastered and decorated.	0.826	
Windows are u-PVC double glazed windows and doors.		

* As a basis for a theory of possibility

Description

Detached house.

Ground Floor - Entrance vestibule, hallway, living room, sitting room, dining room, kitchen/dining room with utility room off and WC. apartment. First Floor - Landing, master bedroom with en-suite shower room, 2 further bedrooms, each with en-suite shower rooms, bedroom and bathroom.



Weather **Dry and bright.**

Heating and hot water

Gas fired boiler located in utility room serving panel radiators throughout property via thermal store which supplies hot water.

Gross internal floor area (m²) 231 m² **approx.**

Address

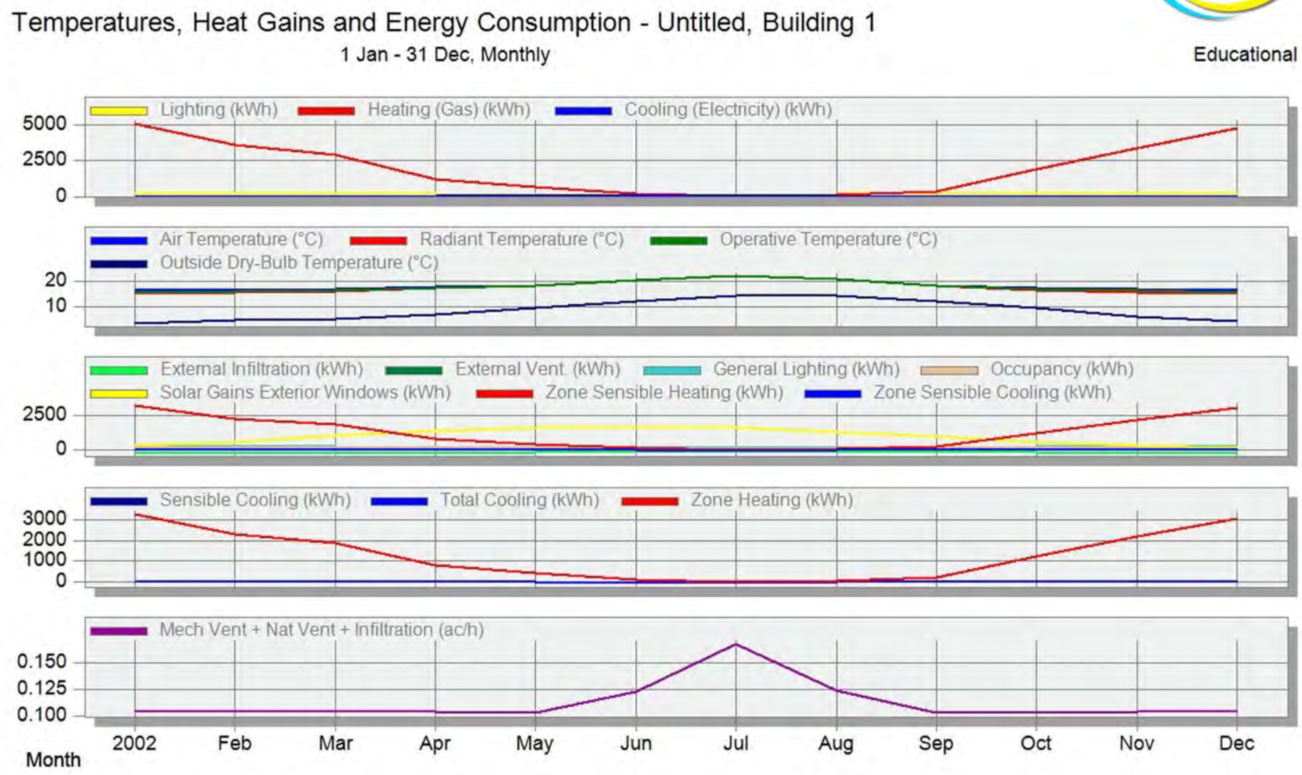
EDINBURGH EH12 8HJ

Figure A37. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.04
Operative Temperature (°C)	16.52
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.73
Walls (kW)	-3.27
Ceilings (int) (kW)	-0.62
Floors (int) (kW)	-0.00
Ground Floors (kW)	0.22
Partitions (int) (kW)	0.00
Roofs (kW)	-3.26
Floors (ext) (kW)	-0.01
External Infiltration (kW)	-0.69
External Vent. (kW)	-20.64
Zone Sensible Heating (kW)	30.94

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 38.690 (kW)				
Ground Floor Total Design Heating Capacity = 23.720 (kW)				
Garage	15.88	3.49	**4.36**	156.2983
Kitchen BreakfastRoom	15.66	3.64	**4.56**	177.4469
Family Room	16.64	1.85	**2.31**	134.5812
Utility Room	14.26	2.30	**2.87**	263.1887
Service	17.34	0.30	**0.38**	123.9267
Hall	17.59	1.16	**1.46**	107.2080
Dressing Room	16.78	1.26	**1.57**	136.1563
Vestibule	16.60	0.68	**0.85**	161.1684
Living Room	16.65	4.29	**5.36**	127.2320
Entrance Total Design Heating Capacity = 2.080 (kW)				
Zone 8	14.80	1.66	**2.08**	445.3179
First Floor Total Design Heating Capacity = 12.890 (kW)				
Master BedRoom	17.15	2.16	**2.71**	109.6761
Service	17.34	0.43	**0.54**	122.5080
Hall	17.49	1.13	**1.41**	103.7072
Service	16.63	1.25	**1.56**	135.3275
Bed Room	16.71	1.26	**1.58**	132.6940
Bed Room	16.61	1.89	**2.37**	128.3618
Bed Room	16.73	1.72	**2.15**	125.4526
Service	17.20	0.46	**0.57**	120.6309
Main Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-2.91	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.47	0.00	**0.00**	0.0000
Roof 3 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.27	0.00	**0.00**	0.0000

Figure A38. The heating design simulation and data of the house.



Lighting (kWh)	245.61	202.62	198.06	155.89	144.45	131.29	140.80	155.05	174.88	214.81	227.25	247.16
Heating (Gas) (kWh)	5057.93	3551.71	2857.89	1200.09	674.13	205.55	23.25	114.67	366.28	1908.38	3353.50	4716.96
Cooling (Electricity) (kWh)	0.00	0.00	0.00	1.79	0.96	15.24	41.38	11.34	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.55	16.78	17.06	17.72	18.43	20.39	22.23	20.96	18.48	17.28	16.90	16.59
Radiant Temperature (°C)	15.12	15.64	16.25	17.44	18.31	20.45	22.42	21.01	18.39	16.64	15.85	15.23
Operative Temperature (°C)	15.83	16.21	16.66	17.58	18.37	20.42	22.32	20.99	18.44	16.96	16.38	15.91
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-275.96	-228.96	-247.61	-214.97	-180.54	-159.06	-155.29	-134.84	-123.21	-159.44	-215.01	-255.12
External Vent. (kWh)	0.00	0.00	-0.62	-1.27	-0.64	-28.61	-95.69	-23.75	-0.89	0.00	0.00	0.00
General Lighting (kWh)	245.61	202.62	198.06	155.89	144.45	131.29	140.80	155.05	174.88	214.81	227.25	247.16
Occupancy (kWh)	140.41	126.42	142.90	137.15	136.70	123.74	107.78	118.19	131.21	137.21	136.74	146.57
Solar Gains Exterior Windows (kWh)	277.95	555.39	1040.86	1396.84	1577.12	1625.82	1619.70	1309.46	929.67	550.12	333.18	183.98
Zone Sensible Heating (kWh)	3267.09	2294.24	1845.88	775.00	435.35	132.75	15.00	74.00	236.50	1233.28	2166.03	3046.99
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	-2.97	-1.60	-25.03	-65.19	-16.83	-0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	-2.98	-1.61	-25.25	-65.57	-16.93	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	-2.98	-1.61	-25.45	-69.10	-18.94	-0.00	0.00	0.00	0.00
Zone Heating (kWh)	3287.66	2308.61	1857.63	780.06	438.19	133.61	15.11	74.53	238.08	1240.45	2179.78	3066.02
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.12	0.17	0.12	0.10	0.10	0.10	0.10

Figure A39. The simulation detailed results of the house.

Case 14. A House Built in 2005

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of cavity timber frame construction with a masonry roughcast outer leaf.	0.391	Increase 14 cm Insulation
	Flat 0.304	Increase 23 cm Insulation
	Pitched 0.314	Increase 26 cm Insulation
Floor Flooring at ground floor level appears to be of suspended timber construction overlaid with chipboard floor panels.	0.406	Increase 26 cm Insulation
Internal Walls are plasterboard lined.	0.848	
Windows are timber double glazed.		

* As a basis for a theory of possibility

Description

Purpose built two storey detached house .

Ground Floor:

Lounge/Dining Room, Sittingroom ,Study/Bedroom, Shower Room/WC, Kitchen/Breakfast Room, Utility Room and Storeroom   .

First Floor: Landing. Master bedroom Lounge.

Weather   Dry and sunny.

Heating and hot water

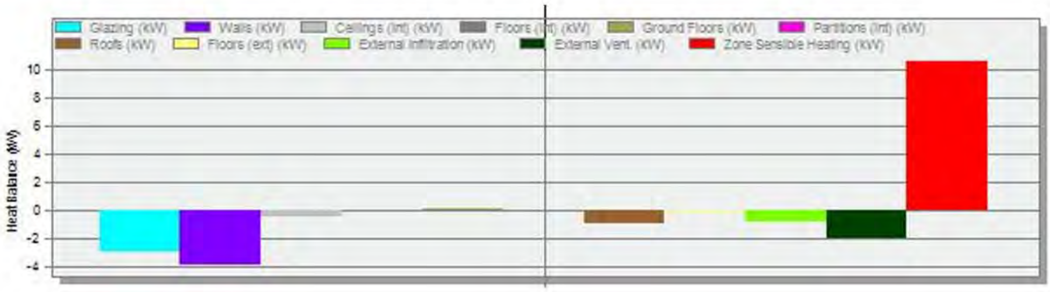
LPG combination boiler providing domestic hot water and serving a wet radiator system. No hot water tank.

Gross internal floor area (m²)   240 m^2

Address

PENICUIK EH26 8PY

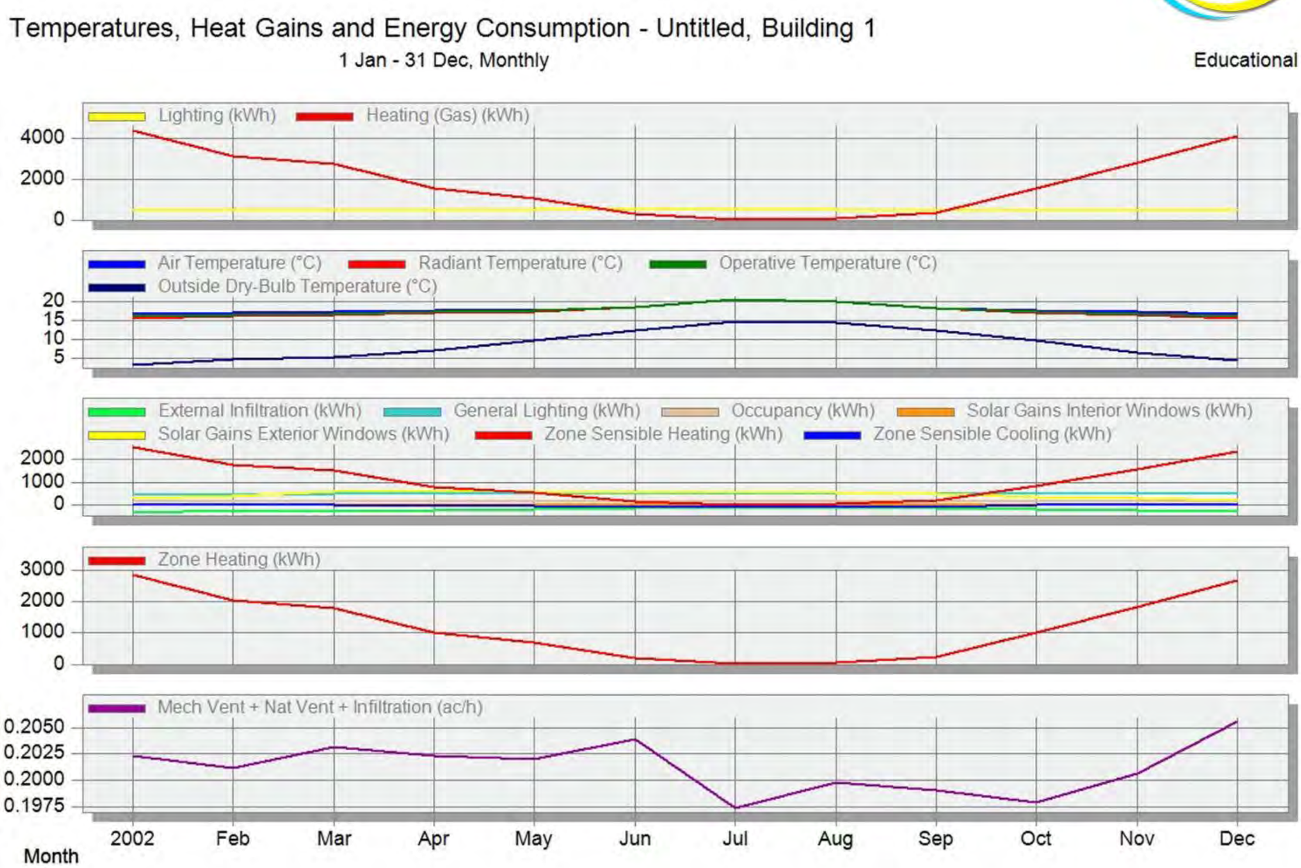
Figure A40. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.29
Operative Temperature (°C)	16.64
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.90
Walls (kW)	-3.89
Ceilings (int) (kW)	-0.42
Floors (int) (kW)	0.05
Ground Floors (kW)	0.19
Partitions (int) (kW)	0.00
Roofs (kW)	-0.90
Floors (ext) (kW)	-0.13
External Infiltration (kW)	-0.78
External Vent. (kW)	-2.03
Zone Sensible Heating (kW)	10.62

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 13.280 (kW)				
Ground Floor Total Design Heating Capacity = 7.660 (kW)				
Kitchen	16.86	0.59	**0.74**	44.7659
BoilerRoom	16.77	0.22	**0.28**	83.2016
DiningRoom	16.72	1.63	**2.04**	38.2221
Garage	15.94	1.53	**1.91**	69.8577
Servie2	16.66	0.33	**0.41**	81.0279
Service1	17.54	0.08	**0.10**	30.4484
FamilyRoom	16.75	0.62	**0.78**	49.7740
LivingRoom	16.78	1.12	**1.40**	40.1958
First Floor Total Design Heating Capacity = 3.280 (kW)				
Bedroom3	16.74	0.57	**0.71**	42.3529
Bedroom5	17.27	0.11	**0.14**	38.6032
Bedroom2	16.59	0.62	**0.77**	48.5927
Bedroom4	16.62	0.22	**0.28**	81.1722
Bedroom1	16.66	1.10	**1.38**	39.7119
Main Roof Total Design Heating Capacity = 2.180 (kW)				
Zone 1	16.62	1.74	**2.18**	30.2536
WindowRoof Total Design Heating Capacity = 0.160 (kW)				
Zone 1	16.35	0.13	**0.16**	1.#INF
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-2.77	0.00	**0.00**	0.0000
MainRoof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.23	0.00	**0.00**	0.0000

Figure A41. The heating design simulation and data of the house.



Lighting (kWh)	501.63	452.69	504.69	489.40	504.69	492.46	498.57	501.63	486.34	498.57	486.34	507.75
Heating (Gas) (kWh)	4410.23	3141.71	2765.80	1530.30	1041.05	285.36	6.00	76.76	354.21	1571.28	2789.93	4096.05
Air Temperature (°C)	16.75	16.96	17.14	17.48	17.61	18.52	20.36	19.79	18.21	17.44	17.13	16.79
Radiant Temperature (°C)	15.54	16.00	16.39	17.07	17.29	18.43	20.38	19.77	18.07	16.92	16.30	15.63
Operative Temperature (°C)	16.14	16.48	16.76	17.28	17.45	18.47	20.37	19.78	18.14	17.18	16.71	16.21
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-317.49	-263.37	-282.49	-238.24	-185.47	-137.85	-131.36	-125.21	-133.40	-184.56	-249.09	-293.76
General Lighting (kWh)	501.63	452.69	504.69	489.40	504.69	492.46	498.57	501.63	486.34	498.57	486.34	507.75
Occupancy (kWh)	159.99	143.90	163.13	158.35	162.37	155.92	136.77	143.90	151.80	156.27	155.58	166.99
Solar Gains Interior Windows (kWh)	0.20	0.28	0.37	0.36	0.32	0.29	0.31	0.28	0.28	0.24	0.23	0.14
Solar Gains Exterior Windows (kWh)	285.73	416.83	596.32	623.19	592.22	556.22	586.56	527.46	473.64	374.69	322.96	191.44
Zone Sensible Heating (kWh)	2541.33	1781.31	1532.85	808.52	550.64	150.42	4.14	42.14	188.03	859.23	1570.61	2345.58
Zone Sensible Cooling (kWh)	-0.06	-7.72	-16.54	-39.08	-47.72	-89.65	-115.65	-104.70	-82.34	-17.27	-10.18	-0.94
Zone Heating (kWh)	2866.65	2042.11	1797.77	994.70	676.68	185.48	3.90	49.89	230.24	1021.33	1813.45	2662.44
Mech Vent + Nat Vent + Infiltration (ac/h)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.21

Figure A42. The simulation detailed results of the house.

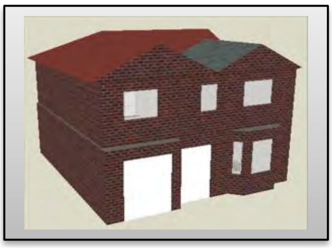
Case 15. A House Built in 2004

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of cavity timber frame construction.	0.394	Increase 15 cm Insulation
	Flat -	-
	Pitched 0.373	Increase 28 cm Insulation
Floor Flooring at ground floor level appears to be of suspended timber construction overlaid with chipboard floor panels.	0.435	Increase 26 cm Insulation
Internal Walls are plasterboard.	0.851	
Windows are timber double glazed.		

* As a basis for a theory of possibility

Description

The subjects from a two storey detached villa set within garden ground and having an integral garage/store room.



Weather Dry and bright.

Heating and hot water

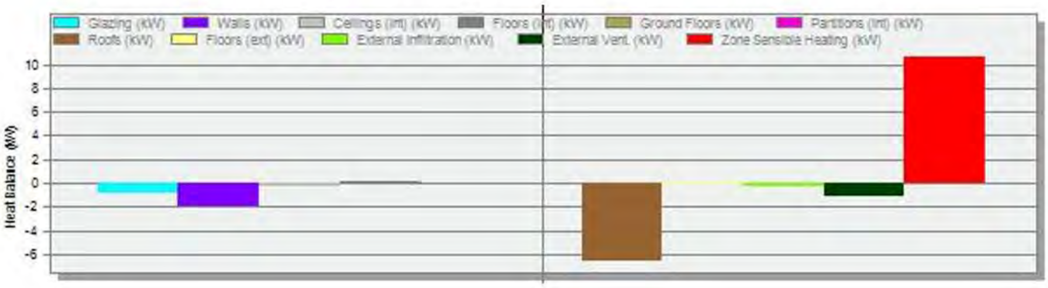
LPG combination boiler providing domestic hot water and serving a wet radiator system. No hot water tank.

Gross internal floor area (m²) 118 m^2

Address

EDINBURGH EH17 7LF

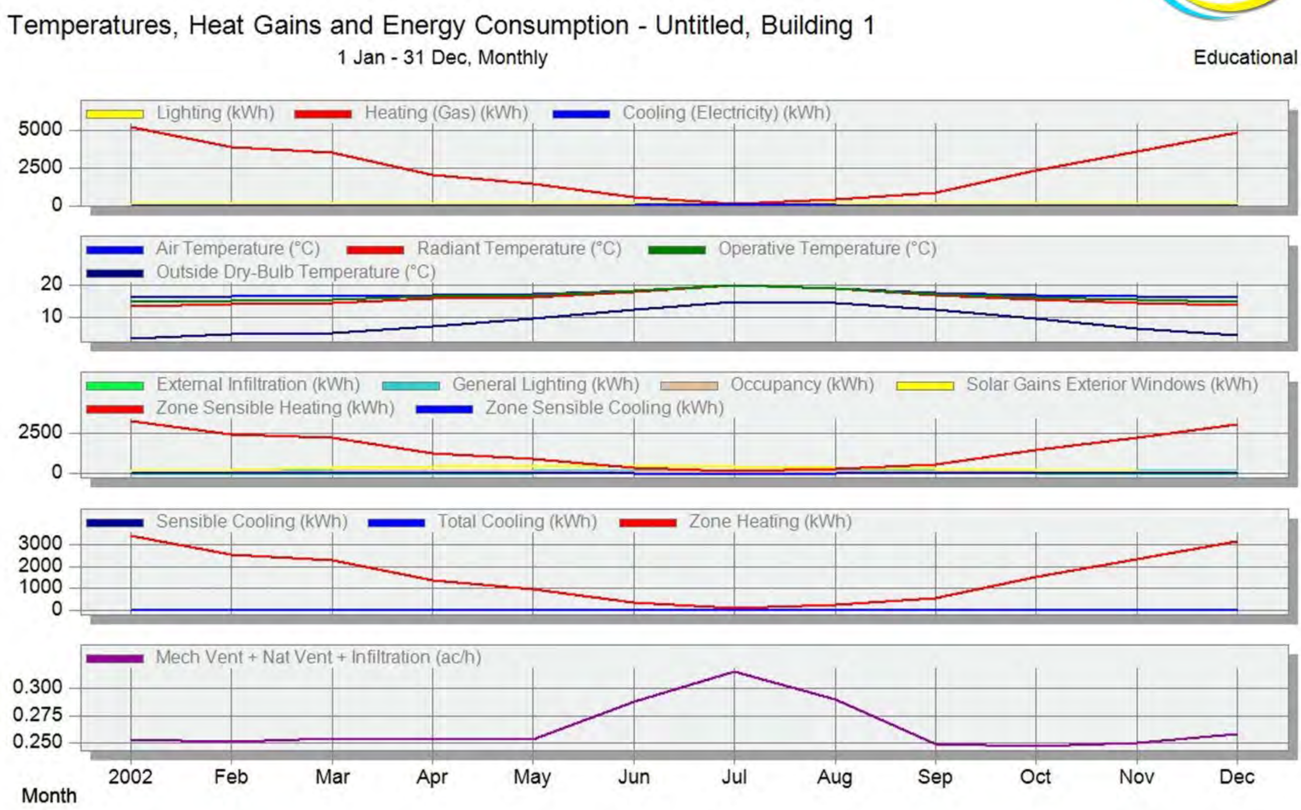
Figure A43. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.70
Operative Temperature (°C)	15.35
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-0.78
Walls (kW)	-1.93
Ceilings (int) (kW)	-0.26
Floors (int) (kW)	0.21
Ground Floors (kW)	0.08
Partitions (int) (kW)	0.00
Roofs (kW)	-6.61
Floors (ext) (kW)	-0.11
External Infiltration (kW)	-0.26
External Vent. (kW)	-1.05
Zone Sensible Heating (kW)	10.68

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 13.350 (kW)				
Ground Floor Total Design Heating Capacity = 3.070 (kW)				
Storage	16.26	0.75	**0.94**	69.9729
Living Room	16.76	0.58	**0.73**	44.6372
Vestibule	16.64	0.25	**0.31**	84.0974
Storage	17.47	0.05	**0.06**	32.9792
Kitchen DiningRoom	16.75	0.61	**0.76**	45.9629
Service	17.28	0.05	**0.06**	60.6724
Service	16.42	0.17	**0.21**	136.1106
First Floor Total Design Heating Capacity = 5.290 (kW)				
Bed Room	16.67	0.46	**0.57**	47.0262
Service	16.82	0.17	**0.21**	57.1219
Bed Room	16.69	0.34	**0.43**	50.3979
Landing Hall	15.00	0.73	**0.92**	159.0384
Master BedRoom	15.83	0.79	**0.99**	82.3930
Bed Room	14.08	1.40	**1.76**	212.5320
Service	15.17	0.33	**0.41**	226.5012
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.44	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 4.990 (kW)				
Zone 1	12.92	3.99	**4.99**	126.1605

Figure A44. The heating design simulation and data of the house.



Lighting (kWh)	140.88	119.13	122.89	104.71	101.41	94.65	99.28	105.46	112.10	129.13	131.94	142.37
Heating (Gas) (kWh)	5245.72	3942.85	3544.14	2067.43	1471.60	564.49	140.61	391.03	880.83	2330.12	3579.90	4870.06
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	1.44	5.64	1.38	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.15	16.30	16.52	16.93	17.15	18.25	19.91	18.97	17.47	16.78	16.43	16.18
Radiant Temperature (°C)	13.33	13.88	14.52	15.68	16.24	17.92	19.91	18.73	16.83	15.30	14.30	13.52
Operative Temperature (°C)	14.74	15.09	15.52	16.31	16.69	18.08	19.91	18.85	17.15	16.04	15.37	14.85
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-104.46	-86.26	-92.71	-78.19	-60.90	-45.79	-42.76	-38.09	-41.13	-59.40	-81.04	-96.47
General Lighting (kWh)	140.88	119.13	122.89	104.71	101.41	94.65	99.28	105.46	112.10	129.13	131.94	142.37
Occupancy (kWh)	76.43	68.82	78.02	75.71	77.61	73.99	66.58	70.82	73.79	74.75	74.45	79.78
Solar Gains Exterior Windows (kWh)	103.57	174.94	301.25	358.85	369.07	358.13	368.92	322.20	254.82	171.92	119.39	69.50
Zone Sensible Heating (kWh)	3238.77	2422.11	2159.83	1236.65	877.44	336.03	85.19	235.50	523.02	1420.61	2194.61	2998.65
Zone Sensible Cooling (kWh)	0.00	0.00	-3.30	-10.59	-12.25	-50.75	-92.91	-51.26	-11.86	-0.17	-0.19	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-3.58	-11.99	-3.11	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	-0.00	-3.60	-14.10	-3.45	0.00	0.00	0.00	0.00
Zone Heating (kWh)	3409.72	2562.85	2303.69	1343.83	956.54	366.92	91.39	254.17	572.54	1514.58	2326.94	3165.54
Mech Vent + Nat Vent + Infiltration (ac/h)	0.25	0.25	0.25	0.25	0.25	0.29	0.32	0.29	0.25	0.25	0.25	0.26

Figure A45. The simulation detailed results of the house.

Case 16. A House Built in 2003

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are built of traditional cavity brick/block work.	0.389	Increase 15 cm Insulation
	Flat 0.351	Increase 23 cm Insulation
	Pitched 0.374	Increase 29 cm Insulation
Floors have fitted floor coverings.	0.438	Increase 26 cm Insulation
Internal Walls are plaster finishes.	0.849	
Windows are timber double glazed.		

* As a basis for a theory of possibility

Description

The property comprises a detached villa.

Ground Floor: Sitting room, kitchen, utility room and WC apartment.

Lower Ground Floor: Living room and dining room.

First Floor: Master bedroom with en-suite shower room, four further bedrooms and family bathroom.

Weather Dry and sunny.

Heating and hot water

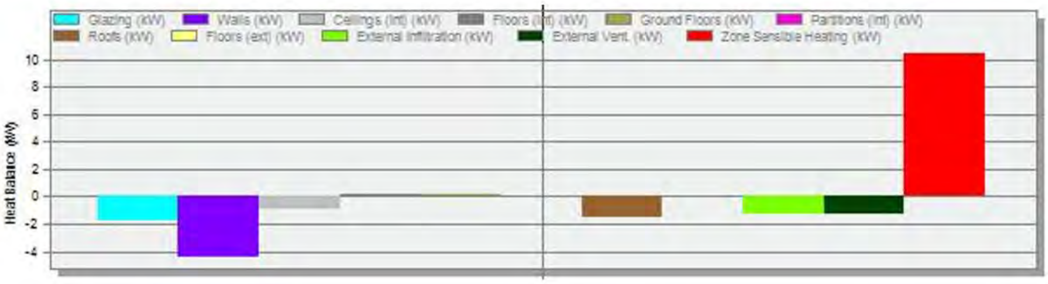
The property benefits from a gas fired central heating system with the gas boiler located in the utility room. This boiler provides hot water. There is a gas fire in the living room.

Gross internal floor area (m²) 152 m^2

Address

EDINBURGH EH4 7TD

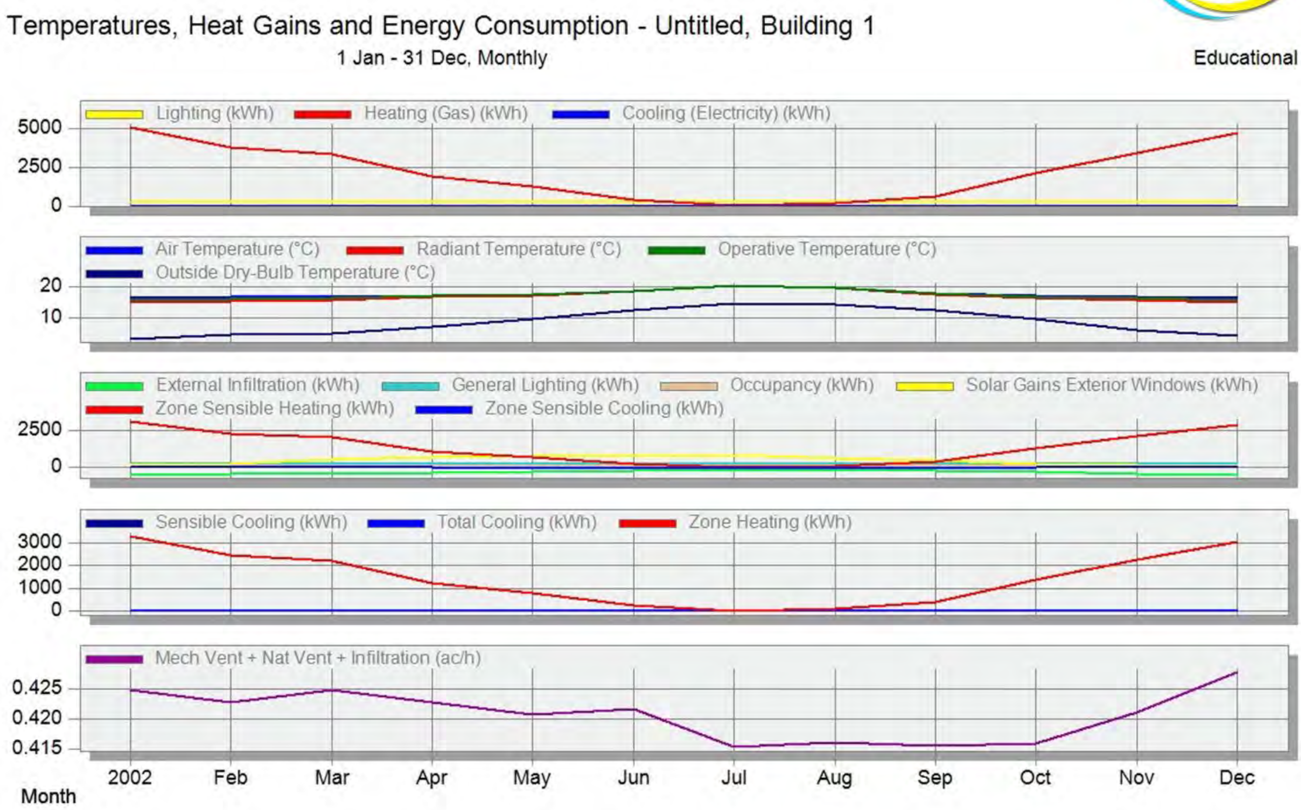
Figure A46. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.69
Operative Temperature (°C)	16.35
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.72
Walls (kW)	-4.46
Ceilings (int) (kW)	-0.89
Floors (int) (kW)	0.17
Ground Floors (kW)	0.20
Partitions (int) (kW)	0.01
Roofs (kW)	-1.47
Floors (ext) (kW)	-0.00
External Infiltration (kW)	-1.26
External Vent. (kW)	-1.24
Zone Sensible Heating (kW)	10.48

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 13.110 (kW)				
Ground Floor Total Design Heating Capacity = 7.490 (kW)				
Sitting Room	16.19	1.26	**1.57**	76.3633
Dining Room	15.62	1.55	**1.93**	102.4979
Kitchen	16.49	0.66	**0.83**	75.4254
Hall	17.24	0.47	**0.58**	42.0759
Garage	15.99	1.06	**1.32**	102.8999
Family Room	16.01	0.82	**1.03**	111.3776
Service	16.75	0.19	**0.23**	131.4320
First Floor Total Design Heating Capacity = 3.880 (kW)				
Service	17.05	0.13	**0.16**	67.6236
Hall	17.23	0.41	**0.51**	36.5857
Study BedRoom	16.74	0.31	**0.39**	65.5916
Double BedRoom	16.55	0.38	**0.48**	80.1787
Master BedRoom	16.61	0.65	**0.81**	57.1122
Service	16.97	0.13	**0.16**	91.5471
Double BedRoom	16.82	0.46	**0.57**	51.9854
Double BedRoom	16.58	0.47	**0.59**	70.3133
Dressing Room	16.75	0.17	**0.21**	100.3427
Slope Roof Total Design Heating Capacity = 1.740 (kW)				
Zone 1	13.76	1.39	**1.74**	221.9707
Main Roof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	2.14	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.40	0.00	**0.00**	0.0000

Figure A47. The heating design simulation and data of the house.



Lighting (kWh)	264.64	238.82	266.26	258.19	266.26	259.80	263.03	264.64	256.57	263.03	256.57	267.87
Heating (Gas) (kWh)	5066.69	3765.98	3362.03	1902.96	1244.14	388.75	32.19	164.35	644.27	2143.69	3441.49	4694.94
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.38	16.58	16.78	17.18	17.40	18.33	20.05	19.32	17.71	17.11	16.76	16.44
Radiant Temperature (°C)	14.80	15.26	15.73	16.62	17.05	18.31	20.21	19.38	17.50	16.33	15.58	14.95
Operative Temperature (°C)	15.59	15.92	16.26	16.90	17.22	18.32	20.13	19.35	17.60	16.72	16.17	15.70
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-501.31	-414.90	-445.58	-376.54	-295.04	-219.52	-206.54	-189.63	-199.79	-288.31	-391.12	-464.00
General Lighting (kWh)	264.64	238.82	266.26	258.19	266.26	259.80	263.03	264.64	256.57	263.03	256.57	267.87
Occupancy (kWh)	84.40	76.00	86.19	83.84	85.95	82.91	73.49	77.91	81.68	82.55	82.20	88.10
Solar Gains Exterior Windows (kWh)	147.79	285.99	541.48	714.02	777.62	800.59	820.03	656.51	474.88	283.21	174.17	97.73
Zone Sensible Heating (kWh)	3090.48	2280.99	2013.51	1107.49	714.58	219.17	18.90	94.54	364.43	1282.71	2080.11	2853.93
Zone Sensible Cooling (kWh)	0.00	-0.14	-2.64	-8.83	-11.98	-40.62	-64.30	-49.40	-16.74	-0.32	-0.31	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.33	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.44	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	3293.35	2447.89	2185.32	1236.93	808.69	252.69	20.92	106.83	418.78	1393.40	2236.97	3051.71
Mech Vent + Nat Vent + Infiltration (ac/h)	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.43

Figure A48. The simulation detailed results of the house.

Case 17. A House Built in 2003

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of modern load bearing timber frame construction with a rendered masonry external leaf.	0.409	Increase 16 cm Insulation
	Flat 0.300	Increase 23 cm Insulation
	Pitched 0.375	Increase 29 cm Insulation
Floor is of suspended timber construction with fitted coverings throughout.	0.488	Increase 27 cm Insulation
Internal Walls are plaster lined.	0.878	
Windows are timber framed double glazed.		

* As a basis for a theory of possibility

Description

The property comprises a two storey detached villa.

Ground Floor: Entrance Vestibule and Hallway, Living room, Dining room ,Family Room to open plan Kitchen with Sun Room off, Study Room, Utility Room and WC Apartment.

First Floor: Master Bedroom with Dressing Room and En-Suite Bathroom.

Weather Dry and clear.

Heating and hot water

Space heating is provided by a gas fired radiator central heating installation.

The boiler is located within Utility Room cupboard.

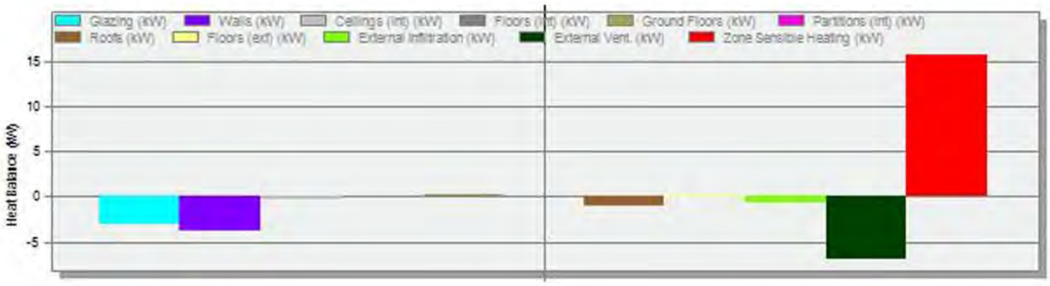
Hot water is stored within a Megaflo Heatrae Sadia tank which is located within landing cupboard.

Gross internal floor area (m²) 260 m^2

Address

EDINBURGH EH13 3QR

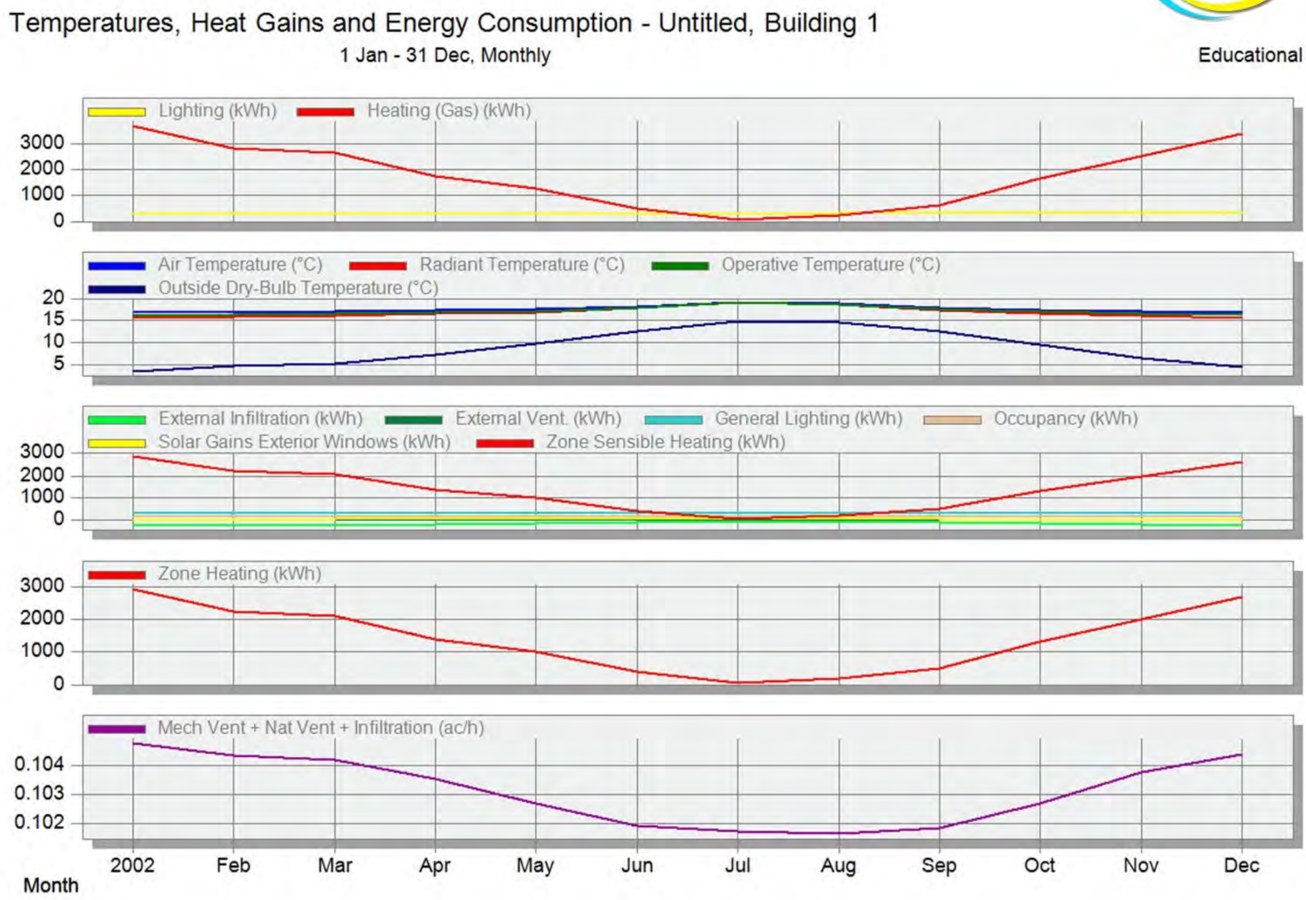
Figure A49. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.47
Operative Temperature (°C)	16.73
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.06
Walls (kW)	-3.83
Ceilings (int) (kW)	-0.40
Floors (int) (kW)	0.04
Ground Floors (kW)	0.20
Partitions (int) (kW)	0.00
Roofs (kW)	-1.02
Floors (ext) (kW)	-0.15
External Infiltration (kW)	-0.70
External Vent. (kW)	-6.98
Zone Sensible Heating (kW)	15.70

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 19.630 (kW)				
Ground Floor Total Design Heating Capacity = 11.740 (kW)				
Kitchen	17.20	0.74	**0.93**	55.6305
Sun Room	14.56	1.24	**1.55**	153.2145
Breakfast Room	17.43	0.79	**0.98**	47.6149
Hall	17.42	0.77	**0.96**	50.0319
Dining Room	16.78	0.80	**1.00**	71.1128
Garage	16.31	1.78	**2.22**	78.8569
Sitting Room	16.26	1.78	**2.22**	82.5527
Study Room	16.96	0.60	**0.75**	67.3412
Cloak Room	17.58	0.12	**0.15**	51.1213
Vestibule	16.45	0.18	**0.23**	154.6679
Utility Room	17.03	0.42	**0.52**	70.7329
Service	16.64	0.18	**0.23**	147.0841
First Floor Total Design Heating Capacity = 5.520 (kW)				
Bed Room	16.65	0.76	**0.95**	72.9373
Master BedRoom	16.28	1.58	**1.98**	77.8958
Hall	17.36	0.46	**0.57**	48.6441
Landing	17.10	0.43	**0.54**	60.0997
Service	17.22	0.31	**0.39**	56.1168
Dressing Room	16.68	0.42	**0.52**	86.5541
Service	16.95	0.33	**0.41**	72.8501
Service	17.21	0.12	**0.16**	71.2388
First Floor Roof Total Design Heating Capacity = 2.090 (kW)				
Bed Room	16.53	0.65	**0.81**	32.0190
Bed Room	16.80	0.55	**0.69**	30.8360
Bed Room	16.88	0.25	**0.31**	28.2965
Hall	17.17	0.22	**0.28**	36.7500

Figure A50. The heating design simulation and data of the house.



Lighting (kWh)	327.62	288.45	311.95	294.17	299.79	291.26	298.84	304.84	303.95	320.36	314.65	332.11
Heating (Gas) (kWh)	3693.93	2831.42	2665.85	1724.38	1277.70	497.96	75.25	242.66	629.17	1652.14	2524.48	3362.97
Air Temperature (°C)	16.54	16.69	16.81	17.07	17.27	17.88	18.97	18.56	17.60	17.16	16.88	16.60
Radiant Temperature (°C)	15.35	15.64	15.89	16.39	16.71	17.58	18.83	18.35	17.23	16.48	15.95	15.49
Operative Temperature (°C)	15.94	16.17	16.35	16.73	16.99	17.73	18.90	18.45	17.42	16.82	16.42	16.05
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-280.73	-231.41	-246.73	-205.35	-159.26	-110.70	-88.99	-86.99	-107.54	-159.86	-218.42	-260.03
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.05	-0.41	-0.18	-0.04	0.00	0.00	0.00
General Lighting (kWh)	327.62	288.45	311.95	294.17	299.79	291.26	298.84	304.84	303.95	320.36	314.65	332.11
Occupancy (kWh)	160.47	144.49	163.95	159.67	163.62	159.70	146.26	152.49	155.24	156.95	156.31	167.51
Solar Gains Exterior Windows (kWh)	8.69	17.71	33.94	43.28	41.48	40.04	41.55	33.46	24.85	15.47	9.92	5.60
Zone Sensible Heating (kWh)	2939.52	2253.57	2121.72	1372.66	1017.12	396.29	59.88	193.17	500.99	1315.96	2009.82	2676.47
Zone Heating (kWh)	2955.14	2265.14	2132.68	1379.51	1022.16	398.37	60.20	194.13	503.34	1321.71	2019.59	2690.37
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Figure A51. The simulation detailed results of the house.

Case 18. A House Built in 2002

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of modern timber frame construction with an outer leaf of concrete block.	0.410	Increase 15 cm Insulation
	Flat -	-
	Pitched 0.382	Increase 29 cm Insulation
Floor is of suspended timber within including wooden flooring, tiling and carpets.	0.493	Increase 26 cm Insulation
Internal Walls are of timber stud and plasterboard.	0.893	
Windows are of a u-PVC frame double glazed design with Velux roof lights.		

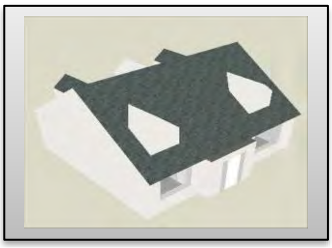
* As a basis for a theory of possibility

Description

The property comprises a detached two storey dwelling house.

Ground Floor: entrance hallway, lounge, sitting room, dining room, dining kitchen and cloakroom with WC.

First Floor: master bedroom with en suite,



Weather Dry and clear.

Heating and hot water

Within the property there is a gas fired central heating system serving radiators with the boiler being located within the kitchen.

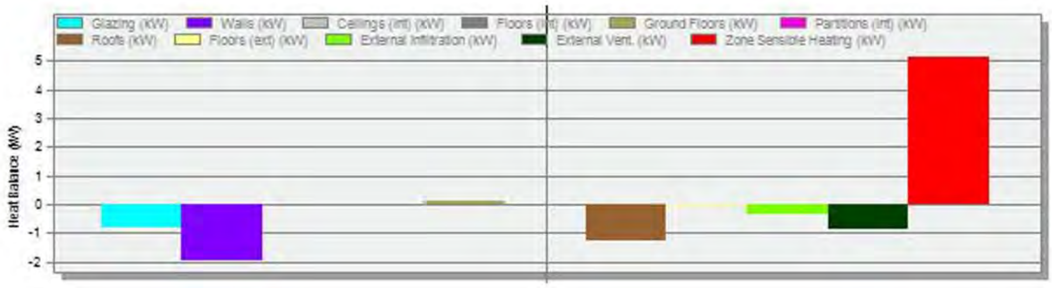
The hot water cylinder is at first floor level. Hot water is stored within a Megaflo Heatrae Sadia tank which is located within landing cupboard.

Gross internal floor area (m²) 150 m^2

Address

KIRKINTILLOCH G66 3LG

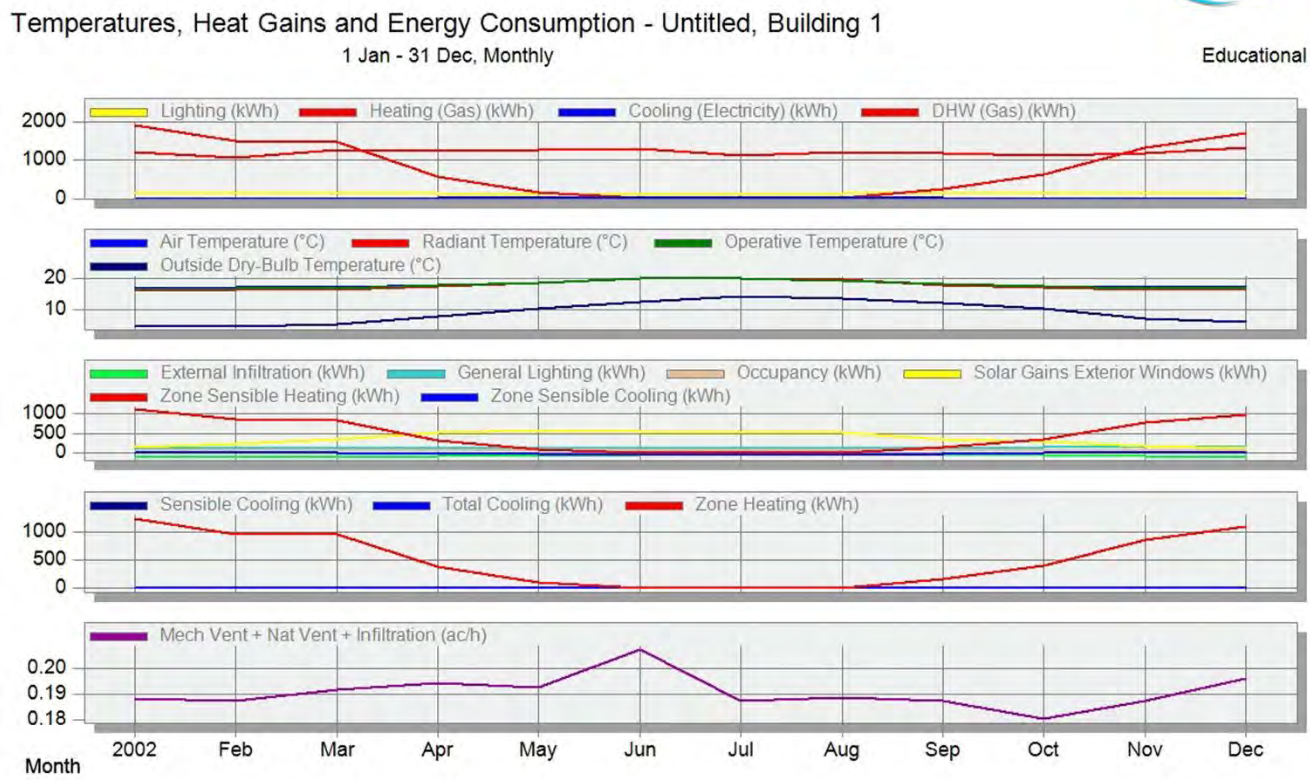
Figure A52. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.91
Operative Temperature (°C)	16.96
Outside Dry-Bulb Temperature (°C)	-6.10
Glazing (kW)	-0.79
Walls (kW)	-1.97
Ceilings (int) (kW)	-0.01
Floors (int) (kW)	0.01
Ground Floors (kW)	0.09
Partitions (int) (kW)	0.00
Roofs (kW)	-1.24
Floors (ext) (kW)	-0.03
External Infiltration (kW)	-0.36
External Vent. (kW)	-0.88
Zone Sensible Heating (kW)	5.15

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 6.470 (kW)				
Ground Floor Total Design Heating Capacity = 3.200 (kW)				
Hall	16.96	0.59	**0.74**	37.5298
Lounge	16.93	0.49	**0.62**	36.1180
Sitting Room	16.93	0.42	**0.53**	39.8973
Kitchen	16.79	0.56	**0.69**	42.7918
Dining Room	16.84	0.37	**0.46**	47.3077
Service	17.29	0.13	**0.16**	36.6676
First Floor Roof Total Design Heating Capacity = 2.530 (kW)				
Bed Room	16.94	0.27	**0.34**	32.6477
Service	16.93	0.27	**0.34**	32.6222
Service	17.14	0.27	**0.34**	23.8080
Bed Room	16.89	0.38	**0.48**	35.0555
Hall	17.34	0.15	**0.19**	32.7664
Master BedRoom	16.87	0.46	**0.58**	32.6782
Landing	17.10	0.20	**0.26**	26.1908
Window Roof Total Design Heating Capacity = 0.140 (kW)				
Zone 1	16.44	0.11	**0.14**	1.#INF
Window Roof Total Design Heating Capacity = 0.140 (kW)				
Zone 1	16.44	0.11	**0.14**	1.#INF
Window Roof Total Design Heating Capacity = 0.160 (kW)				
Zone 1	16.41	0.12	**0.16**	1.#INF
Window Roof Total Design Heating Capacity = 0.150 (kW)				
Zone 1	16.39	0.12	**0.15**	1.#INF
Window Roof Total Design Heating Capacity = 0.150 (kW)				
Zone 1	16.39	0.12	**0.15**	1.#INF

Figure A53. The heating design simulation and data of the house.



Lighting (kWh)	147.90	124.17	131.54	121.17	116.28	113.09	108.50	117.44	125.08	133.60	139.12	158.34
Heating (Gas) (kWh)	1916.64	1491.08	1467.88	578.87	155.96	19.31	8.32	3.65	250.71	613.39	1323.67	1704.36
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.03	0.26	1.36	0.73	0.33	0.07	0.00	0.00	0.00
DHW (Gas) (kWh)	1198.29	1073.93	1263.32	1243.55	1263.32	1308.59	1133.25	1198.29	1178.51	1133.25	1178.51	1328.36
Air Temperature (°C)	16.94	17.08	17.17	17.86	18.47	19.87	19.99	19.37	18.08	17.60	17.20	17.13
Radiant Temperature (°C)	16.03	16.29	16.47	17.59	18.46	19.96	20.03	19.41	17.94	17.25	16.51	16.30
Operative Temperature (°C)	16.48	16.68	16.82	17.72	18.46	19.92	20.01	19.39	18.01	17.42	16.85	16.71
Outside Dry-Bulb Temperature (°C)	4.82	5.07	5.52	8.07	10.65	12.73	14.30	13.67	12.13	10.58	7.34	6.19
External Infiltration (kWh)	-129.69	-115.97	-125.43	-102.69	-84.04	-73.71	-60.27	-60.94	-61.08	-75.84	-102.69	-117.21
General Lighting (kWh)	147.90	124.17	131.54	121.17	116.28	113.09	108.50	117.44	125.08	133.60	139.12	158.34
Occupancy (kWh)	61.24	54.87	64.51	62.68	62.73	61.32	52.07	56.98	59.34	57.81	60.22	67.89
Solar Gains Exterior Windows (kWh)	132.74	232.74	346.03	521.44	575.76	541.16	521.96	508.43	354.72	294.48	180.82	110.08
Zone Sensible Heating (kWh)	1131.73	868.44	844.77	310.42	76.70	7.92	4.45	1.97	130.31	343.10	767.64	989.38
Zone Sensible Cooling (kWh)	0.00	-1.47	-3.82	-26.65	-45.37	-74.14	-49.32	-51.38	-19.49	-6.33	-1.53	-0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	-0.07	-0.65	-3.21	-1.76	-0.83	-0.18	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	-0.07	-0.65	-3.40	-1.81	-0.83	-0.18	0.00	0.00	0.00
Zone Heating (kWh)	1245.82	969.21	954.12	376.27	101.37	12.55	5.41	2.37	162.96	398.70	860.38	1107.83
Mech Vent + Nat Vent + Infiltration (ac/h)	0.19	0.19	0.19	0.19	0.19	0.21	0.19	0.19	0.19	0.18	0.19	0.20

Figure A54. The simulation detailed results of the house.

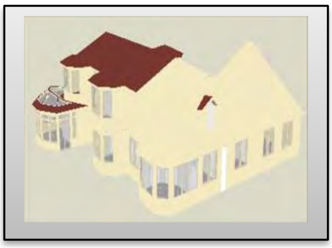
Case 19. A House Built in 2000

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of load bearing timber framed construction.	0.419	Increase 14 cm Insulation
	Flat 0.350	Increase 23 cm Insulation
	Pitched 0.386	Increase 29 cm Insulation
Floor is of suspended timber construction.	0.499	Increase 26 cm Insulation
Internal Walls are of timber framing and plasterboard.	0.922	
Windows are of a u-PVC frame double glazed.		

* As a basis for a theory of possibility

Description

Detached two storey villa with integral double garage and surrounding garden grounds.



Weather Overcast with rain.

Heating and hot water

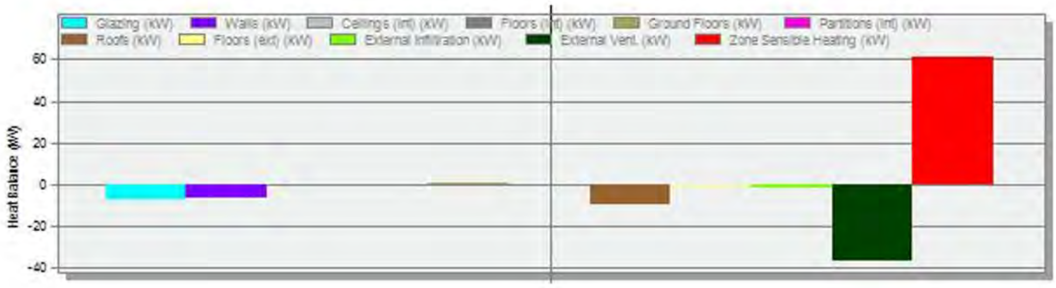
The property has two separate gas fired central heating systems to radiator outlets. Domestic hot water is provided indirectly by the gas central heating boilers to a modern insulated hot water tanks located in a cupboard off the kitchen/breakfast room and first floor landing.

Gross internal floor area (m²) 390 m^2

Address

PEEBLES EH45 9LL

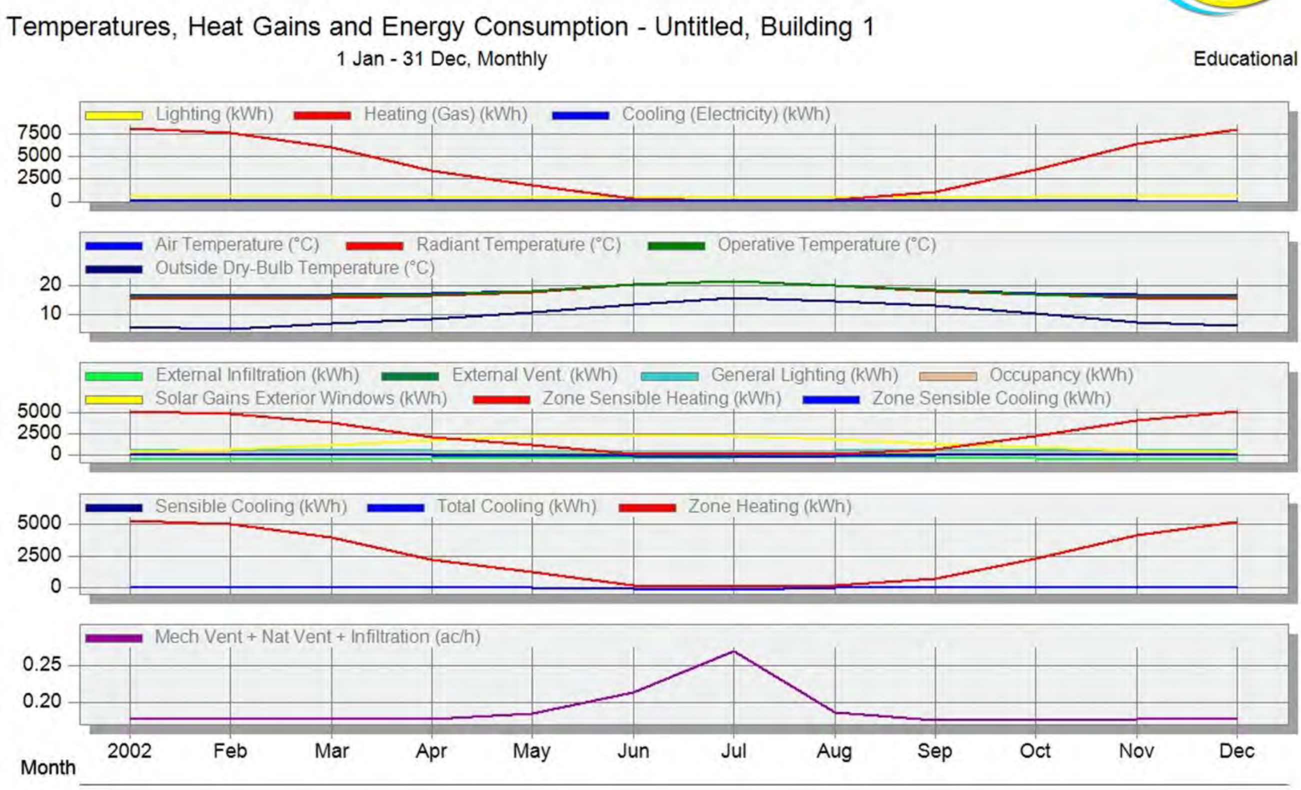
Figure A55. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.65
Operative Temperature (°C)	16.32
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-6.91
Walls (kW)	-6.36
Ceilings (int) (kW)	-0.15
Floors (int) (kW)	0.12
Ground Floors (kW)	0.48
Partitions (int) (kW)	0.00
Roofs (kW)	-9.49
Floors (ext) (kW)	-0.66
External Infiltration (kW)	-1.86
External Vent. (kW)	-36.80
Zone Sensible Heating (kW)	61.44

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 76.820 (kW)				
Ground Floor Total Design Heating Capacity = 38.250 (kW)				
Double BedRoom	16.11	4.14	**5.18**	143.6715
Study Room	14.27	3.81	**4.77**	230.9390
Hall	17.36	2.37	**2.96**	111.3966
Snug	17.03	1.45	**1.81**	124.0936
Sun Room	16.92	1.51	**1.89**	126.2072
Utility Room	16.76	1.45	**1.82**	132.8403
Family Room	16.78	2.25	**2.81**	128.1230
Vestibule	14.82	1.41	**1.77**	260.8615
Dining Room	16.64	1.92	**2.40**	143.4485
Sitting Room	17.12	2.52	**3.15**	117.8555
Kitchen BreakfastRoo...	14.52	5.04	**6.29**	225.0677
Service	15.77	0.67	**0.84**	220.3887
TV Room	15.95	2.05	**2.56**	175.1856
Window Total Design Heating Capacity = 0.310 (kW)				
Zone 10	15.76	0.25	**0.31**	-6918.2305
First Floor Total Design Heating Capacity = 14.950 (kW)				
Service	16.62	0.48	**0.60**	161.2106
Service	17.60	0.33	**0.41**	104.9585
Wardrobe	16.96	0.97	**1.21**	128.4173
Double BedRoom	17.45	1.38	**1.72**	105.8122
Master BedRoom	17.57	1.23	**1.54**	100.9335
Zone 4	17.62	1.17	**1.47**	98.6726
Service	17.21	0.43	**0.54**	117.8715
Service	17.58	0.46	**0.58**	101.3782
Bed Room	17.05	2.09	**2.61**	114.5172
Service	17.57	0.50	**0.62**	104.2372
Bed Room	15.31	2.92	**3.65**	195.1719

Figure A56. The heating design simulation and data of the house.



Lighting (kWh)	582.80	505.09	520.72	463.67	454.65	432.12	447.70	467.85	485.44	544.55	551.10	589.69
Heating (Gas) (kWh)	8197.55	7681.51	6091.54	3438.69	1839.99	294.02	93.20	245.26	1036.49	3561.28	6417.29	8054.26
Cooling (Electricity) (kWh)	0.01	0.21	0.69	7.26	28.99	80.46	135.38	27.33	7.53	1.13	0.01	0.00
Air Temperature (°C)	16.58	16.56	16.79	17.20	18.05	20.35	21.49	19.84	18.39	17.36	16.74	16.57
Radiant Temperature (°C)	15.30	15.27	15.80	16.61	17.76	20.39	21.60	19.81	18.17	16.72	15.67	15.31
Operative Temperature (°C)	15.94	15.91	16.30	16.91	17.90	20.37	21.54	19.82	18.28	17.04	16.20	15.94
Outside Dry-Bulb Temperature (°C)	5.78	4.82	6.81	8.51	10.55	13.52	15.65	14.61	13.21	10.51	7.19	6.25
External Infiltration (kWh)	-580.59	-576.29	-533.37	-446.30	-401.08	-347.66	-300.95	-272.32	-262.09	-363.53	-495.46	-555.03
External Vent. (kWh)	-0.03	-0.26	-0.47	-1.92	-15.42	-51.52	-132.29	-19.34	-2.16	-0.28	-0.06	0.00
General Lighting (kWh)	582.80	505.09	520.72	463.67	454.65	432.12	447.70	467.85	485.44	544.55	551.10	589.69
Occupancy (kWh)	310.21	279.30	316.59	306.65	303.52	269.24	243.82	274.49	287.43	299.95	302.10	323.84
Solar Gains Exterior Windows (kWh)	419.61	652.25	1180.34	1675.46	2262.83	2289.12	2277.51	1886.58	1303.50	904.91	507.80	339.14
Zone Sensible Heating (kWh)	5197.79	4868.91	3848.06	2154.27	1150.98	180.91	57.86	153.47	649.29	2248.35	4063.37	5105.10
Zone Sensible Cooling (kWh)	-0.18	-0.97	-4.57	-21.11	-79.18	-190.32	-286.70	-86.48	-37.24	-10.50	-1.31	0.00
Sensible Cooling (kWh)	-0.01	-0.35	-1.16	-12.12	-48.42	-129.13	-222.22	-45.10	-12.51	-1.87	-0.02	0.00
Total Cooling (kWh)	-0.01	-0.35	-1.16	-12.12	-48.42	-134.41	-227.90	-45.65	-12.58	-1.89	-0.02	0.00
Zone Heating (kWh)	5328.41	4992.98	3959.50	2235.15	1196.00	191.11	60.58	159.42	673.72	2314.83	4171.24	5235.27
Mech Vent + Nat Vent + Infiltration (ac/h)	0.18	0.18	0.18	0.18	0.18	0.21	0.27	0.19	0.18	0.18	0.18	0.18

Figure A57. The simulation detailed results of the house.

Case 20. A House Built in 1999

Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are of 275mm cavity incorporating a structural timber frame inner leaf and concrete block outer leaf,	0.439	Increase 15 cm Insulation
	Flat -	-
	Pitched 0.389	Increase 29 cm Insulation
Floors are of timber stud lined with Plasterboard.	0.555	Increase 27 cm Insulation
Internal Walls are of timber framing and plasterboard.	0.961	
Windows are of a timber frame double glazed.		

* As a basis for a theory of possibility

Description

Detached house. GROUND FLOOR: Entrance Vestibule, Hall, Drawing Room, Dining Room, Family Room, Kitchen/Breakfast Room, Utility Room, Study and Toilet.

FIRST FLOOR: Master Bedroom with En Suite Bathroo.

Weather Dry and sunny although frosty and cold.

Heating and hot water

There is a Glow-worm Ultimate gas fired central heating boiler wall mounted in the utility room. This supplies steel panel radiators and also provides domestic hot water.

Gross internal floor area (m²) 237 m^2

Address

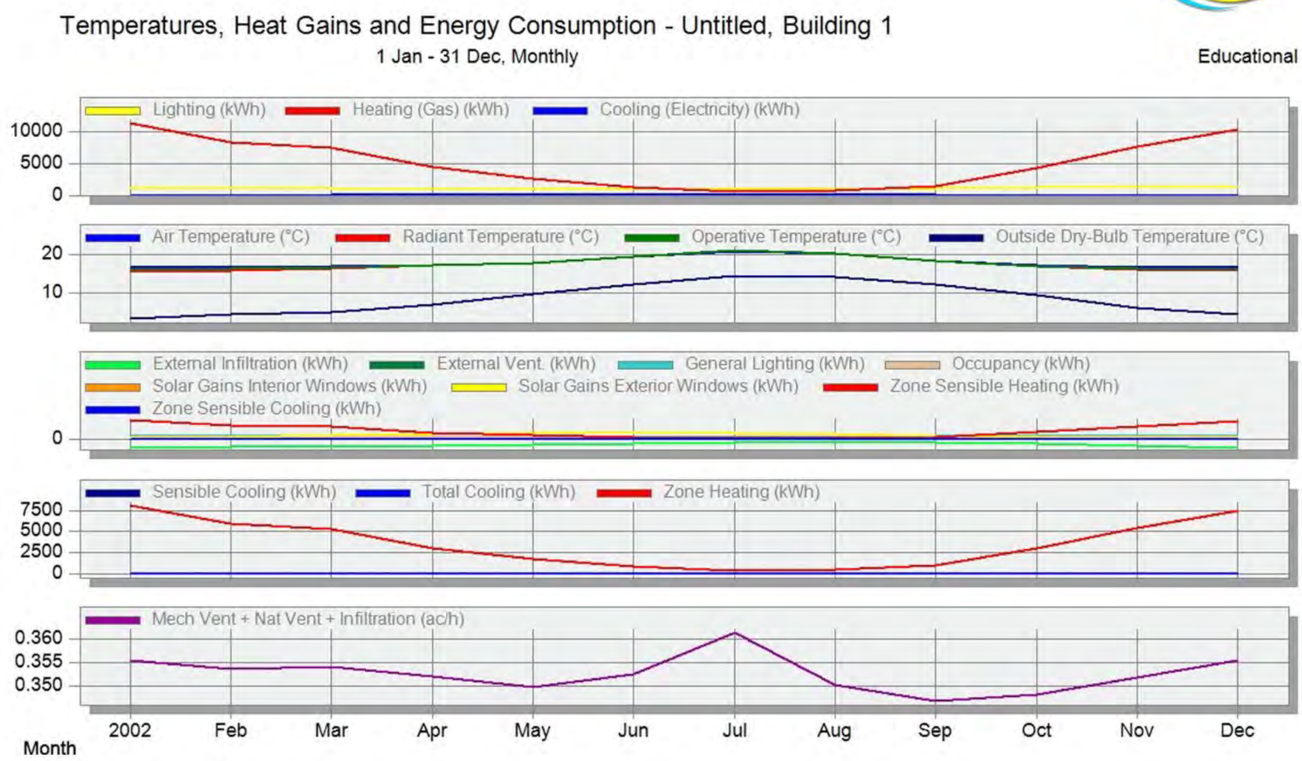
NORTH QUEENSFERRY,
INVERKEITHING, KY11 1EU

Figure A58. The software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.90
Operative Temperature (°C)	16.95
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-4.16
Walls (kW)	-6.43
Ceilings (int) (kW)	-0.21
Floors (int) (kW)	0.18
Ground Floors (kW)	0.45
Partitions (int) (kW)	0.00
Roofs (kW)	-5.68
Floors (ext) (kW)	-0.14
External Infiltration (kW)	-9.08
External Vent. (kW)	-25.50
Zone Sensible Heating (kW)	50.43

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 63.030 (kW)				
Ground Floor Total Design Heating Capacity = 23.240 (kW)				
Office	16.88	2.23	**2.79**	54.7018
Utility Room	16.56	0.89	**1.12**	80.5127
Kitchen	17.23	6.95	**8.68**	44.7199
Dining Room	17.25	2.09	**2.61**	47.3177
Hall	17.75	1.05	**1.32**	38.3476
Vestibule	16.71	0.78	**0.98**	71.1750
Front Room	16.92	1.86	**2.32**	55.1785
Service	17.74	0.23	**0.29**	40.3527
Lounge	16.88	2.50	**3.13**	57.0297
First Floor Total Design Heating Capacity = 20.850 (kW)				
Store	17.12	0.59	**0.74**	53.3328
Service	17.72	1.01	**1.26**	36.5793
Landing	16.85	2.34	**2.92**	52.9630
Bed Room	16.88	1.81	**2.26**	53.6561
Dressing Room	17.74	0.83	**1.04**	36.4144
Bed Room	17.37	4.56	**5.70**	40.9738
Bed Room	16.87	1.11	**1.39**	58.7121
Bed Room	16.96	1.34	**1.67**	54.0085
Service	16.93	1.36	**1.70**	54.1098
Service	16.69	1.73	**2.17**	59.4768
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.43	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 18.540 (kW)				
Zone 1	16.55	14.83	**18.54**	42.3181
Window Roof Total Design Heating Capacity = 0.400 (kW)				
Zone 1	14.64	0.32	**0.40**	305.5145

Figure A59. The heating design simulation and data of the house.



Lighting (kWh)	1333.26	1109.10	1129.28	960.99	924.76	860.44	908.24	970.72	1040.38	1213.86	1244.85	1354.13
Heating (Gas) (kWh)	11424.48	8410.72	7578.88	4394.00	2702.98	1227.94	533.70	764.98	1487.26	4344.74	7671.11	10418.83
Cooling (Electricity) (kWh)	0.00	0.00	0.78	4.17	7.06	15.66	30.65	8.73	1.16	0.00	0.00	0.00
Air Temperature (°C)	16.61	16.75	16.94	17.38	17.88	19.35	21.00	20.19	18.39	17.22	16.84	16.65
Radiant Temperature (°C)	15.63	15.98	16.41	17.22	17.87	19.48	21.22	20.31	18.37	16.85	16.15	15.74
Operative Temperature (°C)	16.12	16.36	16.67	17.30	17.87	19.41	21.11	20.25	18.38	17.03	16.49	16.19
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3495.36	-2854.32	-3046.16	-2519.94	-1982.37	-1538.61	-1367.29	-1266.72	-1370.82	-1910.32	-2647.82	-3219.75
External Vent. (kWh)	0.00	0.00	-0.07	-0.28	-0.28	-2.82	-37.87	-2.85	-0.06	0.00	0.00	0.00
General Lighting (kWh)	1333.26	1109.10	1129.28	960.99	924.76	860.44	908.24	970.72	1040.38	1213.86	1244.85	1354.13
Occupancy (kWh)	701.79	631.74	714.43	687.43	691.09	641.30	565.74	604.17	648.25	682.42	682.90	732.50
Solar Gains Interior Windows (kWh)	0.40	0.96	2.02	2.75	3.22	3.38	3.36	2.65	1.84	1.01	0.49	0.26
Solar Gains Exterior Windows (kWh)	362.03	785.40	1565.76	2101.59	2406.20	2498.47	2522.99	2001.48	1414.13	800.37	437.57	236.85
Zone Sensible Heating (kWh)	7651.08	5549.41	4888.65	2677.10	1590.22	709.78	314.34	441.14	848.76	2764.12	5055.12	6948.83
Zone Sensible Cooling (kWh)	0.00	0.00	-8.56	-27.93	-50.16	-130.23	-177.18	-118.87	-48.84	-5.86	-2.13	0.00
Sensible Cooling (kWh)	0.00	0.00	-1.08	-5.82	-9.85	-21.96	-47.05	-12.06	-1.59	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	-1.09	-5.83	-9.89	-22.02	-52.82	-12.28	-1.63	0.00	0.00	0.00
Zone Heating (kWh)	8123.68	5938.71	5285.44	2976.51	1804.03	805.67	347.18	498.76	979.18	3020.12	5421.98	7408.70
Mech Vent + Nat Vent + Infiltration (ac/h)	0.36	0.35	0.35	0.35	0.35	0.35	0.36	0.35	0.35	0.35	0.35	0.36

Figure A60. The simulation detailed results of the house.

Case 21. A House Built in 1999

Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Wall is of solid stone, partly roughcast and with some walls being of rough casted brickwork	0.426	Increase 15 cm Insulation
	Flat 0.351	Increase 23 cm Insulation
	Pitched 0.380	Increase 29 cm Insulation
Floor is partly of timber and concrete, partly suspended timber.	0.550	Increase 27 cm Insulation
Internal Walls are plasterboard with some finishes being tiled.	0.955	
Windows are of a timber frame double glazed.		

* As a basis for a theory of possibility

Description

The subjects comprise a detached 2 storey house incorporating guest wing and self- contained cottage.

Weather Sunny.

Heating and hot water

Heating is provided by an oil fired central heating boiler located in the cupboard in the hall (Eurostar 190/240). There are also two hot water storage tanks; one within the hallway and one in the rear hall in the guest wing.

Gross internal floor area (m²) 386 m^2

Address

LADEDDIE KY15 5TY

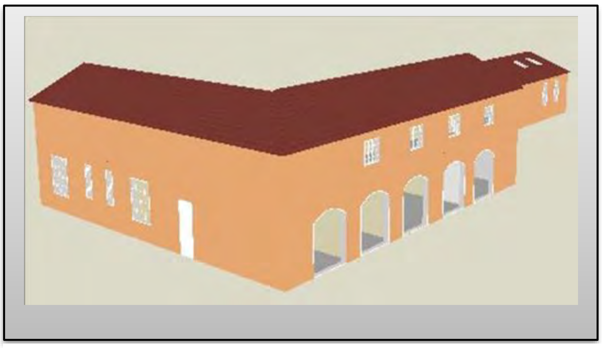
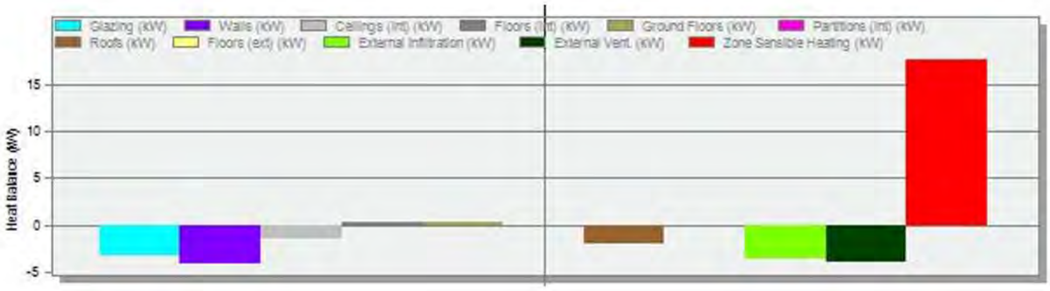


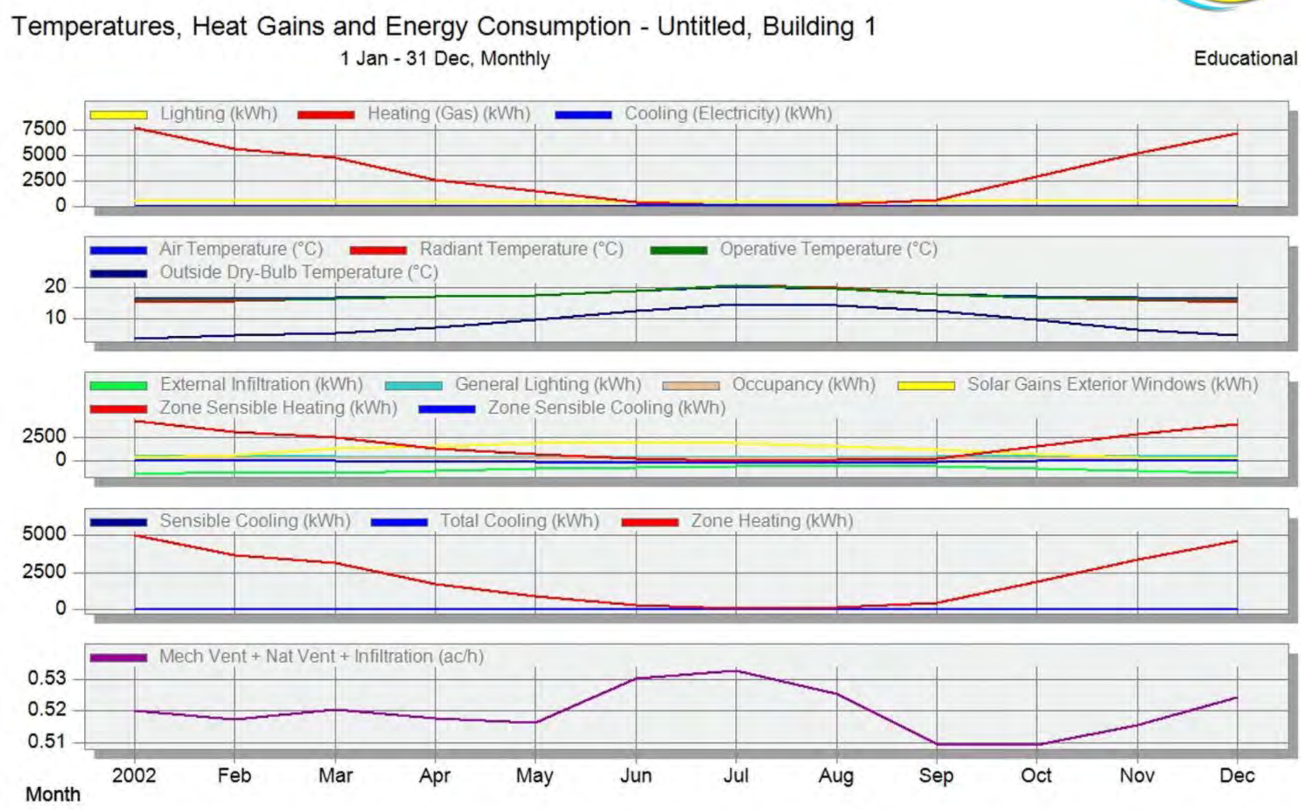
Figure A61. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.73
Operative Temperature (°C)	16.87
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.19
Walls (kW)	-4.16
Ceilings (int) (kW)	-1.44
Floors (int) (kW)	0.27
Ground Floors (kW)	0.38
Partitions (int) (kW)	0.01
Roofs (kW)	-1.98
Floors (ext) (kW)	-0.10
External Infiltration (kW)	-3.64
External Vent. (kW)	-3.98
Zone Sensible Heating (kW)	17.67

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 22.100 (kW)				
Ground Floor Total Design Heating Capacity = 11.580 (kW)				
Courtyard	17.31	0.59	**0.74**	30.8250
Hall	17.65	0.24	**0.30**	26.3337
Bed Room	17.28	0.37	**0.46**	37.2184
Service	17.28	0.12	**0.15**	65.1331
Family Room	16.98	0.72	**0.89**	42.4378
Kitchen	17.42	0.83	**1.04**	25.8206
Sitting Room	16.97	1.63	**2.04**	38.8828
Bed Room	17.41	0.28	**0.35**	31.4263
Store	17.62	0.05	**0.06**	36.2779
Bed Room	16.95	0.50	**0.63**	49.3791
Kitchen	16.70	0.93	**1.16**	50.7721
Sitting Room	16.94	0.96	**1.20**	39.6629
Landing Hall	16.97	0.45	**0.56**	50.9091
Dining Room	16.86	0.85	**1.06**	50.3030
Store	17.09	0.08	**0.10**	109.5701
Bed Room	16.73	0.67	**0.84**	52.6989
First Floor Total Design Heating Capacity = 5.000 (kW)				
BathRoom	16.96	0.29	**0.36**	41.9827
Service	17.35	0.07	**0.09**	35.1697
Bed Room	16.87	0.46	**0.58**	38.8113
Dressing Room	17.11	0.10	**0.12**	47.7216
Hall	16.80	0.64	**0.81**	44.6649
Bed Room	16.55	0.74	**0.92**	44.2504
Bed Room	16.97	0.36	**0.45**	35.3087
Bed Room	17.05	0.43	**0.54**	31.8635
Service	17.17	0.10	**0.12**	52.2272
Landing	17.15	0.19	**0.24**	36.9228

Figure A62. The heating design simulation and data of the house.



Lighting (kWh)	580.49	484.73	480.78	403.40	376.65	343.28	372.91	401.67	444.15	525.17	543.78	587.88
Heating (Gas) (kWh)	7737.06	5610.08	4796.65	2616.98	1432.07	434.93	86.71	174.62	633.81	2875.40	5205.94	7169.28
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.94	4.97	0.36	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.45	16.63	16.87	17.25	17.70	18.85	20.56	19.78	18.01	17.14	16.73	16.50
Radiant Temperature (°C)	15.40	15.80	16.31	17.08	17.73	19.07	20.87	19.99	18.06	16.74	15.98	15.51
Operative Temperature (°C)	15.93	16.22	16.59	17.17	17.71	18.96	20.71	19.89	18.03	16.94	16.36	16.01
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1460.57	-1206.43	-1298.55	-1094.63	-881.62	-683.14	-641.79	-590.24	-605.29	-836.79	-1130.22	-1350.88
General Lighting (kWh)	580.49	484.73	480.78	403.40	376.65	343.28	372.91	401.67	444.15	525.17	543.78	587.88
Occupancy (kWh)	309.32	278.50	315.42	305.90	310.21	292.68	259.68	275.68	294.16	302.24	301.26	322.87
Solar Gains Exterior Windows (kWh)	337.65	665.97	1335.89	1610.94	1921.47	1960.87	1964.71	1614.96	1210.50	731.40	394.70	214.57
Zone Sensible Heating (kWh)	4394.49	3123.91	2590.67	1323.82	700.68	215.90	54.17	97.55	309.76	1530.76	2892.01	4040.23
Zone Sensible Cooling (kWh)	0.00	-1.40	-23.09	-65.54	-122.22	-223.33	-290.92	-233.35	-141.01	-13.61	-2.74	-0.01
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-2.33	-10.51	-0.77	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	-0.00	-2.35	-12.41	-0.90	0.00	0.00	0.00	0.00
Zone Heating (kWh)	5029.09	3646.55	3117.82	1701.04	930.85	282.70	56.36	113.51	411.98	1869.01	3383.86	4660.03
Mech Vent + Nat Vent + Infiltration (ac/h)	0.52	0.52	0.52	0.52	0.52	0.53	0.53	0.53	0.51	0.51	0.52	0.52

Figure A63. The simulation detailed results of the house.

Case 22. A House Built in 1998

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of structural timber framed inner leaf with block render and reconstituted stone outer leaf.	0.429	Increase 14 cm Insulation
	Flat -	-
	Pitched 0.390	Increase 29 cm Insulation
Floor is of suspended timber joists with timber boards.	0.551	Increase 27 cm Insulation
Internal Walls are of timber stud with plasterboard finish.	0.978	
Windows are of a timber frame double glazed.		

* As a basis for a theory of possibility

Description

Substantial detached bungalow with attic floor gallery and detached double car garage

Ground floor - Entrance vestibule, garden room, dining hall, kitchen utility room, WC compartment, lounge, master bedroom with en-suite shower room, family bathroom and three further bedrooms.

Attic floor - gallery landing/lounge with sauna.

Weather Overcast with rain.

Heating and hot water

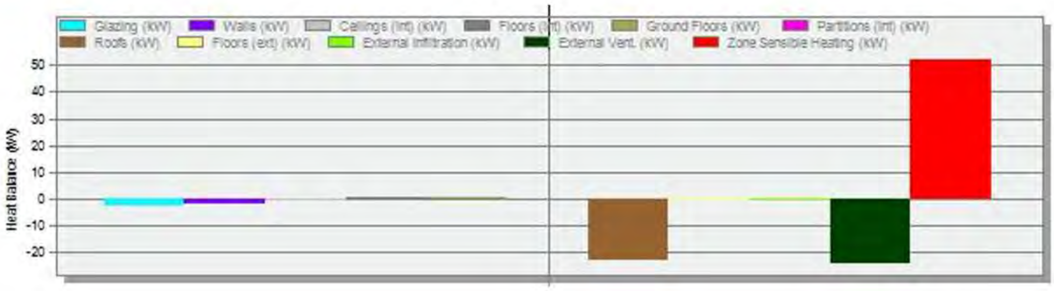
Heating is provided by a Glow Worm gas-fired boiler located in the utility room. This supplies steel panelled radiators and also provides domestic hot water. There is a pre-insulated hot water storage tank with immersion heater located in the master bedroom wardrobe.

Gross internal floor area (m²) 190 m^2

Address

KINROSS KY13 8AF

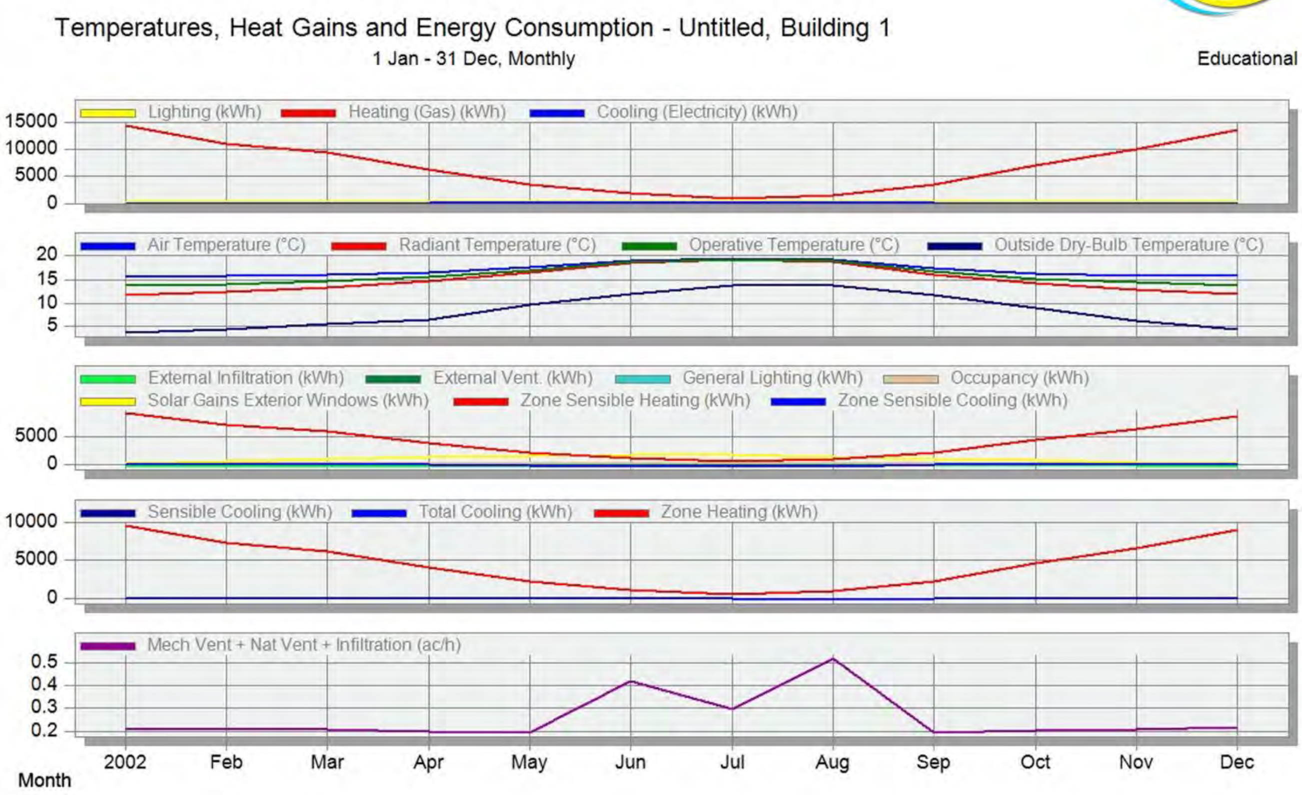
Figure A64. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	10.47
Operative Temperature (°C)	14.24
Outside Dry-Bulb Temperature (°C)	-5.30
Glazing (kW)	-2.42
Walls (kW)	-1.78
Ceilings (int) (kW)	-0.54
Floors (int) (kW)	0.54
Ground Floors (kW)	0.35
Partitions (int) (kW)	0.00
Roofs (kW)	-22.95
Floors (ext) (kW)	-0.35
External Infiltration (kW)	-0.74
External Vent. (kW)	-24.35
Zone Sensible Heating (kW)	52.18

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 65.220 (kW)				
Ground Floor Total Design Heating Capacity = 30.190 (kW)				
Bed Room	14.03	2.53	**3.16**	276.1709
Sitting Room	16.34	3.51	**4.39**	143.9055
Service	17.12	0.64	**0.80**	131.6904
Dining Room	15.88	3.92	**4.90**	174.5449
Study Room	16.87	0.80	**1.00**	143.7481
Master BedRoom	16.51	2.21	**2.77**	145.2255
Service	16.96	0.69	**0.87**	142.8682
Vestibule	16.18	0.66	**0.83**	185.2907
Sun Room	15.76	1.45	**1.81**	184.9728
Kitchen	14.06	2.06	**2.57**	289.1136
Breakfast Room	14.29	1.63	**2.04**	293.5994
Service	17.12	0.27	**0.34**	144.1135
Utility Room	14.51	1.31	**1.64**	301.5907
Bed Room	16.13	1.37	**1.72**	170.0320
Store	15.11	1.08	**1.35**	282.9227
Gallery Total Design Heating Capacity = 5.360 (kW)				
Gallery	12.44	3.42	**4.27**	225.1243
Sauna	13.46	0.67	**0.84**	271.9320
Service	14.38	0.20	**0.25**	398.1246
Roof 1 Total Design Heating Capacity = 29.670 (kW)				
Zone 1	12.90	23.74	**29.67**	178.6601

Figure A65. The heating design simulation and data of the house.



Lighting (kWh)	349.09	304.96	325.01	292.24	291.17	277.68	286.47	296.06	302.61	331.82	331.86	351.72
Heating (Gas) (kWh)	14467.97	11070.06	9470.20	6286.32	3535.21	1837.43	896.96	1506.41	3399.31	7075.45	10015.67	13695.43
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.01	0.04	18.36	6.76	64.89	0.90	0.00	0.00	0.00
Air Temperature (°C)	15.78	15.92	16.25	16.70	17.74	19.28	19.64	19.36	17.46	16.44	16.01	15.83
Radiant Temperature (°C)	11.78	12.45	13.49	14.76	16.65	18.81	19.39	18.97	16.26	14.22	12.96	12.03
Operative Temperature (°C)	13.78	14.19	14.87	15.73	17.20	19.04	19.52	19.16	16.86	15.33	14.49	13.93
Outside Dry-Bulb Temperature (°C)	3.64	4.35	5.62	6.52	9.58	11.90	13.89	13.89	11.79	8.98	6.14	4.24
External Infiltration (kWh)	-273.91	-238.64	-244.20	-225.91	-187.69	-162.73	-130.94	-123.57	-124.15	-169.22	-217.70	-263.45
External Vent. (kWh)	0.00	-1.49	-5.58	-7.36	-20.78	-87.86	-65.79	-36.45	-6.37	-0.99	-0.72	0.00
General Lighting (kWh)	349.09	304.96	325.01	292.24	291.17	277.68	286.47	296.06	302.61	331.82	331.86	351.72
Occupancy (kWh)	183.24	164.89	186.33	179.67	177.21	164.87	156.34	162.76	172.76	178.56	178.37	191.24
Solar Gains Exterior Windows (kWh)	314.95	566.38	1042.33	1335.70	1593.56	1740.21	1647.74	1455.89	1019.57	716.37	437.54	251.89
Zone Sensible Heating (kWh)	9023.02	6875.80	5846.11	3851.46	2163.25	1120.30	547.60	925.09	2092.56	4377.09	6208.65	8517.39
Zone Sensible Cooling (kWh)	-0.08	-2.21	-9.59	-17.95	-48.07	-250.88	-146.61	-313.69	-20.40	-1.95	-0.75	-0.01
Sensible Cooling (kWh)	0.00	-0.00	-0.00	-0.01	-0.07	-26.39	-11.29	-97.74	-1.37	0.00	0.00	0.00
Total Cooling (kWh)	0.00	-0.00	-0.00	-0.01	-0.07	-30.66	-11.29	-108.36	-1.51	-0.00	-0.00	0.00
Zone Heating (kWh)	9404.18	7195.54	6155.63	4086.11	2297.89	1194.33	583.02	979.17	2209.55	4599.04	6510.19	8902.03
Mech Vent + Nat Vent + Infiltration (ac/h)	0.21	0.21	0.21	0.20	0.19	0.42	0.30	0.52	0.19	0.20	0.21	0.22

Figure A66. The simulation detailed results of the house.

Case 23. A House Built in 1998

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Wall is of timber frame construction externally clad in a mixture of Anstone	0.432	Increase 14 cm Insulation
	Flat -	-
	Pitched 0.410	Increase 29 cm Insulation
Floor is of suspended timber joists overlaid in tongued and grooved boarding.	0.560	Increase 27 cm Insulation
Internal Walls are all formed in sheet Plasterboard.	0.998	
Windows are of a PVC framed design all fitted with hermetically sealed double-glazed panes.		

* As a basis for a theory of possibility

Description

The subjects comprise a purpose built two-storey detached dwelling house.

Ground Floor: Entrance Vestibule, Hall, Lounge, Dining Room, Living Room, Garden Room, Kitchen/Breakfast Room, Study,

Utility Room and WC Compartment.

First Floor: Master Bedroom with En-suite Dressing Room.

Weather Dry.

Heating and hot water

Central heating takes the form of an oil fired central heating boiler in the garage serving pressed steel radiators throughout the property.

The radiators are all fitted with individual thermostatic valves.

Gross internal floor area (m²) 258 m²

Address

EDINBURGH EH2 1JX

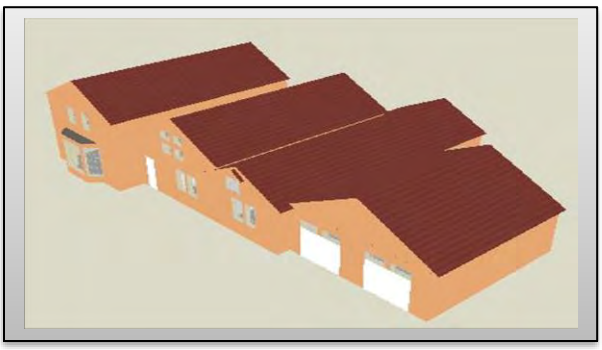
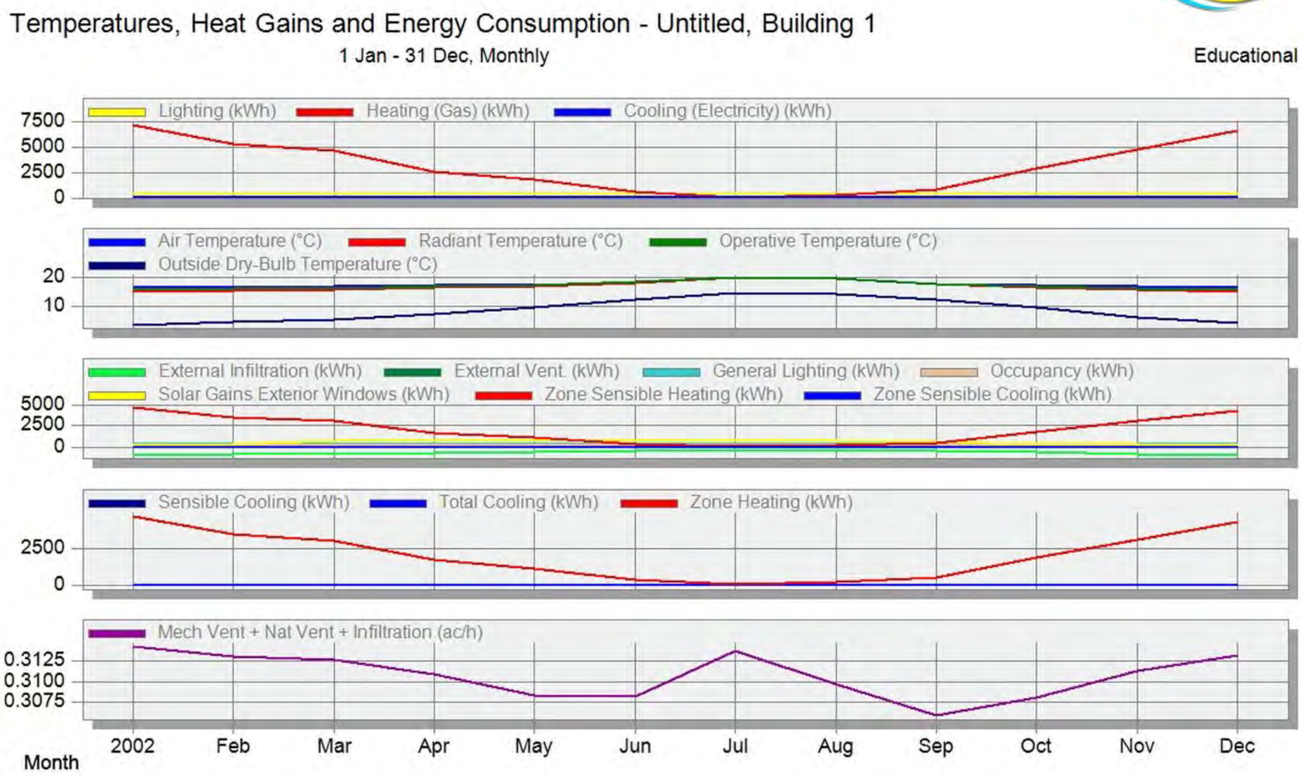


Figure A67. The software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.92
Operative Temperature (°C)	16.46
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.41
Walls (kW)	-4.02
Ceilings (int) (kW)	-0.81
Floors (int) (kW)	0.25
Ground Floors (kW)	0.50
Partitions (int) (kW)	0.00
Roofs (kW)	-6.28
Floors (ext) (kW)	-0.25
External Infiltration (kW)	-2.37
External Vent. (kW)	-23.72
Zone Sensible Heating (kW)	38.03

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 47.540 (kW)				
Ground Floor Total Design Heating Capacity = 35.390 (kW)				
Lounge	16.62	4.20	**5.25**	134.9703
Vestibule	16.91	0.43	**0.54**	154.1350
Study Room	17.12	1.10	**1.38**	130.7396
Family Room	17.00	2.05	**2.56**	128.2673
Double Garage	14.16	9.31	**11.64**	205.9886
Hall	17.52	1.63	**2.04**	115.7134
Service	17.62	0.41	**0.52**	116.7617
Dining Room	16.89	2.49	**3.12**	130.6115
Kitchen BreakfastRoo...	16.78	3.24	**4.05**	134.3919
Utility Room	15.98	1.25	**1.57**	180.5017
Garden Room	16.32	2.17	**2.72**	153.6393
First Floor Total Design Heating Capacity = 5.040 (kW)				
Bed Room	16.73	1.56	**1.95**	83.4327
Dressing Room	16.99	0.82	**1.02**	80.4205
Master BedRoom	16.57	1.66	**2.07**	87.8808
First Floor Total Design Heating Capacity = 1.970 (kW)				
Landing	17.43	0.19	**0.24**	32.4466
Bed Room	17.14	0.56	**0.69**	35.4147
Service	17.36	0.18	**0.22**	33.6787
Bed Room	17.13	0.40	**0.50**	38.2781
Hall	17.44	0.26	**0.32**	31.8648
Roof Garage Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.13	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	2.64	0.00	**0.00**	0.0000
Roof 3 Total Design Heating Capacity = 2.490 (kW)				
Zone 1	16.65	2.00	**2.49**	45.7352

Figure A68. The heating design simulation and data of the house.



Lighting (kWh)	461.46	391.04	404.62	357.78	350.85	330.89	347.03	363.40	380.09	429.82	433.92	466.95
Heating (Gas) (kWh)	7192.15	5286.20	4658.84	2610.19	1782.08	636.54	94.79	310.33	863.49	2847.32	4775.08	6624.10
Cooling (Electricity) (kWh)	0.11	1.22	2.15	2.75	1.83	4.05	10.70	4.95	1.85	0.67	0.75	0.09
Air Temperature (°C)	16.47	16.65	16.83	17.19	17.44	18.40	20.12	19.53	17.91	17.14	16.80	16.53
Radiant Temperature (°C)	14.97	15.40	15.84	16.64	17.04	18.27	20.16	19.47	17.67	16.43	15.71	15.12
Operative Temperature (°C)	15.72	16.02	16.34	16.91	17.24	18.34	20.14	19.50	17.79	16.79	16.26	15.82
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-943.34	-778.03	-834.24	-701.94	-549.88	-409.13	-379.18	-356.47	-381.34	-536.66	-731.12	-872.11
External Vent. (kWh)	-0.09	-0.07	-0.19	-0.19	-0.23	-2.31	-12.15	-5.02	-0.13	-0.08	-0.05	-0.09
General Lighting (kWh)	461.46	391.04	404.62	357.78	350.85	330.89	347.03	363.40	380.09	429.82	433.92	466.95
Occupancy (kWh)	240.62	216.63	245.52	238.37	243.74	233.59	206.44	217.41	229.39	235.17	234.33	251.17
Solar Gains Exterior Windows (kWh)	281.65	439.42	720.07	802.80	800.45	743.07	810.39	715.74	596.87	418.68	321.84	186.74
Zone Sensible Heating (kWh)	4648.05	3415.67	3010.03	1685.69	1150.53	410.87	61.13	200.13	557.24	1839.55	3084.75	4280.92
Zone Sensible Cooling (kWh)	-0.18	-2.03	-3.57	-4.57	-3.03	-6.68	-15.99	-7.39	-3.06	-1.11	-1.25	-0.15
Sensible Cooling (kWh)	-0.18	-2.04	-3.59	-4.60	-3.05	-6.73	-16.09	-7.43	-3.09	-1.12	-1.25	-0.15
Total Cooling (kWh)	-0.18	-2.04	-3.59	-4.60	-3.05	-6.77	-17.87	-8.26	-3.09	-1.12	-1.25	-0.15
Zone Heating (kWh)	4674.90	3436.03	3028.24	1696.63	1158.35	413.75	61.61	201.72	561.27	1850.76	3103.80	4305.67
Mech Vent + Nat Vent + Infiltration (ac/h)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31

Figure A69. The simulation detailed results of the house.

Case 24. A House Built in 1997

Material	U-Value W/m^{2}K	How to reach Zero Carbon home (theoretically*)
Main Walls are of modern timber frame construction with an outer leaf over decorative blockwork	0.440	Increase 14.7 cm Insulation
	Flat 0.353	Increase 23 cm Insulation
	Pitched 0.423	Increase 30 cm Insulation
Floor is of suspended concrete and timber construction.	0.561	Increase 27 cm Insulation
Internal Walls are of stud partition construction with a mixture of paper, paint.	0.990	
Windows are of timber double glazed variety.		

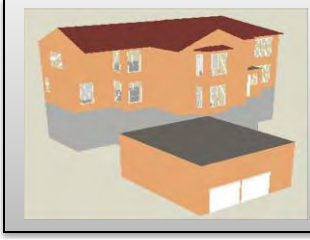
* As a basis for a theory of possibility

Description

Detached two storey house.

GROUND FLOOR: Entrance Vestibule, Inner Hall, Living Room/Drawing Room, Dining Room, Sitting Room, Kitchen/Dining Room, Larder, Utility Room and Toilet.

FIRST FLOOR: Landing with Study Area, Master Bedroom.



Weather

Dry and bright.

Heating and hot water

There is a Glowworm Flexicom 35 HX gas fired central heating boiler wall mounted within the utility room. This supplies steel panel radiators throughout and also provides domestic hot water.

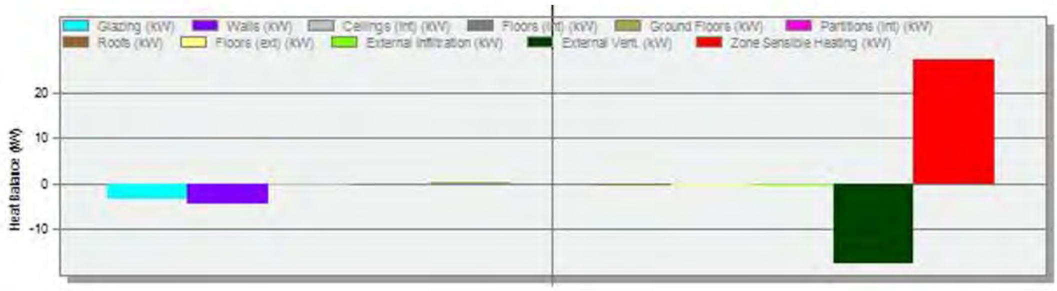
Gross internal floor area (m²)

234 m^2

Address

NORTH QUEENSFERRY
INVERKEITHING KY11 1EU

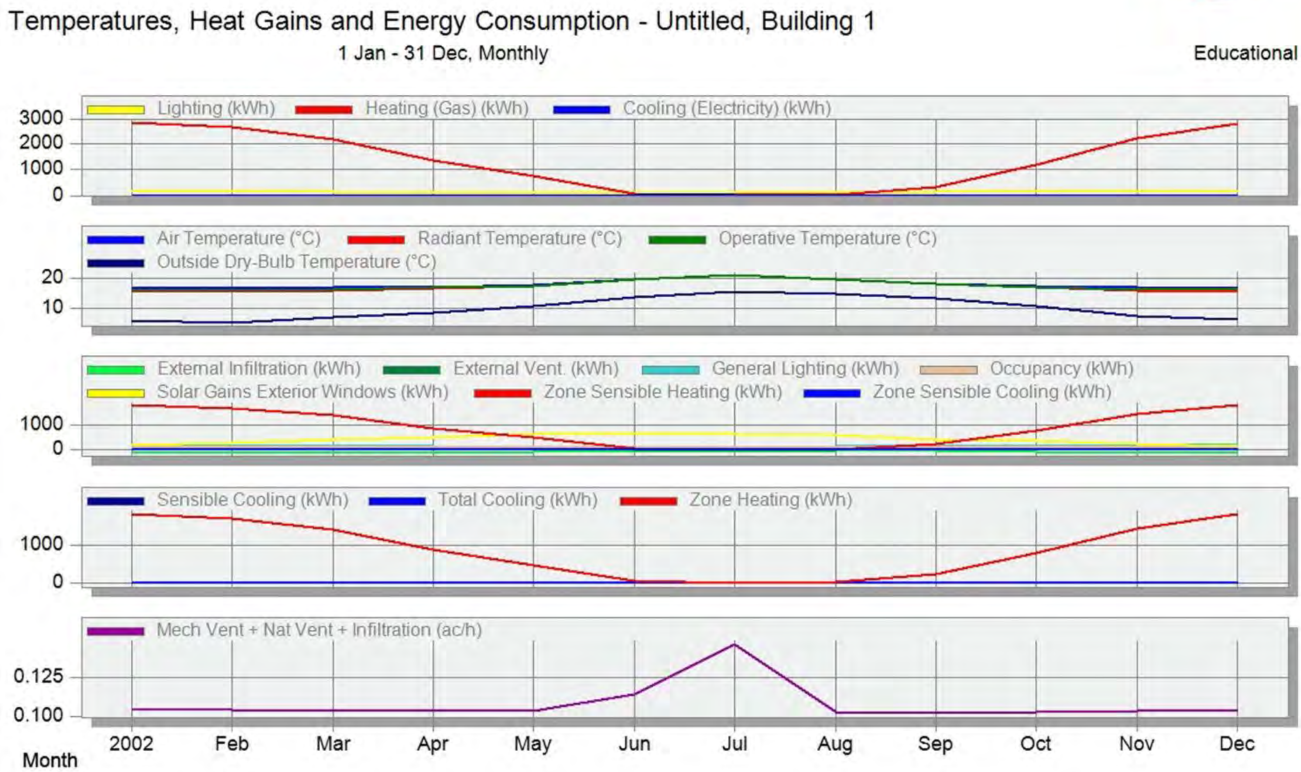
Figure A70. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.97
Operative Temperature (°C)	16.48
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.39
Walls (kW)	-4.42
Ceilings (int) (kW)	-0.43
Floors (int) (kW)	-0.00
Ground Floors (kW)	0.08
Partitions (int) (kW)	0.00
Roofs (kW)	-0.41
Floors (ext) (kW)	-0.63
External Infiltration (kW)	-0.59
External Vent. (kW)	-17.73
Zone Sensible Heating (kW)	27.31

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 34.140 (kW)				
Ground Floor Total Design Heating Capacity = 14.080 (kW)				
Vestibule	15.91	0.53	**0.67**	220.3741
Hall	17.05	2.14	**2.67**	112.5870
Sitting Room	15.91	1.98	**2.47**	158.3786
Dining Room	16.16	1.17	**1.47**	163.0035
Kitchen	16.19	2.50	**3.13**	143.1724
Service	17.33	0.19	**0.24**	120.9622
Lounge	16.48	1.53	**1.91**	137.1048
Pantry	16.34	0.68	**0.85**	162.5159
Utility Room	16.12	0.53	**0.67**	199.1269
Double Garage Total Design Heating Capacity = 7.020 (kW)				
Service	16.66	0.19	**0.24**	302.4340
Office Space	16.66	0.83	**1.04**	216.3580
Garage	16.14	4.59	**5.74**	186.3538
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.96	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.96	0.00	**0.00**	0.0000
First Floor Total Design Heating Capacity = 12.000 (kW)				
Landing	17.07	2.08	**2.59**	114.2168
Bed Room	16.43	0.93	**1.16**	151.8466
Bed Room	16.10	1.02	**1.28**	165.4271
Bath Room	17.20	0.66	**0.83**	117.6240
Bed Room	16.58	2.15	**2.69**	131.4476
Wardrobe	17.43	0.18	**0.23**	116.5790
Bed Room	16.57	1.51	**1.88**	135.3134
Bath Room	16.39	1.07	**1.34**	152.7635

Figure A71. The heating design simulation and data of the house.



Lighting (kWh)	177.02	148.56	143.90	118.50	109.98	101.01	107.20	117.26	131.28	158.76	163.30	178.93
Heating (Gas) (kWh)	2852.93	2649.46	2173.80	1356.58	748.35	79.75	3.00	29.35	346.92	1214.59	2247.59	2814.55
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.12	6.83	0.00	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.71	16.69	16.92	17.20	17.77	19.76	21.26	19.53	18.26	17.46	16.90	16.70
Radiant Temperature (°C)	15.55	15.52	16.00	16.58	17.44	19.77	21.34	19.53	18.06	16.88	15.91	15.54
Operative Temperature (°C)	16.13	16.10	16.46	16.89	17.61	19.76	21.30	19.53	18.16	17.17	16.41	16.12
Outside Dry-Bulb Temperature (°C)	5.78	4.82	6.81	8.51	10.55	13.52	15.65	14.61	13.21	10.51	7.19	6.25
External Infiltration (kWh)	-151.29	-149.71	-139.17	-115.21	-99.10	-82.03	-75.77	-66.41	-66.09	-95.57	-130.07	-144.86
External Vent. (kWh)	0.00	0.00	0.00	0.00	-0.48	-6.96	-24.42	-0.53	0.00	0.00	0.00	0.00
General Lighting (kWh)	177.02	148.56	143.90	118.50	109.98	101.01	107.20	117.26	131.28	158.76	163.30	178.93
Occupancy (kWh)	97.94	88.16	100.04	97.39	97.91	88.88	79.14	89.39	92.27	95.16	95.39	102.24
Solar Gains Exterior Windows (kWh)	186.28	268.11	419.00	514.11	652.81	650.93	648.55	579.03	428.15	354.28	208.18	155.18
Zone Sensible Heating (kWh)	1842.99	1710.91	1404.41	876.62	483.29	51.47	1.94	18.96	224.32	784.98	1451.74	1817.80
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.17	-10.59	0.00	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.17	-10.63	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.20	-11.41	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	1854.40	1722.15	1412.97	881.78	486.43	51.84	1.95	19.08	225.50	789.49	1460.93	1829.46
Mech Vent + Nat Vent + Infiltration (ac/h)	0.10	0.10	0.10	0.10	0.10	0.11	0.15	0.10	0.10	0.10	0.10	0.10

Figure A72. The simulation detailed results of the house.

Case 25. A House Built in 1996

Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are of cavity masonry construction, part stone and part render faced.	0.458	Increase 14 cm Insulation
	Flat 0.400	Increase 24 cm Insulation
	Pitched 0.450	Increase 31 cm Insulation
Floor is of suspended timber construction.	0.565	Increase 28 cm Insulation
Internal Walls have been lined with plaster on the hard and plasterboard	0.997	
Windows are of hardwood timber double glazed variety.		

* As a basis for a theory of possibility

Description

The property is a detached house.

Ground floor: dining hall, lounge, sun room, kitchen / breakfast room, pantry, bedroom, dressing area, en-suite shower room with WC and wash hand basin, bathroom with WC and wash hand basin.

First floor: Landing, 4 Bedrooms, 4 En-suite Shower rooms.

Weather Dry and bright.

Heating and hot water

There is a full LPG fired central heating system in the subjects, served by an Ideal Mexico boiler which is located in the first floor cupboard.

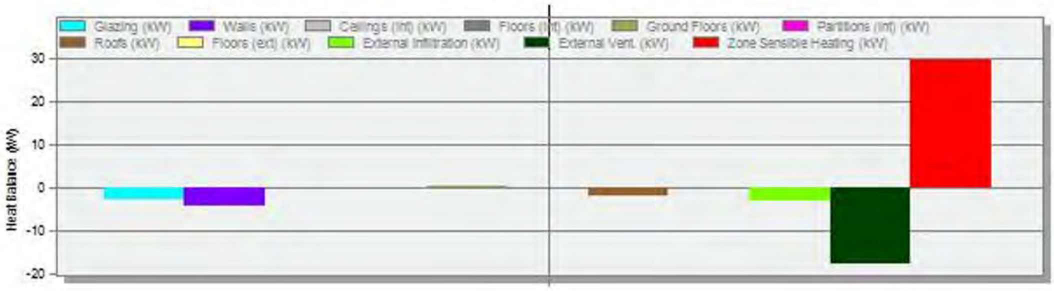
The hot water is provided by the central heating boiler and is supplemented by an electric immersion heater fitted to a foam.

Gross internal floor area (m²) 320 m^2

Address

VIEWFIELD BOWDEN MELROSE TD6 0ST

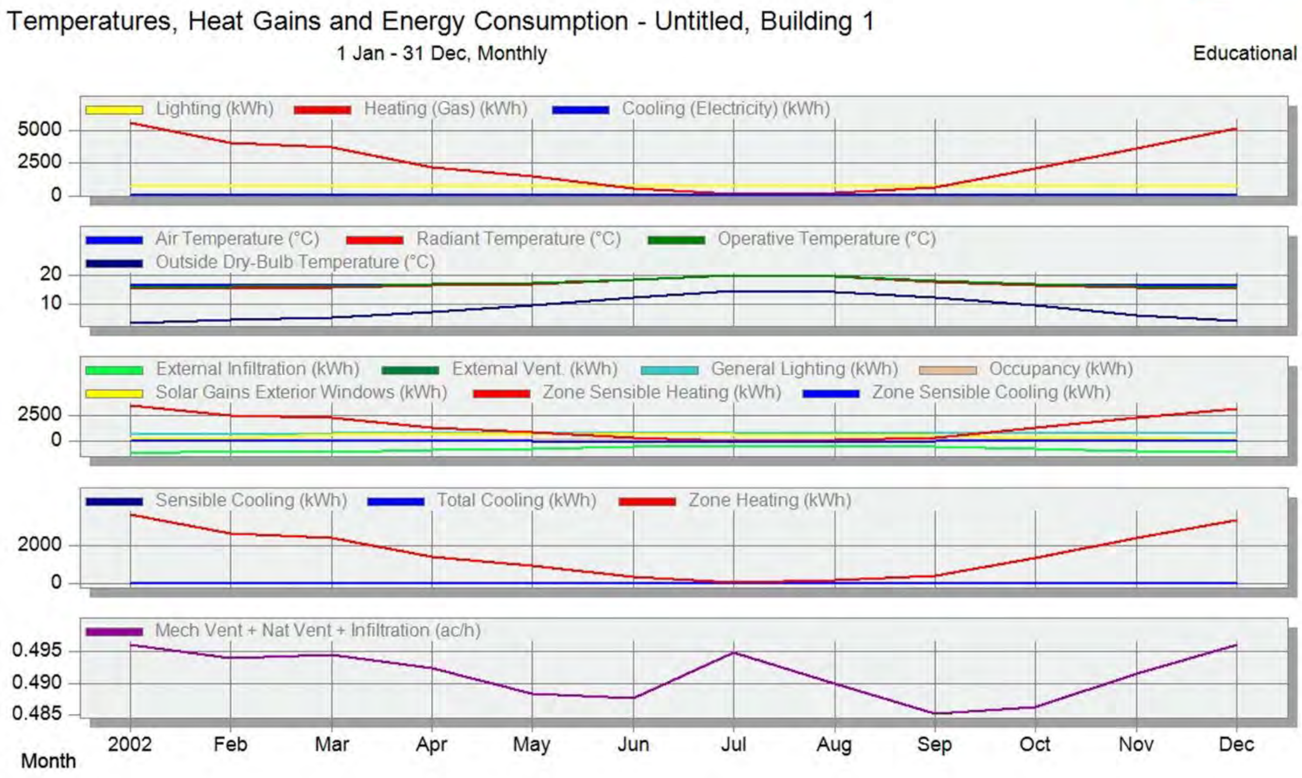
Figure A73. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.42
Operative Temperature (°C)	16.71
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.65
Walls (kW)	-4.15
Ceilings (int) (kW)	-0.01
Floors (int) (kW)	0.01
Ground Floors (kW)	0.19
Partitions (int) (kW)	0.00
Roofs (kW)	-1.95
Floors (ext) (kW)	-0.23
External Infiltration (kW)	-3.01
External Vent. (kW)	-17.83
Zone Sensible Heating (kW)	29.57

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 36.960 (kW)				
Ground Floor Total Design Heating Capacity = 15.790 (kW)				
Sun Room	15.93	2.72	**3.40**	200.9925
Sitting Room	17.33	2.21	**2.76**	138.6574
Kitchen	17.02	1.97	**2.46**	149.2271
Bed Room	16.70	2.00	**2.49**	163.9900
Bath Room	16.84	0.88	**1.10**	182.7763
Dining Room	16.81	1.84	**2.30**	162.9784
Utility Room	16.66	0.48	**0.60**	222.2834
Bath Room	17.12	0.29	**0.36**	179.0771
Store	17.30	0.26	**0.32**	160.3094
Roof 1 Total Design Heating Capacity = 5.210 (kW)				
Zone 1	16.38	4.17	**5.21**	38.9758
Window Total Design Heating Capacity = 0.970 (kW)				
Zone 1	14.25	0.77	**0.97**	-1058.5886
Window Total Design Heating Capacity = 0.140 (kW)				
Zone 1	15.26	0.11	**0.14**	-1448.3444
Window Total Design Heating Capacity = 0.150 (kW)				
Zone 1	15.27	0.12	**0.15**	8315.2836
Window Total Design Heating Capacity = 0.080 (kW)				
Zone 1	15.82	0.06	**0.08**	1.#INF
Window Total Design Heating Capacity = 0.070 (kW)				
Zone 1	16.23	0.06	**0.07**	192.5064
Window Total Design Heating Capacity = 0.080 (kW)				
Zone 1	15.82	0.06	**0.08**	1.#INF
Window Total Design Heating Capacity = 0.070 (kW)				
Zone 1	16.24	0.06	**0.07**	191.5564
Window Total Design Heating Capacity = 0.140 (kW)				
Zone 1	15.24	0.11	**0.14**	-2101.5326

Figure A74. The heating design simulation and data of the house.



Lighting (kWh)	760.91	686.67	765.55	742.35	765.55	746.99	756.27	760.91	737.71	756.27	737.71	770.19
Heating (Gas) (kWh)	5606.65	4077.26	3674.13	2159.48	1461.46	537.43	110.78	244.50	612.55	2088.82	3649.68	5131.97
Cooling (Electricity) (kWh)	0.05	1.24	2.59	3.81	1.77	2.87	9.83	5.40	2.64	0.64	0.99	0.12
Air Temperature (°C)	16.30	16.45	16.61	16.94	17.22	18.31	19.95	19.39	17.92	17.00	16.61	16.37
Radiant Temperature (°C)	15.15	15.51	15.87	16.54	16.95	18.27	20.06	19.41	17.80	16.49	15.80	15.29
Operative Temperature (°C)	15.73	15.98	16.24	16.74	17.09	18.29	20.01	19.40	17.86	16.75	16.21	15.83
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1180.62	-970.84	-1038.20	-866.81	-678.68	-514.37	-472.75	-448.01	-486.19	-668.15	-910.61	-1091.13
External Vent. (kWh)	-0.01	-0.32	-0.56	-1.75	-0.17	-0.43	-9.62	-5.44	-1.51	-0.06	-0.20	-0.05
General Lighting (kWh)	760.91	686.67	765.55	742.35	765.55	746.99	756.27	760.91	737.71	756.27	737.71	770.19
Occupancy (kWh)	179.15	161.23	182.67	177.13	180.69	171.82	152.65	160.33	168.52	174.67	174.31	186.99
Solar Gains Exterior Windows (kWh)	267.01	403.18	642.79	698.46	678.46	622.37	674.14	612.03	525.69	381.43	303.21	177.98
Zone Sensible Heating (kWh)	3494.59	2527.76	2263.63	1311.38	885.54	322.80	66.00	145.01	361.79	1278.88	2257.63	3190.64
Zone Sensible Cooling (kWh)	-0.09	-2.06	-6.41	-13.46	-16.09	-35.62	-57.13	-40.66	-20.77	-2.57	-2.09	-0.21
Sensible Cooling (kWh)	-0.09	-2.07	-4.33	-6.37	-2.95	-4.79	-16.30	-8.72	-4.41	-1.08	-1.66	-0.21
Total Cooling (kWh)	-0.09	-2.07	-4.33	-6.37	-2.95	-4.79	-17.79	-9.02	-4.42	-1.08	-1.66	-0.21
Zone Heating (kWh)	3644.32	2650.22	2388.19	1403.66	949.95	349.33	72.00	158.92	398.16	1357.73	2372.29	3335.78
Mech Vent + Nat Vent + Infiltration (ac/h)	0.50	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.50

Figure A75. The simulation detailed results of the house.

Case 26. A House Built in 1995

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Wall Traditional brick cavity construction and are pointed.	0.467	Increase 14 cm Insulation
	Flat 0.424	Increase 30 cm Insulation
	Pitched 0.448	Increase 30 cm Insulation
Floors are thought to be suspended concrete construction, overlaid with a floating timber finish.	0.580	Increase 27 cm Insulation
Internal Wall appears to be of solid and stud construction and have a plasterboard finish.	1	
Windows are of a timber casement design and are double glazed.		

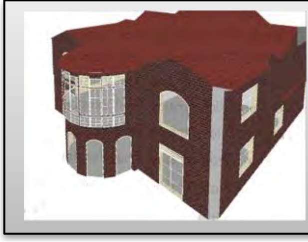
* As a basis for a theory of possibility

Description

Detached villa.

Ground Floor: Vestibule, Hallway, Sitting room, Living room, Dining room, Kitchen/Breakfast room, Bedroom with en-suite Bathroom, Study, Utility room and WC apartment.

First Floor: Drawing room, Master Bedroom with en-suite Shower room and Dressing room, Guest Bedroom with en-suite Shower room, Bedroom and WC apartment.



Weather Dry and Sunny.

Heating and hot water

Heating takes the form of a gas fired central heating system. The boiler is connected to wall mounted radiators.

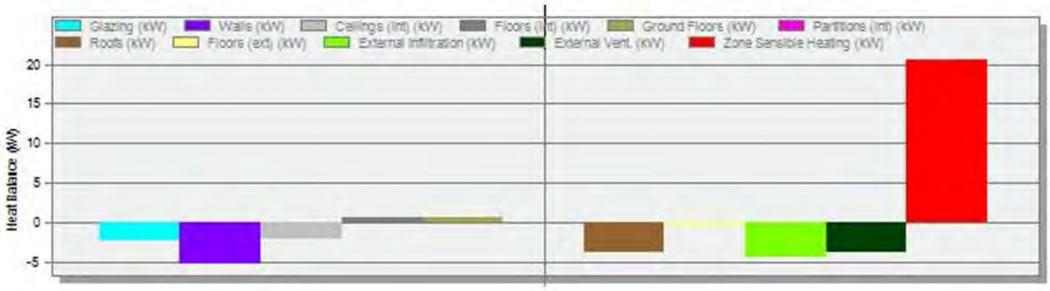
Hot water is supplied from the boilers via a pre-insulated and copper circulating tank which is also fitted with an electric immersion heater.

Gross internal floor area (m²) 511 m² **approx.**

Address

EDINBURGH, EH4 6DF

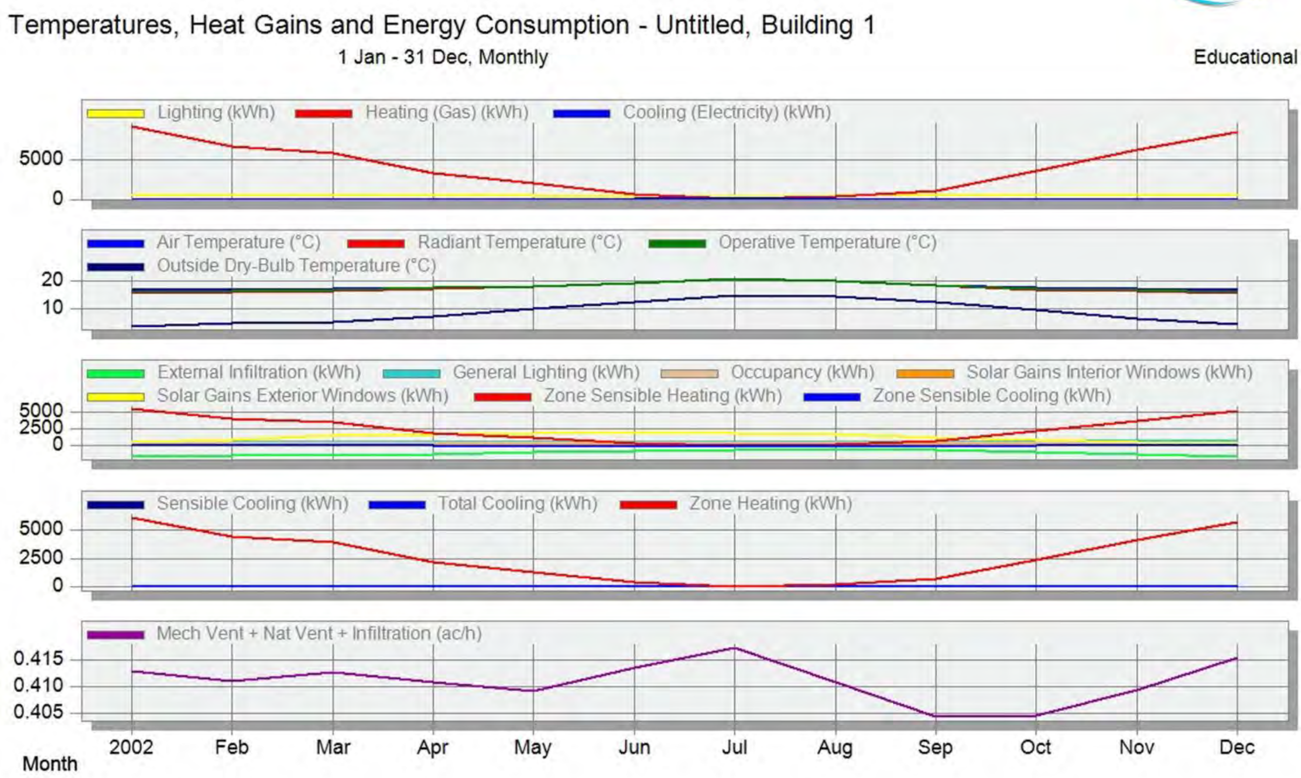
Figure A76. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.48
Operative Temperature (°C)	16.74
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.36
Walls (kW)	-5.29
Ceilings (int) (kW)	-2.00
Floors (int) (kW)	0.55
Ground Floors (kW)	0.54
Partitions (int) (kW)	0.00
Roofs (kW)	-3.71
Floors (ext) (kW)	-0.33
External Infiltration (kW)	-4.32
External Vent. (kW)	-3.80
Zone Sensible Heating (kW)	20.60

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 25.760 (kW)				
Ground Floor Total Design Heating Capacity = 9.120 (kW)				
Garden Room	17.12	1.18	**1.47**	34.2429
Dining Room	16.93	0.87	**1.09**	38.9475
Hall	17.64	0.72	**0.90**	20.6697
Kitchen BreakfastRoo...	17.14	0.87	**1.08**	29.7280
Cupboard	17.34	0.11	**0.14**	43.1730
Utility Room	16.75	0.53	**0.66**	53.7900
Sitting Room	16.93	0.89	**1.11**	39.3607
Double BedRoom	17.21	0.64	**0.80**	31.9602
Service	17.61	0.12	**0.15**	25.7694
Vestibule	16.69	0.40	**0.51**	60.5910
Study Room	17.12	0.33	**0.41**	41.4493
Garden Store	16.34	0.41	**0.51**	88.0800
Service	17.07	0.23	**0.29**	53.5097
Garage Total Design Heating Capacity = 2.630 (kW)				
Zone 1	16.28	2.11	**2.63**	51.9216

Figure A77. The heating design simulation and data of the house.



Lighting (kWh)	598.61	509.16	522.75	447.26	432.92	406.57	424.88	449.70	477.24	548.03	562.86	603.65
Heating (Gas) (kWh)	9361.12	6825.75	5952.12	3306.10	2063.46	667.18	73.29	288.73	1034.90	3691.73	6351.64	8685.69
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.09	1.15	0.08	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.49	16.71	16.94	17.39	17.75	18.88	20.46	19.68	18.07	17.26	16.87	16.54
Radiant Temperature (°C)	15.32	15.79	16.31	17.17	17.69	19.03	20.73	19.84	18.06	16.78	16.02	15.43
Operative Temperature (°C)	15.90	16.25	16.63	17.28	17.72	18.95	20.59	19.76	18.07	17.02	16.45	15.99
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1734.20	-1437.94	-1549.48	-1317.62	-1057.90	-822.77	-762.42	-699.39	-732.47	-1006.19	-1353.71	-1604.82
General Lighting (kWh)	598.61	509.16	522.75	447.26	432.92	406.57	424.88	449.70	477.24	548.03	562.86	603.65
Occupancy (kWh)	324.39	292.00	330.57	320.60	326.23	310.13	275.90	293.21	309.30	317.06	315.88	338.60
Solar Gains Interior Windows (kWh)	0.02	0.05	0.11	0.16	0.20	0.21	0.19	0.15	0.10	0.05	0.03	0.01
Solar Gains Exterior Windows (kWh)	445.41	765.12	1388.41	1646.37	1812.55	1804.87	1836.00	1547.19	1200.90	778.52	510.15	293.44
Zone Sensible Heating (kWh)	5465.32	3932.95	3360.55	1794.52	1124.12	361.03	43.07	158.80	559.03	2075.31	3651.78	5041.91
Zone Sensible Cooling (kWh)	0.00	-5.55	-25.59	-73.02	-118.90	-185.82	-254.41	-189.84	-117.37	-14.76	-2.76	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.23	-2.22	-0.20	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	-0.00	-0.00	-0.23	-2.88	-0.21	0.00	0.00	0.00	0.00
Zone Heating (kWh)	6084.73	4436.74	3868.88	2148.96	1341.25	433.67	47.64	187.67	672.69	2399.63	4128.56	5645.70
Mech Vent + Nat Vent + Infiltration (ac/h)	0.41	0.41	0.41	0.41	0.41	0.41	0.42	0.41	0.40	0.40	0.41	0.42

Figure A78. The simulation detailed results of the house.

Case 27. A House Built in 1992

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of cavity construction. Externally the walls are brick	0.542	Increase 15 cm Insulation
	Flat -	-
	Pitched 0.391	Increase 29 cm Insulation
Floors are of a suspended timber type with timber joists and covered with chipboard sheeting.	0.584	Increase 27 cm Insulation
Internal Walls are of timber studwork framed construction.	1.042	
Windows are of timber double glazed variety.		

* As a basis for a theory of possibility

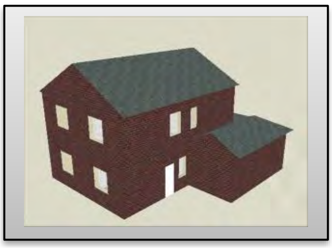
Description

The subjects comprise a two storey detached house.

Ground floor: Entrance Lobby and Hall, Living room, Dining room, Kitchen and Ground floor toilet.

First floor: 4 Bedrooms and Bathroom.

Externally: Single garage.



Weather Dry.

Heating and hot water

The property is heated by a gas fired boiler. Heating to the rooms is provided by water filled radiators.

Hot water is stored in a storage cylinder. An immersion heater is fitted (not tested).The hot water is provided by the central heating boiler and is supplemented by an electric immersion heater fitted to a foam insulated hot water cylinder.

Gross internal floor area (m²) 109 m^2

Address

DALKEITH EH22 5TR

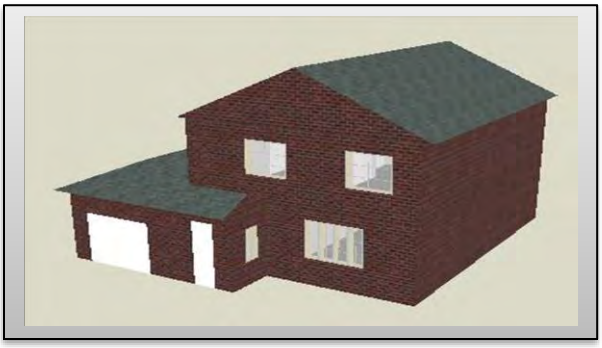
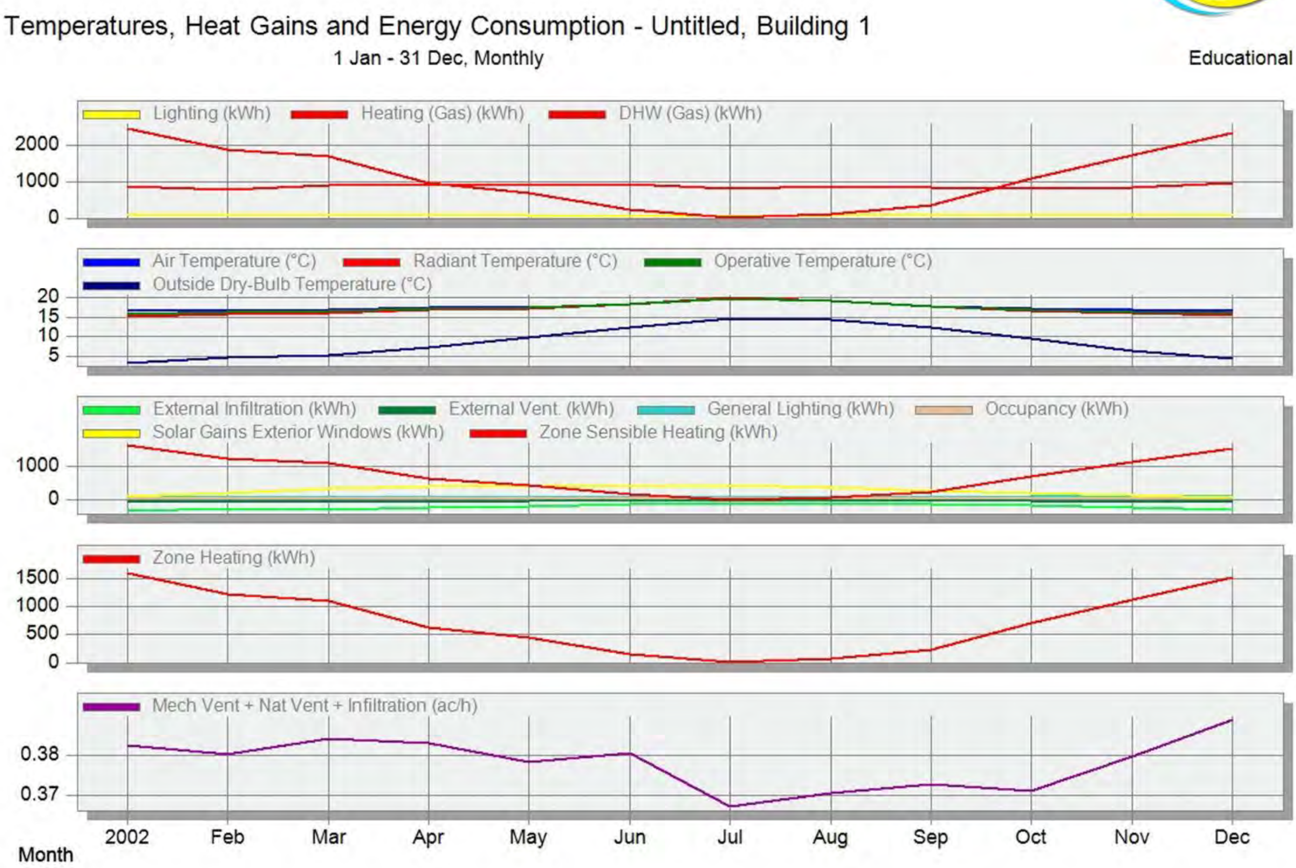


Figure A79. The software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.37
Operative Temperature (°C)	16.68
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-0.79
Walls (kW)	-2.58
Ceilings (int) (kW)	-0.72
Floors (int) (kW)	0.08
Ground Floors (kW)	0.12
Partitions (int) (kW)	0.00
External Infiltration (kW)	-0.80
External Vent. (kW)	-0.56
Zone Sensible Heating (kW)	5.22

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 6.530 (kW)				
Ground Floor Total Design Heating Capacity = 2.590 (kW)				
Hall	17.58	0.12	**0.15**	25.8036
Living Room	16.86	0.63	**0.79**	41.0007
Vestibule	16.07	0.26	**0.33**	136.4958
Service	17.55	0.06	**0.07**	29.4268
Store	17.63	0.02	**0.03**	31.2039
Landing	17.17	0.09	**0.12**	57.1619
Kitchen	16.59	0.46	**0.58**	56.7421
Dining Room	16.72	0.42	**0.52**	51.2206
Garage Total Design Heating Capacity = 1.020 (kW)				
Zone 1	16.04	0.81	**1.02**	76.1643
First Floor Total Design Heating Capacity = 2.920 (kW)				
Bed Room	16.42	0.37	**0.46**	71.4025
Bed Room	16.50	0.52	**0.65**	57.0130
Hall Way	17.12	0.19	**0.24**	50.8437
Bed Room	16.54	0.55	**0.69**	56.3349
Bed Room	16.80	0.30	**0.38**	51.4744
Landing	16.63	0.19	**0.24**	92.9088
Bath Room	16.82	0.21	**0.26**	60.0595

Figure A80. The heating design simulation and data of the house.



Lighting (kWh)	97.29	76.57	76.85	67.15	61.42	57.42	55.64	64.29	71.90	82.09	88.66	104.64
Heating (Gas) (kWh)	2479.37	1868.57	1700.55	969.75	684.84	240.63	19.70	104.11	353.26	1094.59	1734.05	2357.41
DHW (Gas) (kWh)	858.81	769.69	905.43	891.26	905.43	937.87	812.20	858.81	844.64	812.20	844.64	952.04
Air Temperature (°C)	16.48	16.68	16.92	17.33	17.45	18.26	19.70	19.06	17.77	17.21	16.83	16.63
Radiant Temperature (°C)	15.25	15.64	16.09	16.91	17.16	18.26	19.89	19.14	17.62	16.59	15.89	15.42
Operative Temperature (°C)	15.87	16.16	16.51	17.12	17.31	18.26	19.79	19.10	17.70	16.90	16.36	16.02
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-321.42	-265.82	-286.44	-242.14	-187.88	-136.83	-121.31	-113.05	-127.60	-184.99	-249.99	-299.73
External Vent. (kWh)	-74.75	-62.71	-69.08	-56.20	-41.20	-30.01	-22.72	-22.26	-29.15	-42.28	-58.35	-80.58
General Lighting (kWh)	97.29	76.57	76.85	67.15	61.42	57.42	55.64	64.29	71.90	82.09	88.66	104.64
Occupancy (kWh)	43.89	39.34	46.25	45.46	46.19	47.02	38.19	41.44	43.01	41.51	43.17	48.66
Solar Gains Exterior Windows (kWh)	113.36	190.31	325.60	396.92	417.57	407.76	420.67	359.17	278.03	183.08	131.43	76.15
Zone Sensible Heating (kWh)	1611.59	1214.57	1105.36	630.34	445.14	156.41	12.81	67.67	229.62	711.48	1127.13	1532.32
Zone Heating (kWh)	1611.59	1214.57	1105.36	630.34	445.14	156.41	12.81	67.67	229.62	711.48	1127.13	1532.32
Mech Vent + Nat Vent + Infiltration (ac/h)	0.38	0.38	0.38	0.38	0.38	0.38	0.37	0.37	0.37	0.37	0.38	0.39

Figure A81. The simulation detailed results of the house.

Case 28. A House Built in 1991

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls, Traditional masonry construction rendered externally.	0.554	Increase 17 cm Insulation
	Flat 0.472	Increase 26 cm Insulation
	Pitched 0.496	Increase 32 cm Insulation
Floor are solid construction along with suspended timber overlaid in tongued and .groove boarding	0.600	Increase 26 cm Insulation
Internal Walls, plastered and decorated.	1.045	
Windows are of timber double glazed.		

* As a basis for a theory of possibility

Description

Detached house. Ground Floor: Reception/dining hallway, three living rooms, kitchen/dining room, utility room and two WC apartments.

First Floor: Galleried landing and hallway, master bedroom.

Weather Dry and bright.

Heating and hot water

Gas fired boiler for main house located in cupboard at ground level serving panel radiators and providing hot water via two thermal stores.

Combination styled gas fired boiler located in garage serving basement floor.

Gross internal floor area (m²) 602 m^2

Address

EDINBURGH EH14 1BL

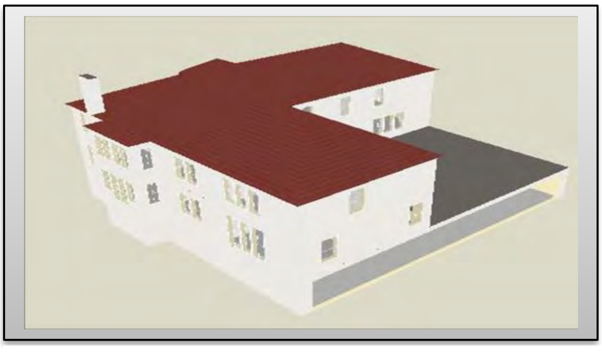
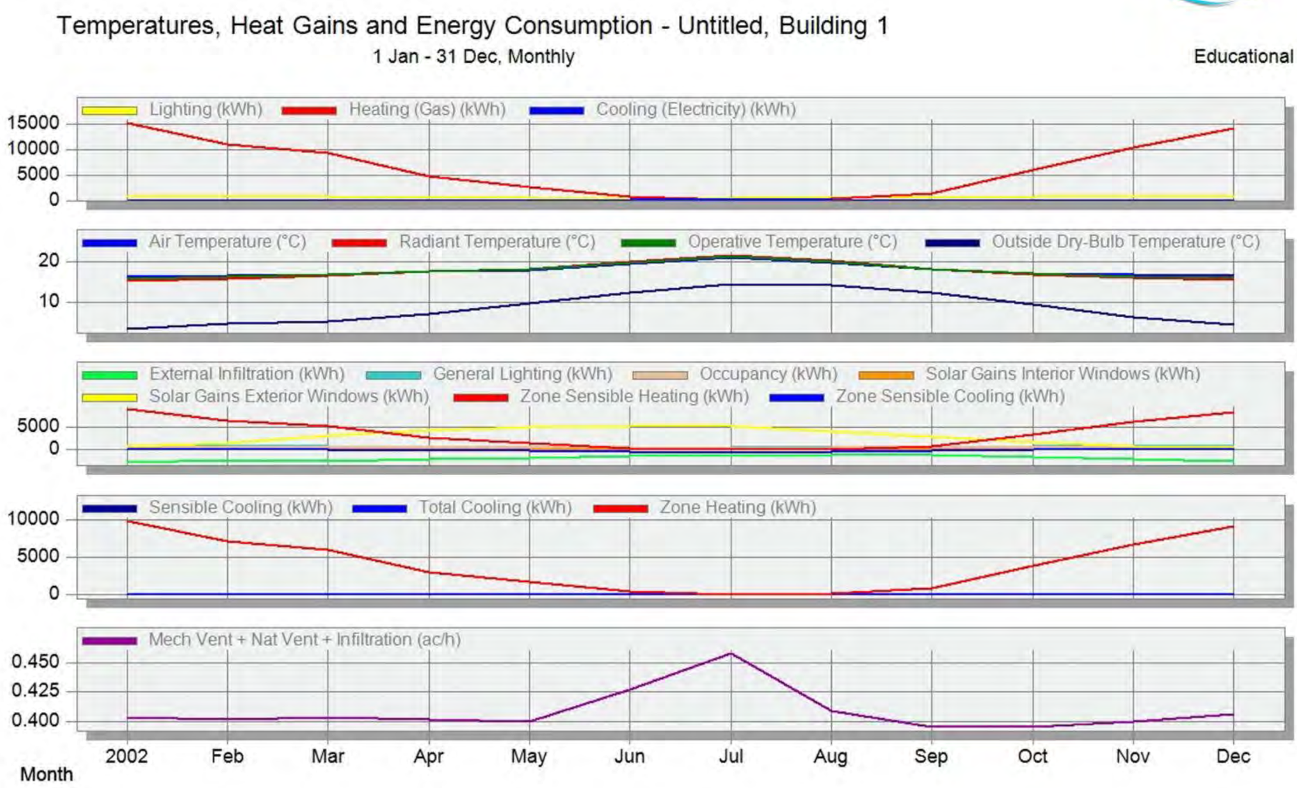


Figure A82. The software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.49
Operative Temperature (°C)	16.74
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-9.91
Walls (kW)	-8.15
Ceilings (int) (kW)	-3.34
Floors (int) (kW)	1.02
Ground Floors (kW)	0.51
Partitions (int) (kW)	0.00
Roofs (kW)	-1.50
External Infiltration (kW)	-6.87
External Vent. (kW)	-5.47
Zone Sensible Heating (kW)	33.52

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 41.890 (kW)				
Basement Total Design Heating Capacity = 16.330 (kW)				
Garage	16.58	2.73	**3.41**	40.3759
UnderGround	16.85	6.15	**7.69**	53.6180
GameRoom	17.11	2.00	**2.51**	29.7623
Landing	17.63	0.43	**0.54**	21.8700
Service	17.63	0.11	**0.14**	25.3940
Sauna	17.11	0.19	**0.24**	50.2265
StudyRoom	16.75	0.93	**1.17**	45.9913
Shower Room	17.06	0.50	**0.63**	37.5405
Ground Floor Total Design Heating Capacity = 11.890 (kW)				
Dining Room	16.62	0.84	**1.05**	51.7297
Kitchen	17.12	0.66	**0.83**	35.0937
Cloak Room	16.94	0.64	**0.80**	55.0399
Play Room	16.35	0.90	**1.12**	61.1328
Landing	17.57	0.18	**0.22**	24.9720
Store 1	17.59	0.08	**0.10**	27.5898
Service 1	17.32	0.14	**0.17**	34.8131
Store	17.06	0.18	**0.22**	48.9114
Hall	16.81	1.80	**2.25**	38.7145
Utility Room	16.29	0.71	**0.89**	74.2414
Service	17.18	0.24	**0.30**	42.2411
Sitting Room	16.33	2.13	**2.66**	49.8838
Day Room	16.56	1.02	**1.28**	51.9900
First Floor Total Design Heating Capacity = 13.440 (kW)				
Service 1	15.90	0.72	**0.90**	97.5402
Double BedRoom 1	16.83	1.04	**1.30**	39.2654
Double BedRoom 2	16.49	0.66	**0.83**	57.6320
Service 2	16.49	0.17	**0.21**	121.6208
Bathroom 1	17.16	0.31	**0.38**	35.0584

Figure A83. The heating design simulation and data of the house.



Lighting (kWh)	842.20	677.05	649.57	503.40	448.75	399.18	439.09	495.22	581.20	735.32	776.13	854.21
Heating (Gas) (kWh)	15127.35	10908.60	9210.68	4680.05	2624.34	698.63	11.75	283.58	1345.08	5987.56	10349.91	14112.41
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.12	8.66	0.02	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.46	16.70	16.96	17.56	18.03	19.49	21.08	19.93	18.10	17.24	16.84	16.51
Radiant Temperature (°C)	15.40	15.94	16.57	17.67	18.32	20.00	21.70	20.36	18.30	16.87	16.09	15.50
Operative Temperature (°C)	15.93	16.32	16.76	17.62	18.17	19.74	21.39	20.14	18.20	17.06	16.47	16.01
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2742.47	-2276.40	-2456.49	-2117.65	-1726.64	-1416.32	-1323.45	-1144.65	-1157.05	-1587.83	-2139.16	-2537.21
General Lighting (kWh)	842.20	677.05	649.57	503.40	448.75	399.18	439.09	495.22	581.20	735.32	776.13	854.21
Occupancy (kWh)	469.65	422.87	479.28	462.29	467.47	437.89	387.83	420.83	448.85	459.31	457.48	490.23
Solar Gains Interior Windows (kWh)	0.57	1.31	2.74	4.11	4.73	5.10	5.06	3.88	2.52	1.39	0.68	0.39
Solar Gains Exterior Windows (kWh)	736.13	1546.90	3097.98	4355.36	4935.30	5214.25	5219.31	4092.24	2791.53	1608.99	876.33	497.58
Zone Sensible Heating (kWh)	8933.33	6353.53	5242.00	2544.82	1403.86	366.72	7.20	150.14	703.06	3407.80	6033.32	8296.22
Zone Sensible Cooling (kWh)	0.00	-0.33	-24.10	-121.69	-193.46	-414.55	-629.97	-314.73	-157.22	-4.46	-0.75	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.31	-18.60	-0.06	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.31	-21.64	-0.06	0.00	0.00	0.00	0.00
Zone Heating (kWh)	9832.78	7090.59	5986.94	3042.03	1705.82	454.11	7.64	184.33	874.30	3891.91	6727.44	9173.06
Mech Vent + Nat Vent + Infiltration (ac/h)	0.40	0.40	0.40	0.40	0.40	0.43	0.46	0.41	0.39	0.40	0.40	0.41

Figure A84. The simulation detailed results of the house.

Case 29. A House Built in 1986

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Wall are 275mm cavity brick, block and timber frame, partly rendered externally.	0.603	Increase 18 cm Insulation
	Flat -	-
	Pitched 0.516	Increase 31 cm Insulation
Floor are of a solid concrete or suspended timber nature	0.610	Increase 28 cm Insulation
Internal Wall, plastered.	1.053	
Windows are of a PVC framed pivot, casement double glazed.		

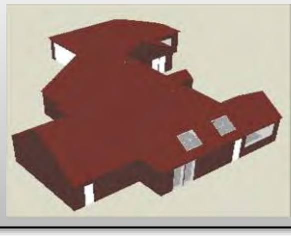
* As a basis for a theory of possibility

Description

Two storey detached house.

Ground Floor: Vestibule, Hallway, Lounge, Dining Room, Kitchen, Utility Room, Study, Music Room, 2 Conservatories, 2 Bedrooms, Bathroom (with WC and en-suite to master bedroom), 2 Shower Rooms/WC. (One en-suite to bedroom(

First Floor: Landing, 4 Bedrooms



Weather Dry and bright.

Heating and hot water

There is a gas fired central heating system serving panel radiators. The boiler for this is a Vokera Mynute 30 HE located within a cupboard off the shower room. The central heating boiler is vented externally by means of a balanced flue. The central heating boiler also provides domestic hot water Combination styled gas fired boiler located in garage serving basement floor.

Gross internal floor area (m²) 239 m²

Address

EDINBURGH EH4 5BN

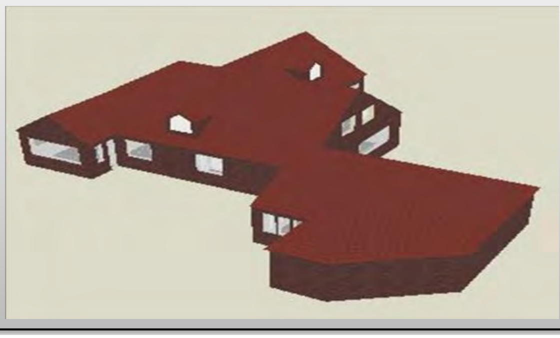
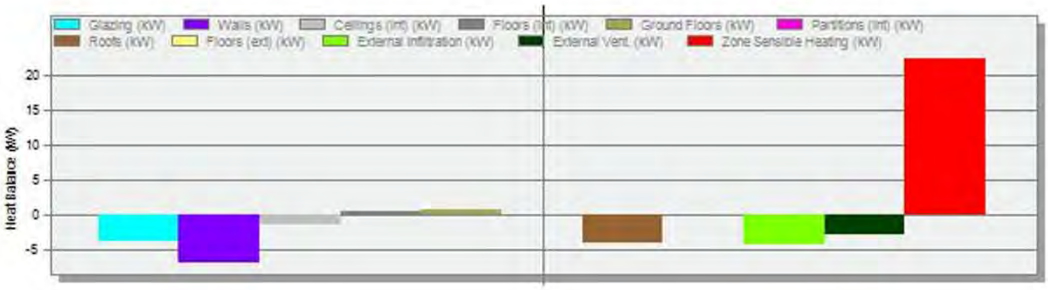


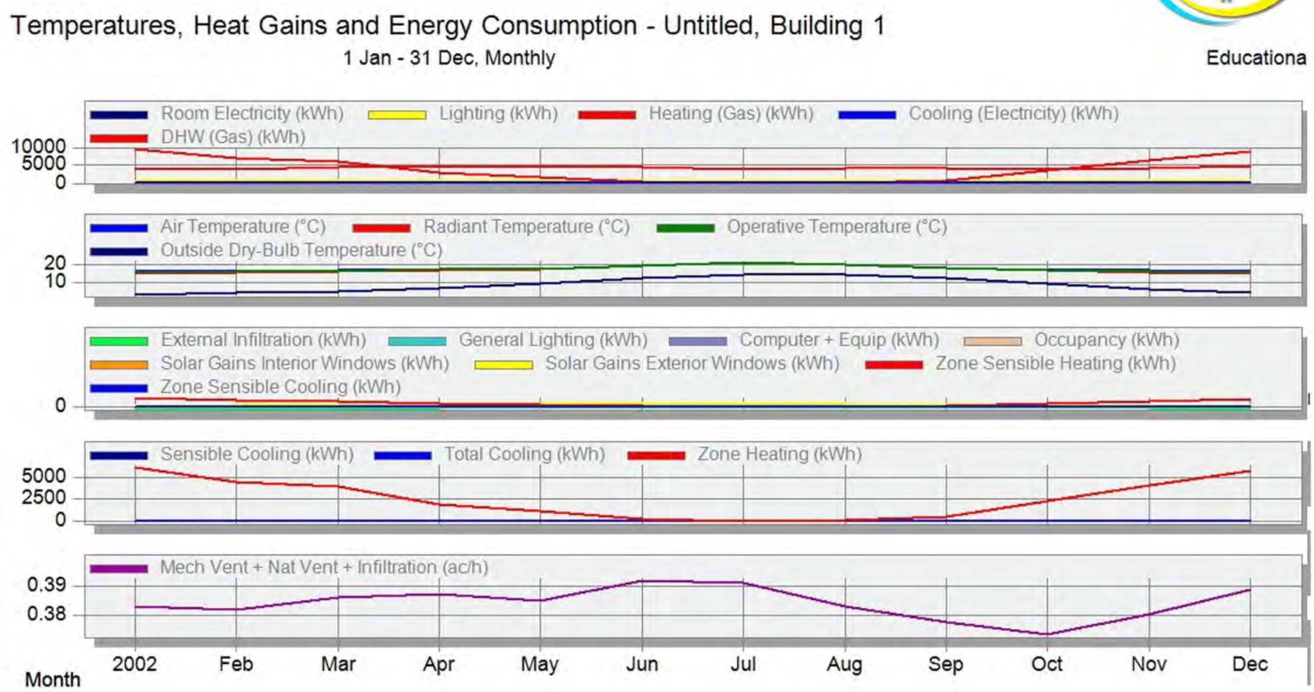
Figure A85. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	15.25
Operative Temperature (°C)	16.62
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.92
Walls (kW)	-7.03
Ceilings (int) (kW)	-1.36
Floors (int) (kW)	0.41
Ground Floors (kW)	0.59
Partitions (int) (kW)	-0.01
Roofs (kW)	-4.06
Floors (ext) (kW)	-0.05
External Infiltration (kW)	-4.28
External Vent. (kW)	-2.85
Zone Sensible Heating (kW)	22.47

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
HallWay	17.61	0.68	**0.86**	23.1983
Lounge	16.68	1.27	**1.58**	46.3276
DiningRoom	17.06	0.56	**0.70**	38.9453
Conservatory	15.84	1.47	**1.84**	87.2044
Kitchen	17.06	0.66	**0.83**	38.0872
Office	17.63	0.36	**0.45**	22.7436
Service	17.51	0.06	**0.08**	37.1114
Office Storage	16.48	0.58	**0.73**	87.3957
Music Room	16.46	1.24	**1.55**	56.2389
HallWay	17.03	0.43	**0.53**	48.2917
UtilityRoom	16.75	0.31	**0.38**	71.2662
Service	17.00	0.16	**0.21**	64.9789
BedRoom	16.63	0.90	**1.12**	52.0549
Service	17.45	0.10	**0.13**	34.5487
Main Roof Total Design Heating Capacity = 9.490 (kW)				
Storage	16.23	0.33	**0.41**	51.2237
BedRoom	16.30	1.01	**1.26**	46.0966
BathRoom	17.00	0.42	**0.52**	35.6672
BedRoom	16.40	1.58	**1.97**	45.9850
BedRoom	16.33	0.99	**1.23**	49.3617
BedRoom	16.42	1.45	**1.81**	37.6075
Hall	16.95	1.42	**1.78**	32.0425
Service	16.61	0.40	**0.51**	39.3673

Figure A86. The heating design simulation and data of the house.



Room Electricity (kWh)	283.67	255.16	291.89	285.12	291.89	293.33	275.46	283.67	276.91	275.46	276.91	300.10
Lighting (kWh)	873.87	785.63	902.33	882.41	902.33	910.87	845.41	873.87	853.94	845.41	853.94	930.80
Heating (Gas) (kWh)	9405.03	6915.80	6021.94	2974.22	1669.89	469.44	49.71	202.41	791.75	3559.06	6348.19	8848.30
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.09	0.63	2.86	7.48	5.41	0.94	0.04	0.03	0.00
DHW (Gas) (kWh)	4218.59	3780.79	4447.56	4377.95	4447.56	4606.92	3989.61	4218.59	4148.98	3989.61	4148.98	4676.53
Air Temperature (°C)	16.29	16.54	16.86	17.40	17.77	19.28	21.11	20.18	18.24	17.20	16.70	16.46
Radiant Temperature (°C)	15.10	15.56	16.13	17.13	17.66	19.33	21.25	20.23	18.16	16.68	15.81	15.29
Operative Temperature (°C)	15.70	16.05	16.50	17.27	17.72	19.31	21.18	20.20	18.20	16.94	16.26	15.87
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1687.37	-1399.67	-1517.62	-1298.32	-1037.34	-843.23	-807.79	-731.81	-734.52	-984.31	-1315.40	-1573.75
General Lighting (kWh)	873.87	785.63	902.33	882.41	902.33	910.87	845.41	873.87	853.94	845.41	853.94	930.80
Computer + Equip (kWh)	283.67	255.16	291.89	285.12	291.89	293.33	275.46	283.67	276.91	275.46	276.91	300.10
Occupancy (kWh)	215.61	193.15	226.54	221.48	222.11	216.84	170.75	188.81	205.46	203.58	211.91	239.01
Solar Gains Interior Windows (kWh)	0.13	0.20	0.36	0.43	0.43	0.40	0.44	0.38	0.30	0.20	0.14	0.08
Solar Gains Exterior Windows (kWh)	535.67	934.28	1666.19	2090.78	2268.99	2255.89	2350.96	1950.30	1458.57	940.88	621.74	354.20
Zone Sensible Heating (kWh)	5676.89	4138.31	3547.56	1700.55	967.32	277.76	30.07	119.57	453.93	2089.01	3799.70	5293.17
Zone Sensible Cooling (kWh)	-1.18	-12.30	-42.11	-112.32	-155.81	-223.41	-246.28	-195.42	-133.02	-21.32	-11.17	-1.21
Sensible Cooling (kWh)	0.00	0.00	-0.01	-0.23	-1.52	-6.88	-14.55	-9.95	-2.31	-0.09	-0.09	0.00
Total Cooling (kWh)	-0.00	-0.00	-0.01	-0.23	-1.57	-7.15	-18.71	-13.53	-2.35	-0.09	-0.09	-0.00
Zone Heating (kWh)	6113.27	4495.27	3914.26	1933.24	1085.43	305.14	32.31	131.57	514.64	2313.39	4126.32	5751.39
Mech Vent + Nat Vent + Infiltration (ac/h)	0.38	0.38	0.39	0.39	0.38	0.39	0.39	0.38	0.38	0.37	0.38	0.39

Figure A87. The simulation detailed results of the house.

Case 30. A House Built in 1986

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Wall appear to be of cavity block construction rendered externally.	0.601	Increase 19 cm Insulation
	Flat 0.680	Increase 28 cm Insulation
	Pitched 0.507	Increase 32 cm Insulation
Floor are of suspended timber construction.	0.622	Increase 28 cm Insulation
Internal Wall, plastered.	1.099	
Windows are of timber framed casement pattern and are double glazed.		

* As a basis for a theory of possibility

Description

The property comprises a two storey detached villa.

On ground floor: entrance vestibule and hallway, lounge, family room, master bedroom with en-suite bathroom, one further bedroom, kitchen/dining room, utility room, WC apartment and conservatory.

On first floor: landing, two bedrooms.

Weather Sunny.

Heating and hot water

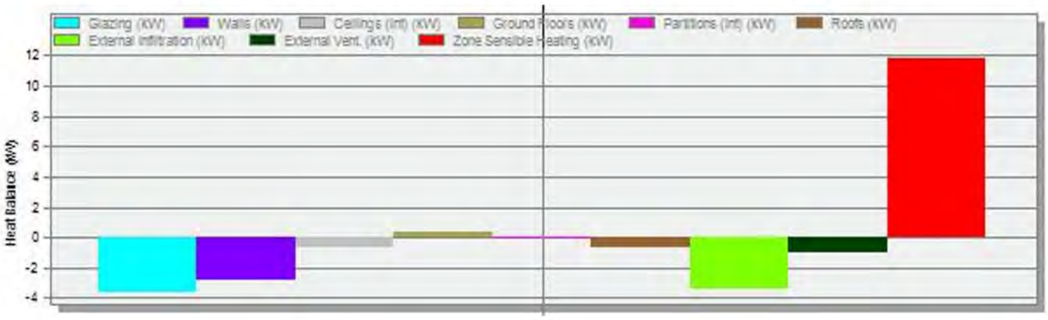
Central heating is from a gas fired Potterton Suprima 80L boiler which is in the kitchen. The boiler serves radiators throughout and also provides a hot water source through a circulating tank which is in the hall cupboard. The tank also has an electric immersion heater.

Gross internal floor area (m²) 186 m^2

Address

EAST LOTHIAN EH39 4NA

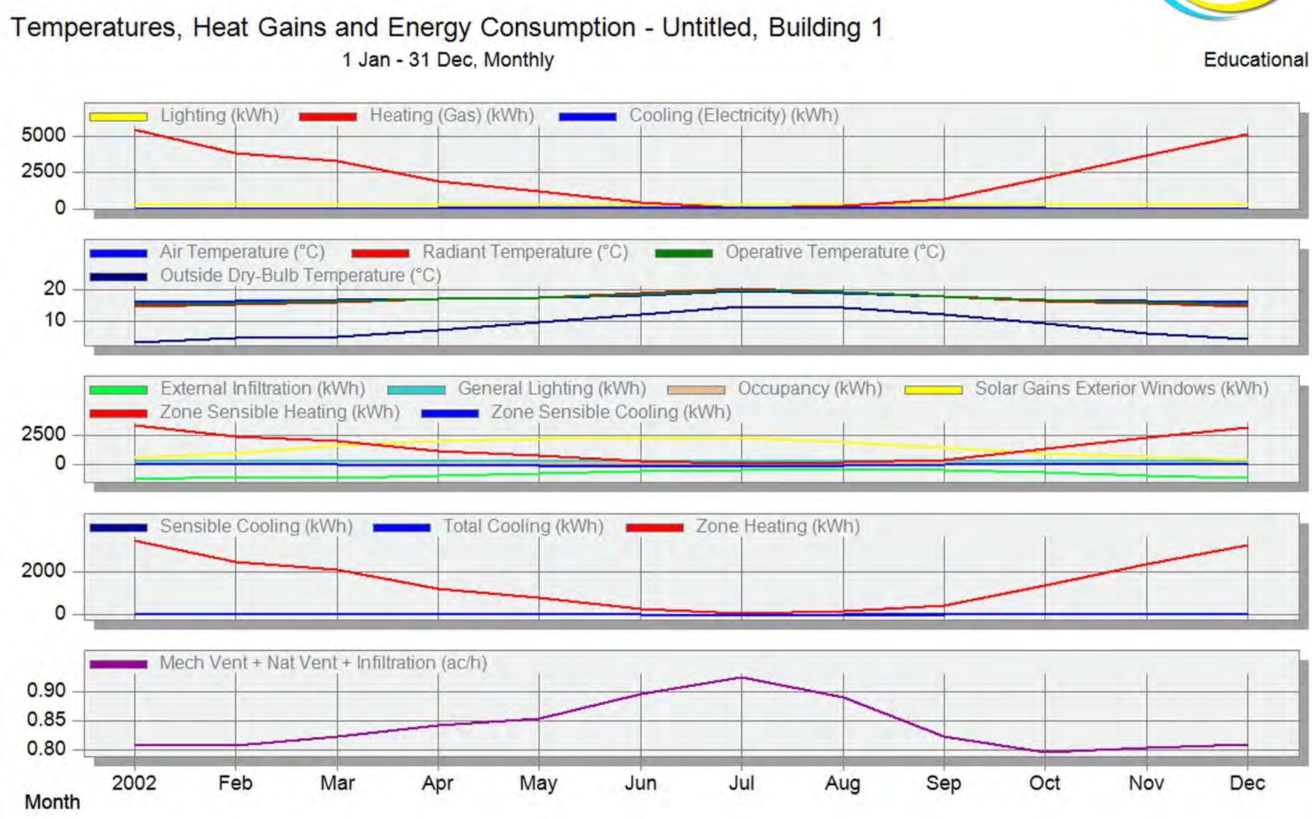
Figure A88. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.62
Operative Temperature (°C)	16.31
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.57
Walls (kW)	-2.83
Ceilings (int) (kW)	-0.62
Ground Floors (kW)	0.33
Partitions (int) (kW)	-0.14
Roofs (kW)	-0.66
External Infiltration (kW)	-3.37
External Vent. (kW)	-1.00
Zone Sensible Heating (kW)	11.79

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Ground Floor Total Design Heating Capacity = 10.740 (kW)				
Store 1	17.24	0.17	**0.21**	65.3993
Kitchen	16.39	1.72	**2.15**	75.3570
UtilityRoom	16.45	0.56	**0.70**	95.9963
Double BedRoom	16.31	1.67	**2.09**	79.5962
Hall	17.54	0.38	**0.48**	44.3285
Service	17.51	0.15	**0.19**	50.8254
Store	17.45	0.14	**0.18**	53.5298
Master Bedroom	16.97	0.78	**0.98**	60.1926
Vestibule	16.41	0.23	**0.29**	151.1376
Study Room	16.72	0.46	**0.58**	83.3067
BathRoom	17.08	0.28	**0.35**	71.4454
Living Room	16.11	2.03	**2.54**	80.5455
Conservatory Glass Total Design Heating Capacity = 3.010 (kW)				
Zone 1	13.18	2.41	**3.01**	239.1241
Main Roof Total Design Heating Capacity = 0.000 (kW)				
Servoce	-2.44	0.00	**0.00**	0.0000
Landing	-2.18	0.00	**0.00**	0.0000
BedRoom 1	-2.72	0.00	**0.00**	0.0000
BedRoom 2	-1.35	0.00	**0.00**	0.0000
BedRoom	-0.51	0.00	**0.00**	0.0000

Figure A89. The heating design simulation and data of the house.



Lighting (kWh)	257.69	232.55	259.26	251.41	259.26	252.98	256.12	257.69	249.84	256.12	249.84	260.83
Heating (Gas) (kWh)	5423.09	3845.76	3302.34	1885.57	1173.34	402.60	32.21	185.32	622.77	2152.73	3645.52	5094.54
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.27	1.95	11.02	32.17	19.18	1.15	0.05	0.00	0.00
Air Temperature (°C)	16.18	16.44	16.74	17.21	17.57	18.49	19.91	19.18	17.92	17.07	16.61	16.21
Radiant Temperature (°C)	14.83	15.46	16.16	17.14	17.68	18.90	20.51	19.59	18.06	16.58	15.69	14.91
Operative Temperature (°C)	15.50	15.95	16.45	17.17	17.62	18.70	20.21	19.38	17.99	16.83	16.15	15.56
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1316.62	-1091.91	-1181.40	-1001.80	-795.87	-594.03	-530.87	-487.30	-549.18	-761.94	-1026.67	-1213.26
General Lighting (kWh)	257.69	232.55	259.26	251.41	259.26	252.98	256.12	257.69	249.84	256.12	249.84	260.83
Occupancy (kWh)	82.18	73.83	83.46	80.85	82.54	79.52	71.69	75.81	78.60	80.23	79.95	85.79
Solar Gains Exterior Windows (kWh)	541.25	915.52	1646.46	1998.83	2209.52	2147.60	2301.47	1920.26	1455.14	941.77	628.72	358.09
Zone Sensible Heating (kWh)	3354.73	2362.85	2008.54	1124.01	692.29	233.34	19.63	108.25	362.43	1309.24	2239.73	3145.46
Zone Sensible Cooling (kWh)	-0.08	-5.68	-40.24	-97.50	-122.57	-194.17	-275.17	-171.73	-59.76	-5.81	-2.95	-0.08
Sensible Cooling (kWh)	0.00	-0.00	-0.00	-0.68	-4.88	-27.03	-61.48	-35.46	-2.88	-0.13	0.00	0.00
Total Cooling (kWh)	0.00	-0.00	-0.00	-0.68	-4.88	-27.55	-80.42	-47.94	-2.89	-0.13	0.00	0.00
Zone Heating (kWh)	3525.01	2499.74	2146.52	1225.62	762.67	261.69	20.94	120.46	404.80	1399.27	2369.59	3311.45
Mech Vent + Nat Vent + Infiltration (ac/h)	0.81	0.81	0.82	0.84	0.86	0.90	0.93	0.89	0.82	0.80	0.80	0.81

Figure A90. The simulation detailed results of the house.

Case 31. A House Built in 1985

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are 275mm cavity brick, block and timber frame, rendered externally	0.640	Increase 18 cm Insulation
	Flat 0.708	Increase 28 cm Insulation
	Pitched 0.551	Increase 32 cm Insulation
Floors are of a suspended timber character with a board covering over timber joists.	0.621	Increase 28 cm Insulation
Internal Wall, plastered nature.	1.096	
Windows are of timber framed casement character and are double glazed.		

* As a basis for a theory of possibility

Description

Detached house. Ground Floor - Vestibule, hallway, lounge, sitting room, kitchen/breakfast room, garden room, dining room, conservatory, six bedrooms, two shower rooms.

First Floor - Landing, bedroom, shower room.

Weather Dry and bright.

Heating and hot water

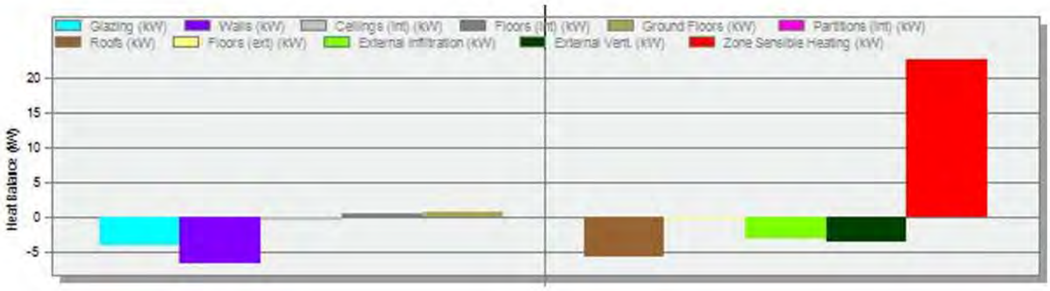
There is a liquid petroleum gas fired central heating system within this property. The boiler for this is a Worcester Bosch High Flow 400 unit located within a kitchen cupboard and vented externally by means of a balanced flue. This system is augmented by a solid fuel stove located within the lounge. This stove is vented through the roof by means of an aluminium flue.

Gross internal floor area (m²) 250 m^2

Address

PENICUIK EH26 9LZ

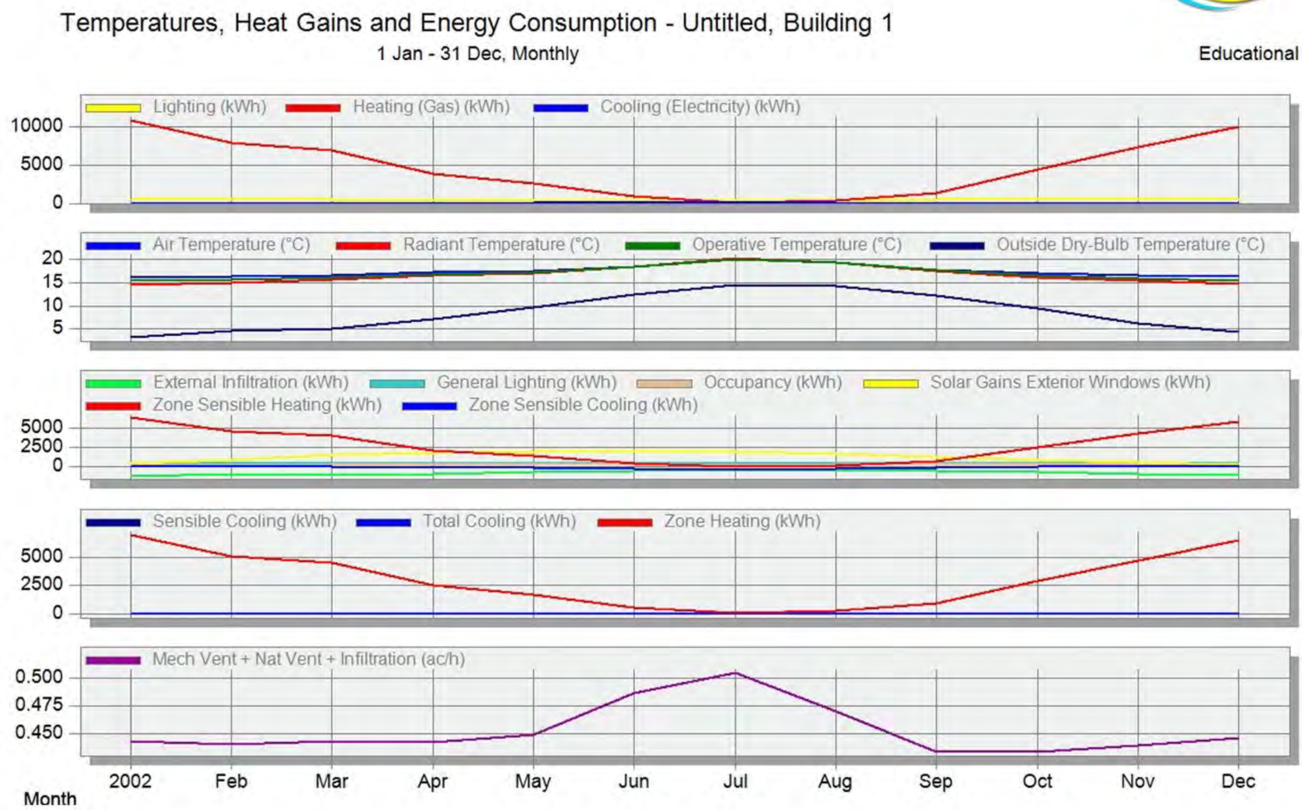
Figure A91. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.54
Operative Temperature (°C)	16.27
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-4.10
Walls (kW)	-6.75
Ceilings (int) (kW)	-0.58
Floors (int) (kW)	0.46
Ground Floors (kW)	0.73
Partitions (int) (kW)	0.01
Roofs (kW)	-5.79
Floors (ext) (kW)	-0.35
External Infiltration (kW)	-3.04
External Vent. (kW)	-3.49
Zone Sensible Heating (kW)	22.69

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 28.350 (kW)				
Block 1 Total Design Heating Capacity = 9.930 (kW)				
Intrance	16.64	0.21	**0.26**	132.8313
Sitting room	16.98	0.96	**1.20**	41.2281
DiningRoom	16.47	1.14	**1.43**	60.6391
Corridor	17.53	0.07	**0.09**	45.0397
Corridor	17.59	0.10	**0.13**	37.7980
Hall	17.49	0.33	**0.42**	32.5564
Service2	16.64	0.31	**0.38**	94.2686
Service1	17.06	0.24	**0.30**	64.5531
Bedroom1	16.70	0.56	**0.70**	63.7969
Bedroom2	17.00	0.36	**0.45**	58.2983
Office	16.97	0.48	**0.59**	49.1423
Bedroom5	16.75	0.65	**0.82**	56.8351
Bedroom4	16.94	0.58	**0.72**	49.6636
Service4	17.08	0.17	**0.21**	86.1693
Service3	16.56	0.34	**0.42**	114.2202
Bedroom3	16.47	0.67	**0.84**	73.4910
Family Room	16.85	0.77	**0.97**	50.6530
Intrance Total Design Heating Capacity = 1.920 (kW)				
Zone 1	15.87	1.54	**1.92**	87.1936
Patio Total Design Heating Capacity = 2.080 (kW)				
Zone 1	14.71	1.67	**2.08**	171.6404
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-3.65	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 1.470 (kW)				
Zone 1	16.24	1.17	**1.47**	39.0541
Roof 3 Total Design Heating Capacity = 6.320 (kW)				

Figure A92. The heating design simulation and data of the house.



Lighting (kWh)	498.78	432.97	457.34	410.73	407.92	389.81	402.00	416.59	426.20	468.85	473.94	503.33
Heating (Gas) (kWh)	10757.10	7894.14	6911.07	3896.11	2526.38	850.69	94.95	384.31	1355.91	4457.83	7314.88	9978.35
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.02	3.68	9.93	1.56	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.23	16.45	16.69	17.16	17.51	18.49	20.04	19.33	17.78	17.05	16.64	16.30
Radiant Temperature (°C)	14.50	15.02	15.59	16.57	17.15	18.46	20.21	19.36	17.53	16.21	15.34	14.66
Operative Temperature (°C)	15.36	15.74	16.14	16.87	17.33	18.48	20.12	19.35	17.66	16.63	15.99	15.48
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1199.00	-991.77	-1068.55	-907.86	-721.66	-538.78	-487.06	-451.99	-486.06	-689.07	-932.55	-1108.41
General Lighting (kWh)	498.78	432.97	457.34	410.73	407.92	389.81	402.00	416.59	426.20	468.85	473.94	503.33
Occupancy (kWh)	261.41	235.30	266.65	258.78	264.10	253.55	227.16	239.93	251.37	255.62	254.59	272.87
Solar Gains Exterior Windows (kWh)	482.79	850.54	1527.74	1871.41	1995.86	1979.06	2034.50	1708.00	1302.89	841.77	558.44	320.80
Zone Sensible Heating (kWh)	6426.47	4666.62	4018.39	2182.92	1406.21	466.52	56.22	217.81	743.48	2589.62	4317.27	5934.12
Zone Sensible Cooling (kWh)	0.00	-2.09	-14.82	-44.21	-99.76	-246.58	-360.35	-212.09	-67.75	-3.19	-2.11	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	-0.00	-0.06	-9.17	-23.12	-3.73	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	-0.00	-0.06	-9.19	-24.83	-3.90	0.00	0.00	0.00	0.00
Zone Heating (kWh)	6992.12	5131.19	4492.20	2532.47	1642.15	552.95	61.72	249.80	881.34	2897.59	4754.67	6485.93
Mech Vent + Nat Vent + Infiltration (ac/h)	0.44	0.44	0.44	0.44	0.45	0.49	0.51	0.47	0.43	0.43	0.44	0.45

Figure A93. The simulation detailed results of the house.

Case 32. A House Built in 1984

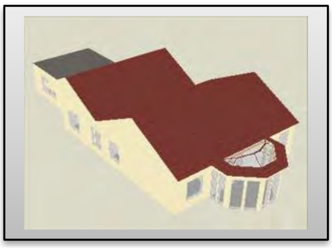
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of cavity timber framed construction with rendered brick/block.	0.706	Increase 19 cm Insulation
	Flat 0.660	Increase 28 cm Insulation
	Pitched 0.621	Increase 33 cm Insulation
Floors are of a suspended timber construction.	0.621	Increase 28 cm Insulation
Internal Wall, plastered.	1.062	
Windows are of timber framed casement pattern and are double glazed.		

* As a basis for a theory of possibility

Description

The property comprises a detached bungalow.

On ground floor: entrance vestibule, dining hall, lounge, master bedroom with en-suite shower room, guest bedroom with en-suite shower room, bedroom three with access to jack and jill bathroom, study/living room, kitchen/dining room, utility room, WC apartment and self-contained conservatory.



Weather Overcast and windy.

Heating and hot water

Central heating is from a LPG fired Worcester Greenstar 30cdi classic boiler which is in the cupboard off the utility room. Adjacent to the boiler is a circulating tank which also has an electric immersion heater. I am advised that the central heating boiler is approximately 2 years old.

Gross internal floor area (m²) 181 m^2

Address

MUSSELBURGH EH21 8PZ

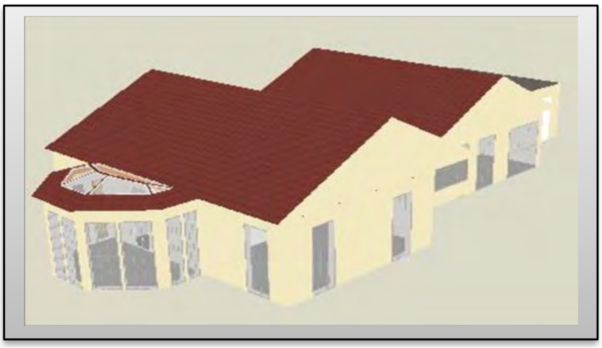
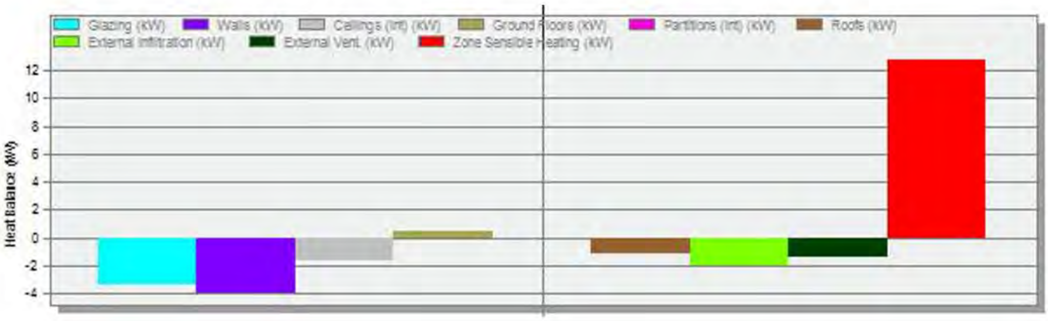


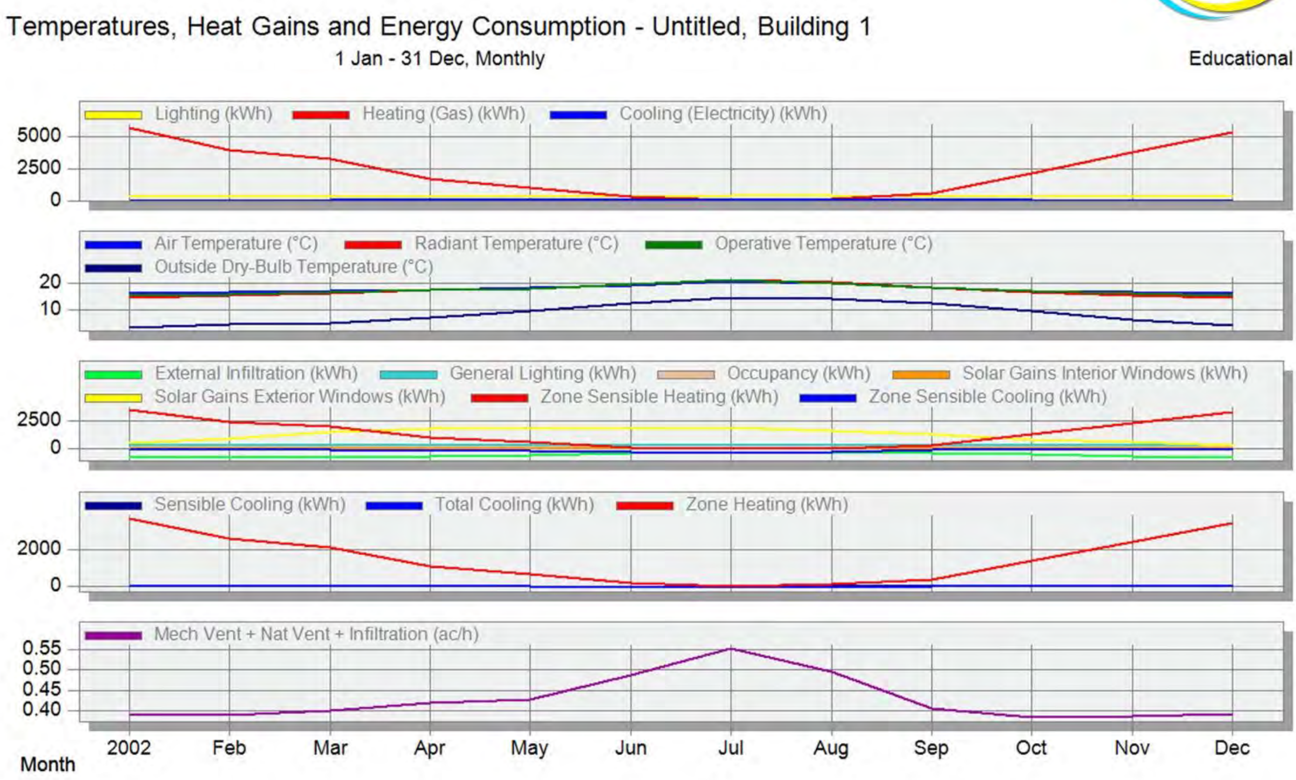
Figure A94. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.34
Operative Temperature (°C)	16.17
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.38
Walls (kW)	-3.93
Ceilings (int) (kW)	-1.61
Ground Floors (kW)	0.51
Partitions (int) (kW)	0.00
Roofs (kW)	-1.10
External Infiltration (kW)	-1.94
External Vent. (kW)	-1.32
Zone Sensible Heating (kW)	12.71

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 15.890 (kW)				
Ground Floor Total Design Heating Capacity = 15.890 (kW)				
Conservatory	14.87	1.40	**1.76**	146.5036
Bed Room	16.29	0.95	**1.19**	68.7232
Bed Room	16.64	0.67	**0.84**	57.5656
Bath Room	16.77	0.39	**0.49**	67.8031
Master BedRoom	16.51	0.98	**1.22**	61.0128
Utility Room	16.45	0.60	**0.75**	72.8082
Garage	15.17	2.44	**3.04**	104.7214
Study Room	16.90	0.51	**0.64**	45.6648
Dining Room	17.04	0.65	**0.81**	40.6585
Kitchen	15.94	1.65	**2.06**	77.7449
Lounge	15.90	1.71	**2.14**	75.7185
Vestibule	16.14	0.48	**0.61**	108.7476
Hall	17.28	0.12	**0.16**	45.4197
Service	17.21	0.15	**0.18**	46.8529
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.65	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.90	0.00	**0.00**	0.0000
Roof 3 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-4.00	0.00	**0.00**	0.0000

Figure A95. The heating design simulation and data of the house.



Lighting (kWh)	347.82	313.89	349.94	339.34	349.94	341.46	345.70	347.82	337.22	345.70	337.22	352.06
Heating (Gas) (kWh)	5669.85	3939.52	3268.04	1680.17	1024.72	322.54	31.41	160.00	548.65	2133.11	3744.87	5310.13
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.02	0.83	7.91	27.98	7.66	0.18	0.03	0.00	0.00
Air Temperature (°C)	16.15	16.48	16.91	17.61	18.03	19.22	20.83	19.95	18.38	17.18	16.64	16.17
Radiant Temperature (°C)	14.49	15.25	16.10	17.38	18.00	19.46	21.24	20.19	18.36	16.52	15.48	14.57
Operative Temperature (°C)	15.32	15.87	16.50	17.49	18.02	19.34	21.03	20.07	18.37	16.85	16.06	15.37
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-755.68	-630.76	-689.76	-599.93	-486.75	-384.05	-358.39	-323.81	-341.80	-444.09	-591.93	-695.38
General Lighting (kWh)	347.82	313.89	349.94	339.34	349.94	341.46	345.70	347.82	337.22	345.70	337.22	352.06
Occupancy (kWh)	110.92	99.37	111.82	107.18	108.81	102.84	91.58	97.78	103.75	107.98	107.69	115.77
Solar Gains Interior Windows (kWh)	3.34	5.91	10.17	13.66	14.25	14.22	15.10	12.15	8.78	5.39	3.97	2.30
Solar Gains Exterior Windows (kWh)	554.86	915.75	1535.12	1827.63	1847.27	1772.48	1886.90	1619.50	1285.45	867.82	640.60	371.36
Zone Sensible Heating (kWh)	3460.85	2383.44	1951.25	980.75	596.63	186.59	18.71	94.67	318.47	1273.34	2264.81	3232.65
Zone Sensible Cooling (kWh)	-1.01	-8.65	-47.58	-127.10	-150.30	-242.46	-360.17	-218.28	-85.92	-11.00	-6.16	-1.15
Sensible Cooling (kWh)	0.00	-0.00	-0.00	-0.04	-2.09	-19.58	-57.01	-16.37	-0.45	-0.07	0.00	0.00
Total Cooling (kWh)	0.00	-0.00	-0.00	-0.04	-2.09	-19.78	-69.94	-19.15	-0.46	-0.07	0.00	0.00
Zone Heating (kWh)	3685.41	2560.69	2124.22	1092.11	666.07	209.65	20.42	104.00	356.62	1386.52	2434.16	3451.59
Mech Vent + Nat Vent + Infiltration (ac/h)	0.39	0.39	0.40	0.42	0.43	0.49	0.55	0.50	0.41	0.38	0.39	0.39

Figure A96. The simulation detailed results of the house.

Case 33. A House Built in 1983

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are cavity brick, block and timber frame with a facing brick external finish.	0.903	Increase 19 cm Insulation
	Flat -	-
	Pitched 0.716	Increase 32 cm Insulation
Floors are of a suspended timber or solid concrete nature.	0.627	Increase 28 cm Insulation
Internal Wall, plastered character.	1.092	
Windows are of timber framed casement character and are double glazed.		

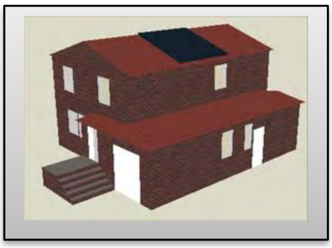
* As a basis for a theory of possibility

Description

This is a two storey detached house.

Ground Floor - Vestibule, hallway, living room, dining room, kitchen/breakfast room, utility room, toilet.

First Floor - Landing, four bedrooms, bathroom (with WC), shower room.



Weather Overcast.

Heating and hot water

There is a gas fired central heating system serving panel radiators. The boiler for this is an Ideal Icos HE 24 unit located within the utility room and vented externally by means of an aluminium flue. The central heating boiler also provides domestic hot water. This is augmented by an electric immersion heater. A hot water cylinder is located within a hall landing cupboard.

Gross internal floor area (m²) 129 m^2

Address

EDINBURGH EH13 0QE

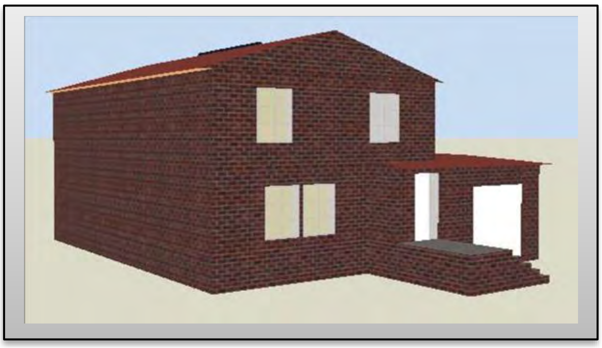
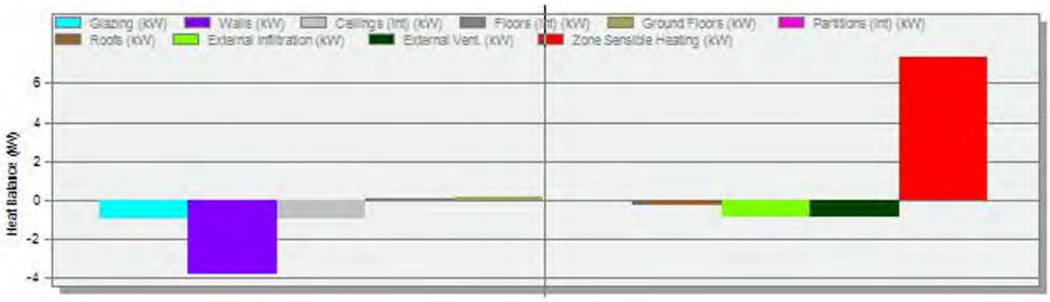


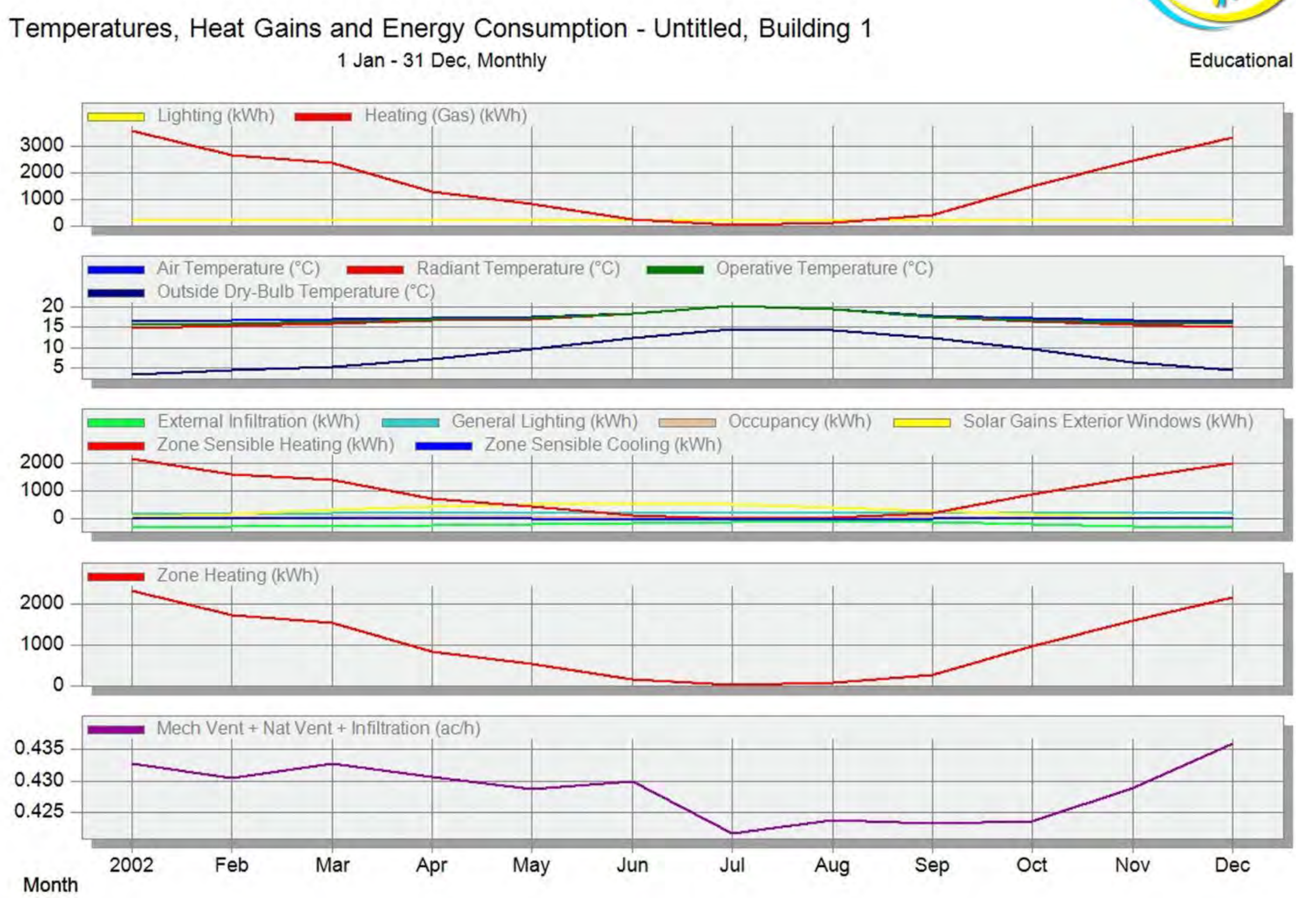
Figure A97. The software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.70
Operative Temperature (°C)	16.35
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-0.94
Walls (kW)	-3.80
Ceilings (int) (kW)	-0.91
Floors (int) (kW)	0.12
Ground Floors (kW)	0.19
Partitions (int) (kW)	0.00
Roofs (kW)	-0.30
External Infiltration (kW)	-0.84
External Vent. (kW)	-0.88
Zone Sensible Heating (kW)	7.32

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 9.160 (kW)				
Ground Floor Total Design Heating Capacity = 5.090 (kW)				
Living Room	16.44	0.86	**1.07**	59.8649
HallWay	17.41	0.25	**0.31**	34.6388
Garage	16.17	0.71	**0.89**	81.1969
Dining Room	16.34	0.72	**0.90**	74.3439
Service	17.54	0.06	**0.07**	42.1693
Utility Room	16.42	0.35	**0.44**	89.4853
Kitchen	16.65	0.44	**0.55**	62.5275
Famil Room	16.03	0.47	**0.59**	109.8392
Store	16.02	0.22	**0.27**	248.7935
First Floor Total Design Heating Capacity = 3.550 (kW)				
Bed Room	16.12	0.69	**0.86**	69.7233
Bed Room	16.05	0.48	**0.60**	88.3034
Hall Way	16.50	0.44	**0.55**	61.7378
Service	17.11	0.11	**0.13**	50.8865
Bed Room	16.12	0.57	**0.72**	75.2753
Bed Room	16.07	0.39	**0.48**	99.1784
Service	16.58	0.17	**0.21**	88.8183
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	0.78	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	1.43	0.00	**0.00**	0.0000
Stair Total Design Heating Capacity = 0.520 (kW)				
Zone 1	14.08	0.41	**0.52**	155.2939

Figure A98. The heating design simulation and data of the house.



Lighting (kWh)	200.73	181.15	201.95	195.83	201.95	197.06	199.51	200.73	194.61	199.51	194.61	203.18
Heating (Gas) (kWh)	3577.28	2655.47	2345.29	1276.96	819.14	216.90	7.28	85.59	403.37	1491.29	2427.74	3304.85
Air Temperature (°C)	16.38	16.60	16.80	17.21	17.41	18.37	20.12	19.26	17.68	17.14	16.77	16.47
Radiant Temperature (°C)	14.75	15.23	15.71	16.61	17.01	18.34	20.25	19.29	17.45	16.32	15.55	14.93
Operative Temperature (°C)	15.57	15.91	16.25	16.91	17.21	18.36	20.18	19.28	17.57	16.73	16.16	15.70
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-332.18	-275.01	-295.12	-249.14	-194.60	-145.24	-136.46	-122.84	-130.74	-190.99	-258.97	-307.93
General Lighting (kWh)	200.73	181.15	201.95	195.83	201.95	197.06	199.51	200.73	194.61	199.51	194.61	203.18
Occupancy (kWh)	64.02	57.64	65.42	63.73	65.38	63.08	55.73	59.44	62.17	62.62	62.36	66.82
Solar Gains Exterior Windows (kWh)	77.77	161.27	330.18	441.21	510.45	538.17	536.72	423.60	298.18	173.12	91.25	51.18
Zone Sensible Heating (kWh)	2181.76	1608.01	1401.53	735.01	462.96	119.95	4.69	47.83	222.90	891.00	1467.02	2008.41
Zone Sensible Cooling (kWh)	0.00	0.00	-0.17	-2.14	-4.90	-31.04	-47.21	-35.31	-10.39	0.00	0.00	0.00
Zone Heating (kWh)	2325.23	1726.05	1524.44	830.02	532.44	140.99	4.73	55.64	262.19	969.34	1578.03	2148.15
Mech Vent + Nat Vent + Infiltration (ac/h)	0.43	0.43	0.43	0.43	0.43	0.43	0.42	0.42	0.42	0.42	0.43	0.44

Figure A99. The simulation detailed results of the house.

Case 34. A House Built in 1982

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are 300mm cavity brick/concrete block construction, plastered on the hard internally.	0.927	Increase 18 cm Insulation
	Flat 0.679	Increase 29 cm Insulation
	Pitched 0.843	Increase 33 cm Insulation
Floors are of a suspended timber construction.	0.639	Increase 28 cm Insulation
Internal Wall, plastered construction and concrete block plastered on the hard.	1.054	
Windows are of timber framed double glazed.		

* As a basis for a theory of possibility

Description

Two storey detached villa with surrounding garden grounds and double garage.

Ground Floor: Entrance vestibule, hallway, lounge, dining room, kitchen, study/office and WC compartment.

First Floor: Landing, bedroom one with en-suite bathroom, bedroom two, bedroom three, bedroom four and bathroom.

Weather Overcast and dry.

Heating and hot water

The property has gas fired central heating to radiator outlets.

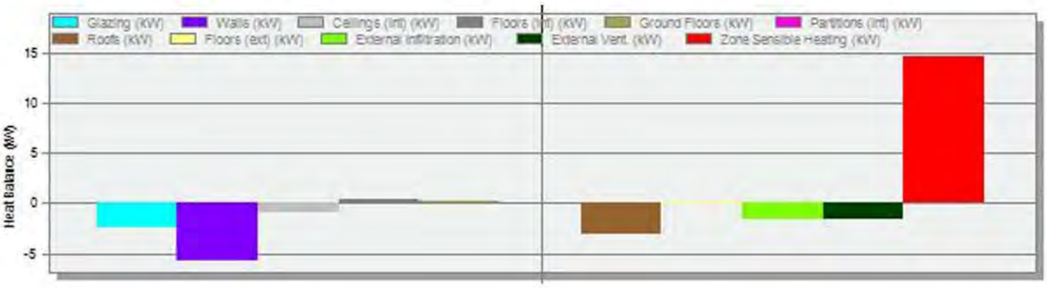
Domestic hot water is provided indirectly by the gas central heating boiler to a modern insulated hot water tank located in the cupboard off the first floor landing.

Gross internal floor area (m²) 204 m^2

Address

EDINBURGH EH6 4DE

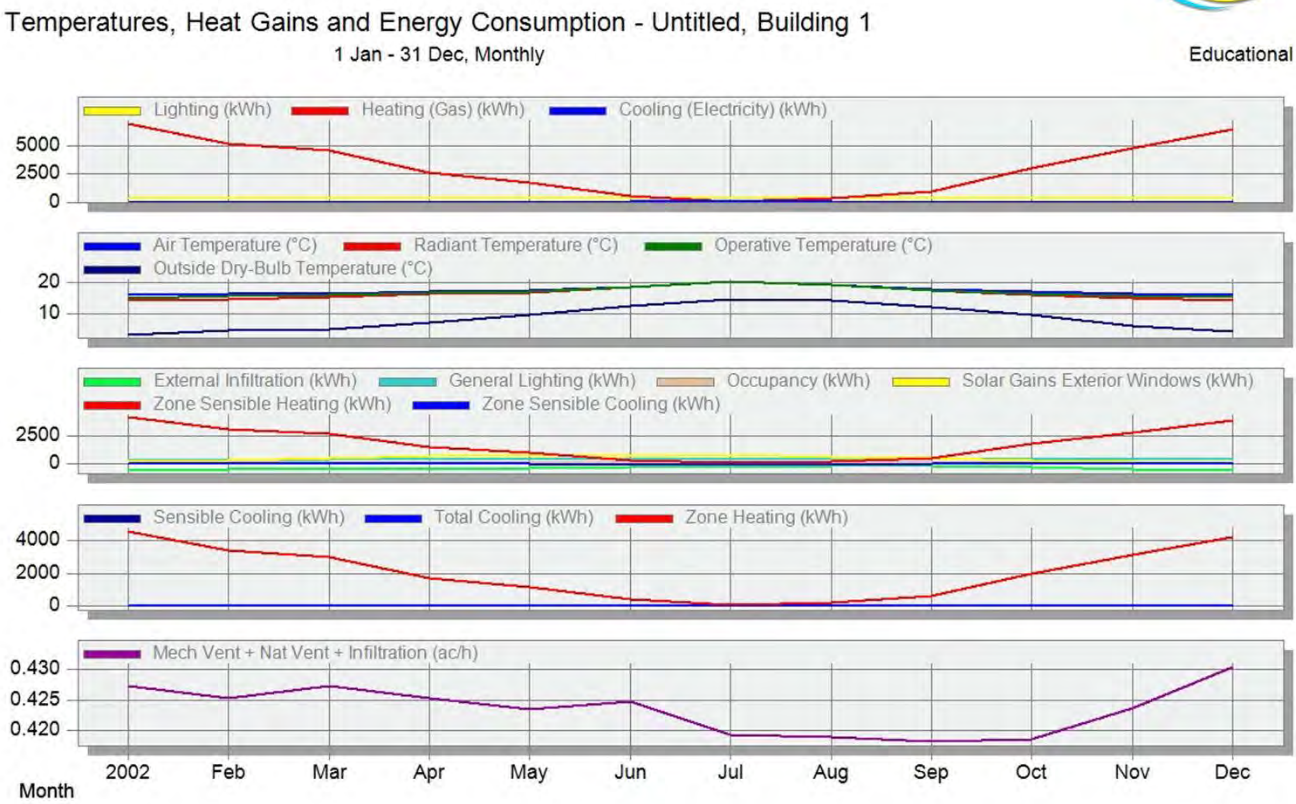
Figure A100. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.99
Operative Temperature (°C)	16.00
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.39
Walls (kW)	-5.77
Ceilings (int) (kW)	-0.95
Floors (int) (kW)	0.42
Ground Floors (kW)	0.32
Partitions (int) (kW)	0.00
Roofs (kW)	-3.13
Floors (ext) (kW)	-0.04
External Infiltration (kW)	-1.60
External Vent. (kW)	-1.62
Zone Sensible Heating (kW)	14.70

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 18.380 (kW)				
Ground Floor Total Design Heating Capacity = 8.440 (kW)				
Landing	17.09	0.31	**0.39**	42.9992
Kitchen	15.97	1.02	**1.28**	77.4256
Hall	16.97	0.39	**0.49**	49.9999
Study Room	16.48	0.55	**0.69**	63.9917
Service	17.05	0.12	**0.15**	85.0169
Garage	15.40	2.30	**2.88**	80.5855
Dining Room	16.17	0.84	**1.06**	69.2547
Sitting Room	16.20	1.20	**1.50**	60.8938
First Floor Total Design Heating Capacity = 6.920 (kW)				
Double BedRoom	15.90	0.81	**1.02**	78.1744
Double BedRoom	15.87	0.82	**1.03**	78.9237
Bath Room	16.38	0.44	**0.56**	68.4300
Double BedRoom	15.83	1.04	**1.30**	77.9617
Hall	16.93	0.30	**0.37**	43.7615
Master BedRoom	15.78	1.38	**1.73**	71.1547
Landing	16.69	0.43	**0.53**	56.9663
Bath Room	16.47	0.31	**0.38**	73.6602
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-5.57	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	1.42	0.00	**0.00**	0.0000
SunShade Total Design Heating Capacity = 1.290 (kW)				
Zone 1	13.68	1.04	**1.29**	228.1867
SunShade Total Design Heating Capacity = 1.730 (kW)				
Zone 1	13.23	1.38	**1.73**	582.5135

Figure A101. The heating design simulation and data of the house.



Lighting (kWh)	377.70	340.85	380.01	368.49	380.01	370.79	375.40	377.70	366.19	375.40	366.19	382.31
Heating (Gas) (kWh)	7009.32	5186.47	4623.90	2586.81	1760.01	589.10	87.30	322.30	929.45	2996.96	4778.94	6494.28
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.10	0.65	0.26	0.00	0.00	0.00	0.00
Air Temperature (°C)	16.08	16.31	16.54	17.03	17.28	18.47	20.15	19.18	17.65	16.93	16.51	16.14
Radiant Temperature (°C)	14.14	14.69	15.26	16.33	16.79	18.38	20.28	19.16	17.34	15.95	15.06	14.31
Operative Temperature (°C)	15.11	15.50	15.90	16.68	17.03	18.42	20.21	19.17	17.49	16.44	15.79	15.23
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-621.69	-514.40	-553.30	-469.57	-367.27	-282.86	-263.55	-231.99	-249.13	-356.65	-484.66	-574.53
General Lighting (kWh)	377.70	340.85	380.01	368.49	380.01	370.79	375.40	377.70	366.19	375.40	366.19	382.31
Occupancy (kWh)	120.46	108.46	122.97	119.52	122.47	116.85	103.64	111.08	116.29	117.81	117.32	125.74
Solar Gains Exterior Windows (kWh)	181.62	318.55	553.79	701.70	756.67	752.42	765.08	641.14	479.13	303.34	212.25	123.43
Zone Sensible Heating (kWh)	4287.80	3150.76	2780.51	1513.99	1025.22	340.01	52.01	187.68	532.08	1802.28	2899.18	3959.81
Zone Sensible Cooling (kWh)	0.00	-0.28	-5.36	-15.04	-21.57	-59.44	-87.36	-59.85	-22.21	-0.58	-0.51	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	-0.00	-0.00	-0.24	-1.17	-0.38	-0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	-0.00	-0.00	-0.24	-1.62	-0.64	-0.00	0.00	0.00	0.00
Zone Heating (kWh)	4556.06	3371.21	3005.54	1681.43	1144.00	382.92	56.75	209.49	604.14	1948.02	3106.31	4221.28
Mech Vent + Nat Vent + Infiltration (ac/h)	0.43	0.43	0.43	0.43	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.43

Figure A102. The simulation detailed results of the house.

Case 35. A House Built in 1981

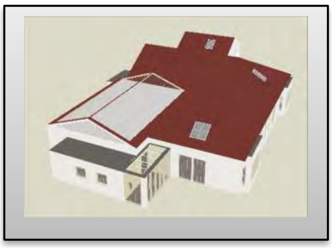
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of timber frame construction externally clad in brick/block work.	0.994	Increase 19 cm Insulation
	Flat 1.089	Increase 30 cm Insulation
	Pitched 1.051	Increase 30 cm Insulation
Floors are of a suspended timber construction.	0.649	Increase 30 cm Insulation
Internal Walls are formed in sheet plasterboard.	1.059	
Windows are of u-PVC framed and double glazed windows.		

* As a basis for a theory of possibility

Description

Two storey detached dwelling. Ground Floor: Entrance vestibule, hallway, lounge, dining room, kitchen, study/office and WC compartment.

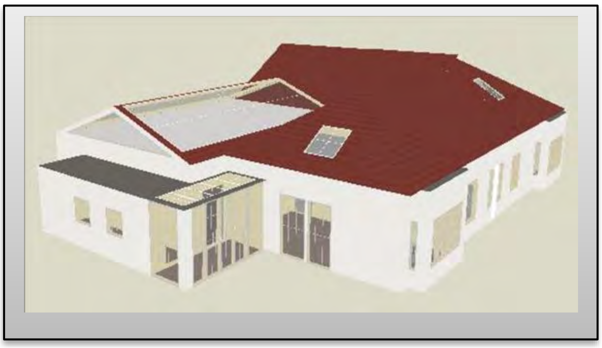
First Floor: Four bedrooms, two bathrooms, two bathrooms both with WC and one separate shower enclosure.



Weather Dry.

Heating and hot water

The property has the benefit of a main supply of cold water. The containment for the cold water is provided by a galvanised tank which is located in the roof space. The tank is insulated.



Gross internal floor area (m²) 325.54 m^2

Address

EDINBURGH EH14 2LX

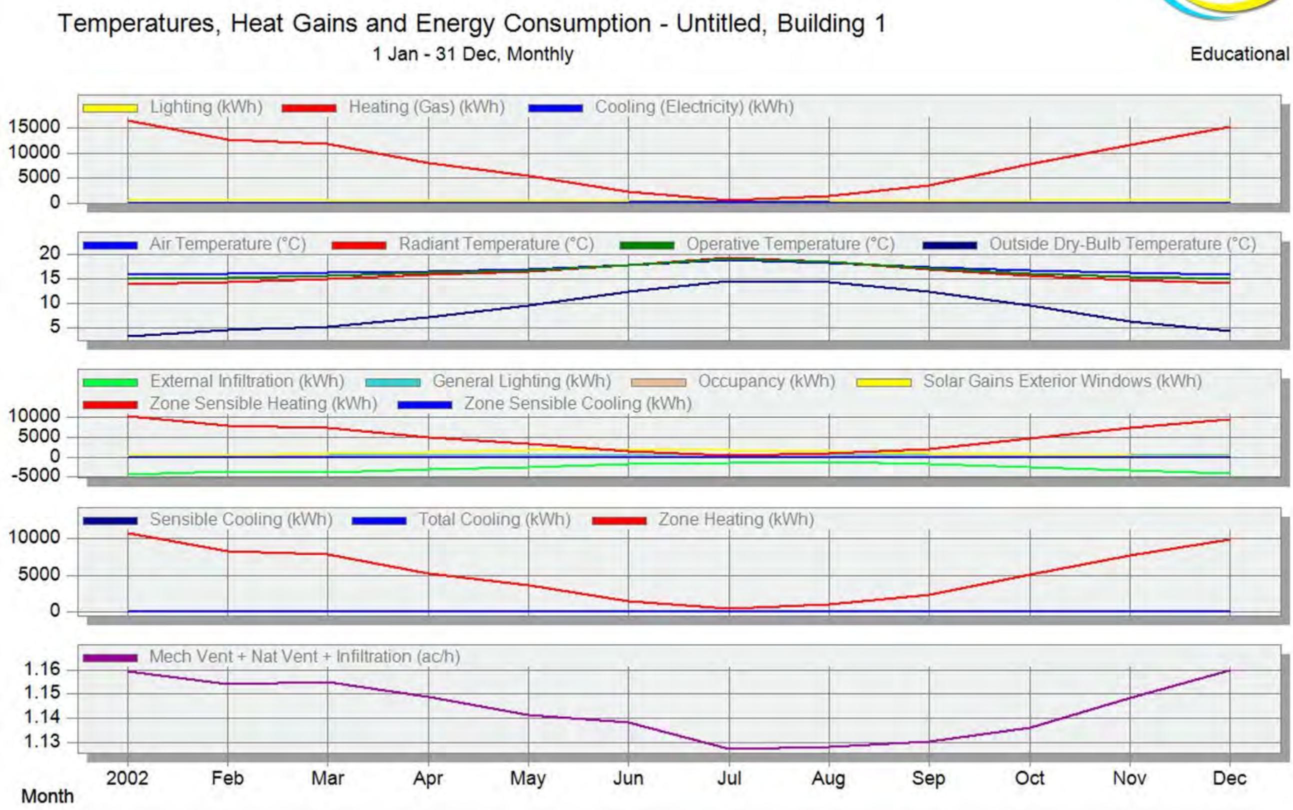
Figure A103. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.76
Operative Temperature (°C)	15.88
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-4.66
Walls (kW)	-8.72
Ceilings (int) (kW)	-1.13
Floors (int) (kW)	1.13
Ground Floors (kW)	0.92
Partitions (int) (kW)	0.00
Roofs (kW)	-11.30
Floors (ext) (kW)	-0.98
External Infiltration (kW)	-13.48
External Vent. (kW)	-4.18
Zone Sensible Heating (kW)	42.27

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 52.820 (kW)				
Ground Floor Total Design Heating Capacity = 26.130 (kW)				
Bed Room	16.66	0.76	**0.94**	90.2212
Hall	17.27	1.79	**2.23**	65.3168
Dining Room	17.43	0.86	**1.07**	57.3882
Pool	15.90	7.75	**9.69**	83.0952
Vestibule	16.50	0.49	**0.62**	116.6757
Sitting Room	16.10	2.63	**3.28**	93.2482
Store	17.63	0.15	**0.19**	61.4671
Study Room	17.44	0.45	**0.56**	60.4567
Kitchen	16.32	2.15	**2.69**	89.3777
Changing Room	16.24	0.51	**0.63**	140.0414
Utility Room	16.72	0.61	**0.77**	92.7931
Master BedRoom	15.99	1.59	**1.99**	108.2167
Service 1	16.85	0.52	**0.64**	90.0317
Service	17.00	0.36	**0.45**	93.4288
Dressing Room	16.94	0.30	**0.38**	101.6220
Plant Room Total Design Heating Capacity = 1.760 (kW)				
Zone 1	15.51	1.41	**1.76**	127.4753
Green House Total Design Heating Capacity = 2.130 (kW)				
Zone 1	13.43	1.70	**2.13**	287.0002
Changing Room Total Design Heating Capacity = 0.940 (kW)				
Zone 1	15.33	0.75	**0.94**	176.8210
Pool Roof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-7.39	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 14.000 (kW)				
Bed Room 1	15.25	1.77	**2.21**	71.1579
Bed Room 2	16.14	1.06	**1.33**	58.6030
Bed Room 3	15.39	2.29	**2.86**	72.2008
Service	15.96	0.72	**0.90**	65.7912

Figure A104. The heating design simulation and data of the house.

Educational



Lighting (kWh)	505.54	430.59	441.80	382.27	372.15	351.14	366.92	386.63	407.20	463.84	476.57	510.36
Heating (Gas) (kWh)	16528.43	12682.56	11988.46	7969.28	5465.72	2278.24	531.50	1437.67	3445.63	7832.40	11774.32	15272.86
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.01	0.74	0.02	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.81	15.97	16.15	16.53	16.91	17.76	18.84	18.27	17.27	16.61	16.17	15.88
Radiant Temperature (°C)	13.88	14.36	14.88	15.81	16.49	17.83	19.22	18.36	16.94	15.63	14.72	14.06
Operative Temperature (°C)	14.85	15.16	15.52	16.17	16.70	17.79	19.03	18.32	17.10	16.12	15.44	14.97
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-4313.42	-3537.28	-3778.57	-3142.12	-2453.93	-1732.70	-1363.19	-1297.42	-1625.22	-2411.54	-3312.88	-3979.23
General Lighting (kWh)	505.54	430.59	441.80	382.27	372.15	351.14	366.92	386.63	407.20	463.84	476.57	510.36
Occupancy (kWh)	270.74	243.78	276.61	269.45	276.18	269.51	249.31	260.03	262.98	264.81	263.73	282.61
Solar Gains Exterior Windows (kWh)	272.95	525.65	1026.74	1324.71	1622.06	1675.73	1692.09	1356.36	960.19	574.26	323.21	180.32
Zone Sensible Heating (kWh)	10165.73	7766.06	7296.21	4790.61	3263.57	1340.96	309.51	847.59	2049.88	4772.26	7203.24	9364.69
Zone Sensible Cooling (kWh)	0.00	0.00	-2.80	-6.75	-14.21	-62.89	-116.00	-61.31	-11.04	-0.10	-0.29	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.03	-1.49	-0.03	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.03	-1.86	-0.05	0.00	0.00	0.00	0.00
Zone Heating (kWh)	10743.48	8243.66	7792.50	5180.03	3552.72	1480.86	345.48	934.49	2239.66	5091.06	7653.31	9927.36
Mech Vent + Nat Vent + Infiltration (ac/h)	1.16	1.15	1.16	1.15	1.14	1.14	1.13	1.13	1.13	1.14	1.15	1.16

Figure A105. The simulation detailed results of the house.

Case 36. A House Built in 1980

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are cavity brick/block, rendered externally.	0.982	Increase 19 cm Insulation
	Flat 1.128	Increase 32 cm Insulation
	Pitched 1.164	Increase 33 cm Insulation
Floors are of a suspended timber construction.	0.650	Increase 29 cm Insulation
Internal Walls are solid and timber stud partitions.	1.070	
Windows are principally PVC double glazed.		

* As a basis for a theory of possibility

Description

Two storey detached dwelling. Ground Floor: Entrance vestibule, hallway, lounge, dining room, kitchen, study/office and WC compartment.

First Floor: Four bedrooms, two bathrooms, two bathrooms both with WC and one separate shower enclosure.

Weather Overcast but dry.

Heating and hot water

A gas fired boiler connected to a hot water tank. The boiler is the hot water source for the wall moun ted wet radiator heating system. Hot water is from the boiler/tank.

Gross internal floor area (m²) 266 m^2

Address

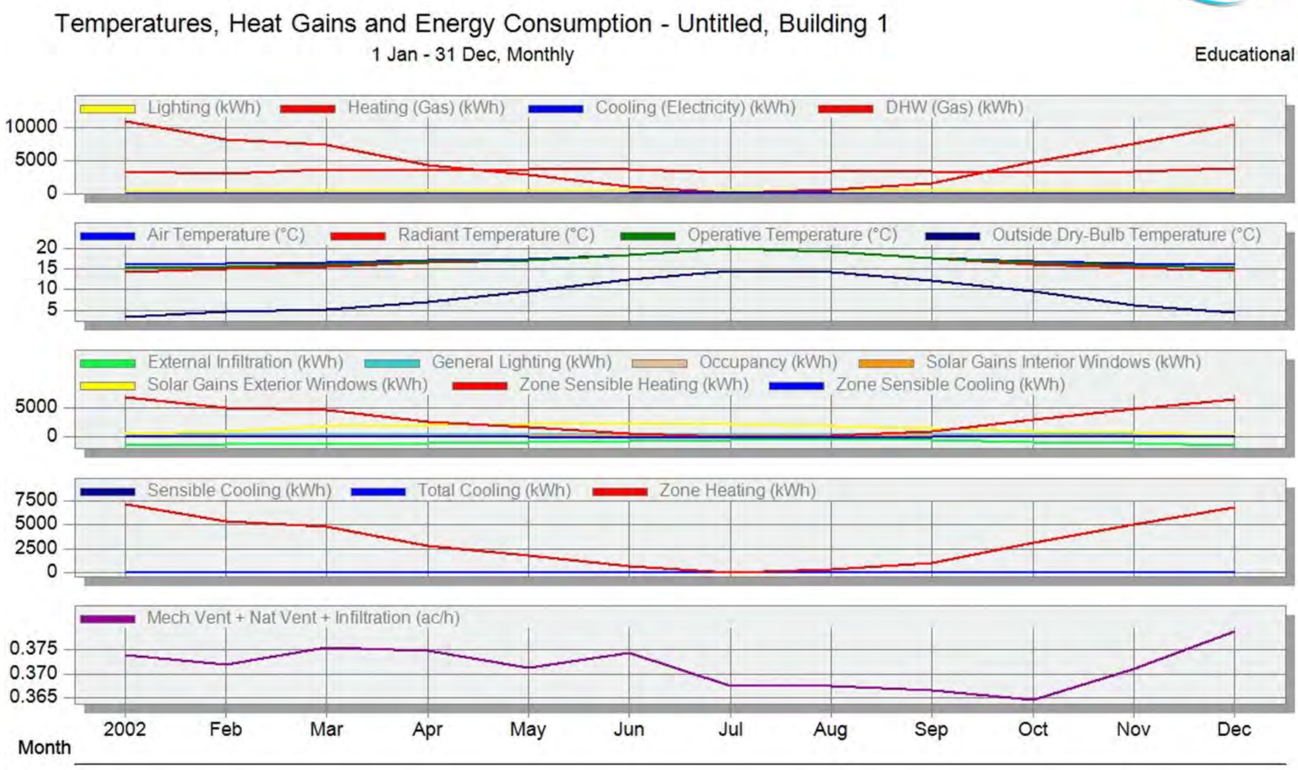
Edinburgh EH13 0DL

Figure A106. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	14.39
Operative Temperature (°C)	16.20
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.93
Walls (kW)	-10.07
Ceilings (int) (kW)	-2.86
Floors (int) (kW)	0.47
Ground Floors (kW)	0.65
Partitions (int) (kW)	-0.01
Roofs (kW)	-1.98
Floors (ext) (kW)	-0.01
External Infiltration (kW)	-3.83
External Vent. (kW)	-2.23
Zone Sensible Heating (kW)	23.65

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 29.550 (kW)				
Ground Floor Total Design Heating Capacity = 17.300 (kW)				
Double Garage	15.29	3.65	**4.56**	80.6783
Shower Room	16.77	0.37	**0.47**	58.6097
Family Room	16.64	0.62	**0.77**	57.2872
Service	17.38	0.19	**0.24**	33.4489
Kitchen	16.69	1.54	**1.92**	45.7079
Hall	17.12	1.03	**1.28**	34.9181
Lounge	16.67	1.67	**2.09**	43.3826
Dining Room	16.27	1.35	**1.69**	60.0192
Sun Room	15.13	2.17	**2.71**	104.7038
Vestibule	15.41	0.88	**1.11**	136.7150
Utility Room	16.52	0.37	**0.46**	79.2304
First Floor Total Design Heating Capacity = 12.250 (kW)				
Service	16.27	0.79	**0.99**	61.3788
Bed Room	15.81	1.16	**1.44**	75.6982
Service	15.92	0.54	**0.68**	96.4423
Bed Room	15.98	1.02	**1.27**	69.6326
HallWay	16.49	1.43	**1.79**	58.9801
Bed Room	15.75	1.31	**1.64**	76.9635
Bed Room	16.38	1.09	**1.36**	50.5007
Master BedRoom	15.59	1.73	**2.16**	80.4835
Landing	17.17	0.15	**0.19**	40.5310
Service	17.18	0.10	**0.13**	45.1003
Service	16.34	0.48	**0.60**	68.9506

Figure A107. The heating design simulation and data of the house.



Lighting (kWh)	468.52	421.21	483.78	473.09	483.78	488.35	453.25	468.52	457.83	453.25	457.83	499.04
Heating (Gas) (kWh)	11070.71	8226.26	7418.93	4264.75	2832.02	998.03	112.03	498.64	1577.42	4808.66	7694.25	10501.49
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.03	0.54	0.03	0.00	0.00	0.00	0.00
DHW (Gas) (kWh)	3426.89	3071.25	3612.89	3556.34	3612.89	3742.34	3240.89	3426.89	3370.34	3240.89	3370.34	3798.89
Air Temperature (°C)	16.05	16.29	16.62	17.14	17.36	18.40	19.87	19.12	17.77	16.97	16.46	16.21
Radiant Temperature (°C)	14.40	14.93	15.56	16.58	17.01	18.38	20.06	19.17	17.56	16.17	15.22	14.59
Operative Temperature (°C)	15.22	15.61	16.09	16.86	17.18	18.39	19.96	19.14	17.67	16.57	15.84	15.40
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1479.63	-1223.83	-1327.67	-1129.57	-882.48	-665.33	-593.41	-542.83	-606.84	-852.94	-1148.11	-1377.60
General Lighting (kWh)	468.52	421.21	483.78	473.09	483.78	488.35	453.25	468.52	457.83	453.25	457.83	499.04
Occupancy (kWh)	175.14	156.90	184.21	180.80	183.39	184.92	150.05	163.26	170.61	165.59	172.17	194.16
Solar Gains Interior Windows (kWh)	0.24	0.36	0.57	0.60	0.57	0.51	0.57	0.53	0.47	0.34	0.27	0.16
Solar Gains Exterior Windows (kWh)	596.11	1014.52	1768.71	2103.50	2206.82	2143.87	2225.15	1915.72	1503.68	996.99	687.57	395.77
Zone Sensible Heating (kWh)	6843.95	5057.37	4518.32	2546.59	1685.43	582.11	66.46	292.88	924.16	2932.77	4732.96	6456.96
Zone Sensible Cooling (kWh)	-0.04	-2.50	-13.41	-28.33	-33.29	-74.95	-112.95	-78.15	-32.41	-1.78	-1.65	-0.11
Sensible Cooling (kWh)	0.00	0.00	-0.00	-0.00	0.00	-0.06	-1.10	-0.04	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	-0.00	-0.00	-0.00	-0.06	-1.34	-0.07	0.00	0.00	0.00	0.00
Zone Heating (kWh)	7195.96	5347.07	4822.30	2772.09	1840.81	648.72	72.82	324.12	1025.33	3125.63	5001.26	6825.97
Mech Vent + Nat Vent + Infiltration (ac/h)	0.37	0.37	0.38	0.37	0.37	0.37	0.37	0.37	0.37	0.36	0.37	0.38

Figure A108. The simulation detailed results of the house.

Case 37. A House Built in 1970

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are brick/block cavity rendered externally.	1.000	Increase 18 cm Insulation
	Flat -	-
	Pitched 1.384	Increase 33 cm Insulation
Floors are of a suspended timber construction.	0.717	Increase 29 cm Insulation
Internal Walls are plasterboard finishes.	1.151	
Windows are u-PVC double glazed.		

* As a basis for a theory of possibility

Description

Two storey detached dwelling. Ground Floor: Entrance vestibule, hallway, living room, Kitchen and office.

First Floor: master bedrooms, two bathrooms.

Weather Dry.

Heating and hot water

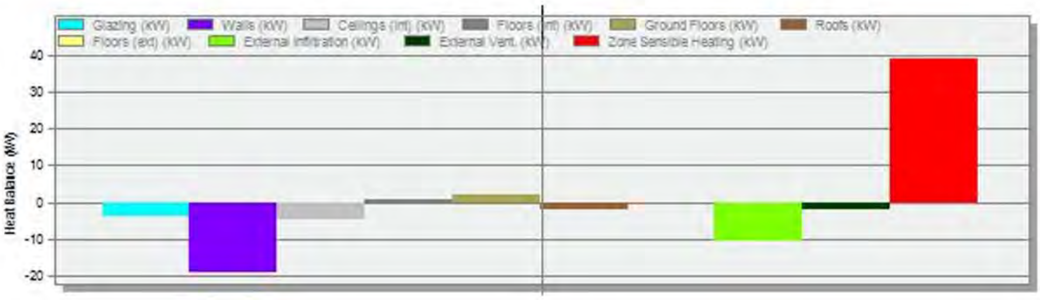
Heating supply is from a wall mounted gas fired boiler located within the bedroom/study at ground floor level, this supplies steel panelled radiators and we assume, domestic hot water.

Gross internal floor area(m²) 385m² + 328m²garage

Address

EDINBURGH EH4 6DF

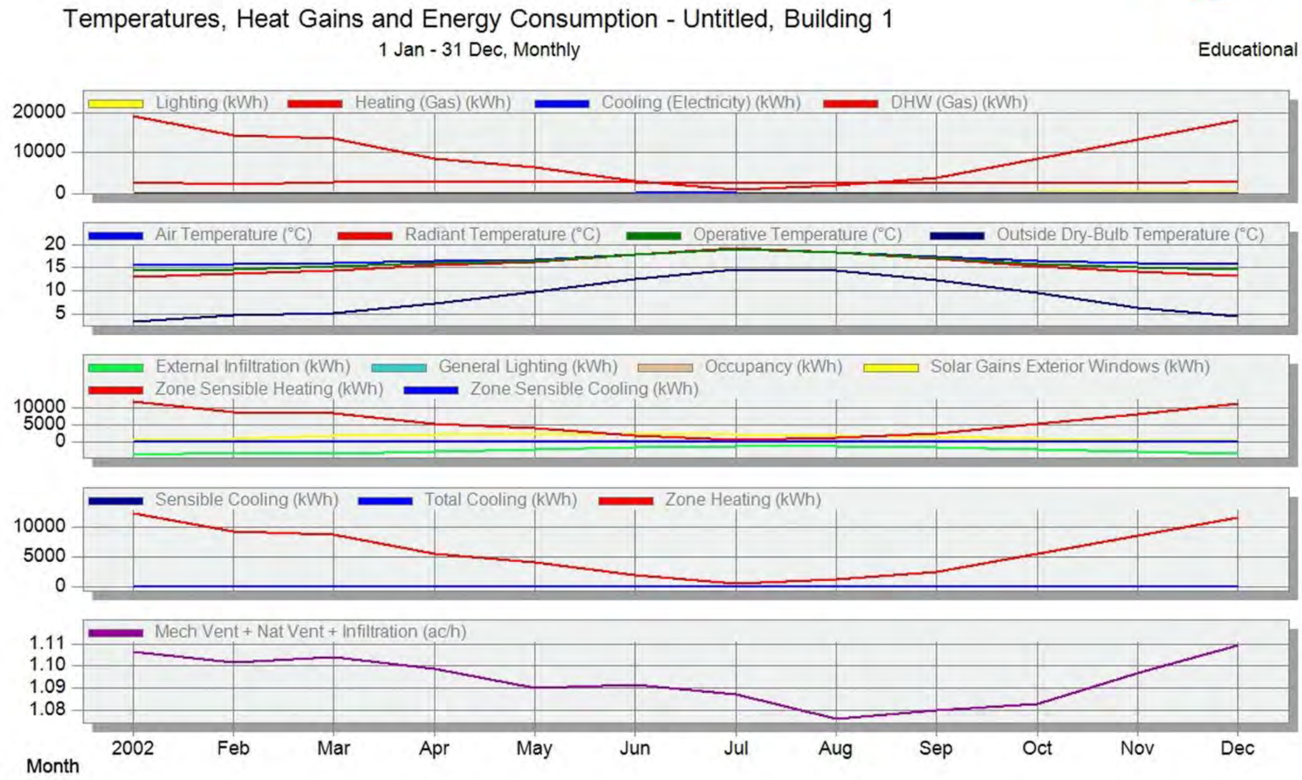
Figure A109. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.42
Operative Temperature (°C)	15.21
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.76
Walls (kW)	-19.12
Ceilings (int) (kW)	-4.67
Floors (int) (kW)	0.82
Ground Floors (kW)	1.93
Roofs (kW)	-2.06
Floors (ext) (kW)	-0.03
External Infiltration (kW)	-10.35
External Vent. (kW)	-1.88
Zone Sensible Heating (kW)	39.01

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 48.750 (kW)				
Ground Floor Total Design Heating Capacity = 25.500 (kW)				
Service	14.96	0.81	**1.01**	276.3919
HallWay	17.16	1.07	**1.34**	62.5848
BedRoom	15.92	1.45	**1.81**	113.8870
Dressing Room	14.58	1.93	**2.41**	201.2620
Family Room	16.12	1.67	**2.09**	98.5653
Sun Room	14.34	5.29	**6.61**	155.9741
Service	16.54	0.31	**0.39**	137.9864
Kitchen	15.01	3.44	**4.30**	138.6563
Dining Room	15.24	1.90	**2.38**	147.4064
Service	17.16	0.27	**0.34**	76.9411
BedRoom	16.38	1.23	**1.54**	92.9736
Lundry	16.15	0.59	**0.74**	135.3912
Service	16.04	0.43	**0.54**	168.9379
Double Garage Total Design Heating Capacity = 5.550 (kW)				
Zone 1	13.67	4.44	**5.55**	170.0551
First Floor Total Design Heating Capacity = 17.700 (kW)				
Study Room	15.27	1.28	**1.59**	136.3656
Dressing Room	14.84	1.81	**2.26**	149.9488
Hall	16.46	1.41	**1.76**	74.4453
Master BedRoom	14.97	2.26	**2.82**	129.3885
Sitting Room	14.56	4.60	**5.75**	133.9016
BedRoom	14.91	2.24	**2.80**	132.1265
Service	15.89	0.57	**0.72**	137.4560

Figure A110. The heating design simulation and data of the house.



Lighting (kWh)	319.91	254.12	252.83	217.89	198.63	187.73	181.34	208.99	238.47	272.51	292.82	342.66
Heating (Gas) (kWh)	18927.86	14161.12	13371.96	8550.57	6373.51	3104.78	930.05	1923.62	3828.79	8612.66	13206.87	17794.19
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.05	2.09	0.00	0.00	0.00	0.00	0.00
DHW (Gas) (kWh)	2625.14	2352.71	2767.63	2724.31	2767.63	2866.80	2482.66	2625.14	2581.83	2482.66	2581.83	2910.11
Air Temperature (°C)	15.52	15.65	15.94	16.41	16.67	17.71	18.74	18.15	17.26	16.31	15.83	15.69
Radiant Temperature (°C)	12.96	13.58	14.29	15.52	16.01	17.62	19.09	18.15	16.86	15.10	13.97	13.23
Operative Temperature (°C)	14.24	14.62	15.11	15.96	16.34	17.67	18.92	18.15	17.06	15.71	14.90	14.46
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3833.94	-3130.77	-3379.09	-2837.18	-2177.88	-1603.37	-1273.71	-1180.62	-1490.16	-2106.07	-2916.27	-3564.16
General Lighting (kWh)	319.91	254.12	252.83	217.89	198.63	187.73	181.34	208.99	238.47	272.51	292.82	342.66
Occupancy (kWh)	140.28	125.72	147.68	145.15	147.63	150.94	127.49	135.68	137.38	132.66	137.95	155.51
Solar Gains Exterior Windows (kWh)	605.25	1016.75	1732.52	2112.39	2159.42	2073.31	2196.14	1880.24	1462.36	963.33	703.69	406.01
Zone Sensible Heating (kWh)	11994.20	8945.67	8416.82	5343.51	3981.35	1924.49	572.96	1194.71	2380.61	5420.97	8343.07	11242.96
Zone Sensible Cooling (kWh)	0.00	-0.16	-5.27	-8.72	-6.57	-25.71	-56.01	-21.80	-6.32	-0.22	-0.40	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.12	-4.13	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.12	-5.23	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	12303.11	9204.73	8691.78	5557.87	4142.78	2018.11	604.54	1250.35	2488.72	5598.23	8584.46	11566.23
Mech Vent + Nat Vent + Infiltration (ac/h)	1.11	1.10	1.10	1.10	1.09	1.09	1.09	1.08	1.08	1.08	1.10	1.11

Figure A111. The simulation detailed results of the house.

Case 38. A House Built in 1968

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls Are cavity brick and Fife stone. .	1.395	Increase 18 cm Insulation
	Flat 1.467	Increase 31 cm Insulation
	Pitched 1.483	Increase 32 cm Insulation
Floors are of a suspended timber construction.	0.762	Increase 29 cm Insulation
Internal Walls are solid plasterboard on the hard.	1.189	
Windows are replacement PVC and aluminium double glazed windows.		

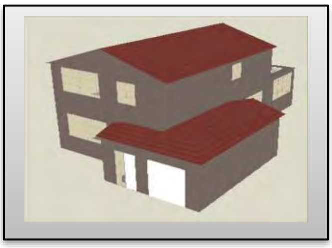
* As a basis for a theory of possibility

Description

Two storey detached house.

Ground Floor: Entrance Vestibule, Hall, Sittingroom, Dining Room, Kitchen with Conservatory off and Cloakroom/WC.

First Floor: Landing, 4 Bedrooms and Bathroom.



Weather Dry and sunny.

Heating and hot water

Modern gas fired boiler providing domestic hot water and serving a wet radiator system. Foam insulated hot water tank.

Gross internal floor area(m²) 125 m^2

Address

BALERNO EH145AJ

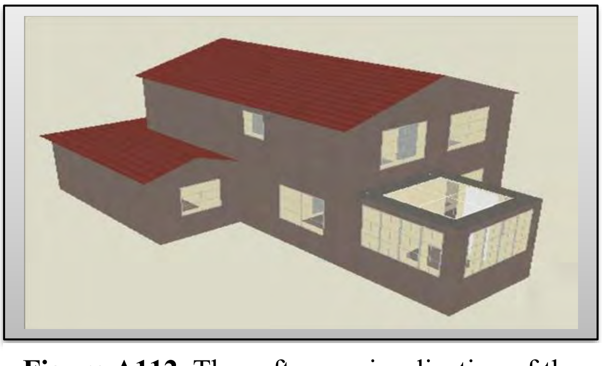
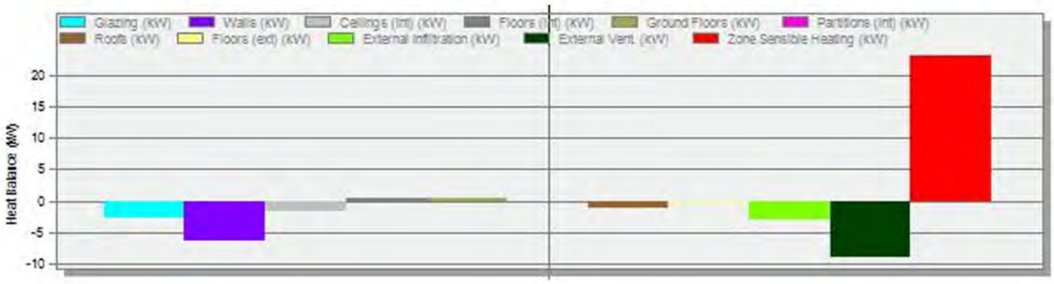


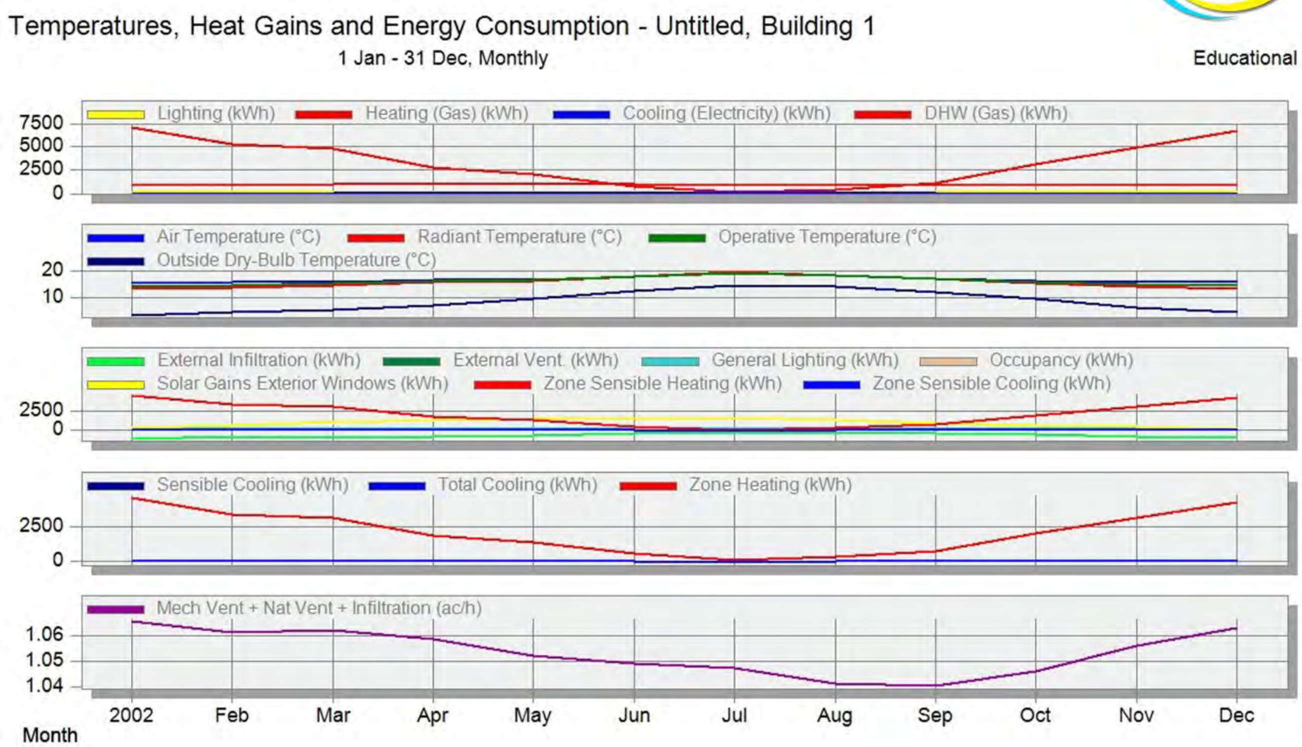
Figure A112. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.85
Operative Temperature (°C)	15.43
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.56
Walls (kW)	-6.25
Ceilings (int) (kW)	-1.68
Floors (int) (kW)	0.33
Ground Floors (kW)	0.32
Partitions (int) (kW)	0.00
Roofs (kW)	-1.11
Floors (ext) (kW)	-0.25
External Infiltration (kW)	-2.96
External Vent. (kW)	-8.98
Zone Sensible Heating (kW)	23.13

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 28.900 (kW)				
Ground Floor Total Design Heating Capacity = 9.170 (kW)				
Living Room	15.88	2.55	**3.19**	182.9542
Vestibule	17.33	0.22	**0.27**	156.8471
Hall	17.41	0.55	**0.69**	144.7725
Service	17.42	0.19	**0.24**	152.3291
Dining Room	15.79	2.06	**2.58**	193.9073
Kitchen	16.25	1.45	**1.82**	179.2716
Service	16.95	0.31	**0.38**	187.9283
Garage Total Design Heating Capacity = 3.960 (kW)				
Zone 1	15.19	3.17	**3.96**	229.9959
First Floor Total Design Heating Capacity = 10.580 (kW)				
Bed Room	15.21	2.19	**2.73**	205.3681
Bed Room	15.25	1.24	**1.55**	234.3591
Hall	15.88	1.25	**1.56**	256.9440
Service	15.93	0.66	**0.82**	217.4437
Bed Room	15.21	2.20	**2.75**	206.8155
Study Room	16.11	0.93	**1.17**	189.8061
Conservatory Total Design Heating Capacity = 3.520 (kW)				
Zone 1	13.11	2.81	**3.52**	442.5851
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	2.12	0.00	**0.00**	0.0000
Roof Garage Total Design Heating Capacity = 1.670 (kW)				
Zone 1	14.13	1.34	**1.67**	110.2719

Figure A113. The heating design simulation and data of the house.



Lighting (kWh)	208.90	187.86	215.27	210.38	215.27	216.75	202.53	208.90	204.01	202.53	204.01	221.64
Heating (Gas) (kWh)	7100.38	5277.76	4812.82	2830.30	2039.48	818.33	125.49	462.20	1148.49	3118.40	4919.85	6676.44
Cooling (Electricity) (kWh)	0.00	0.00	4.18	7.01	7.49	26.17	49.76	21.16	2.62	0.00	0.00	0.00
DHW (Gas) (kWh)	929.28	832.84	979.72	964.38	979.72	1014.82	878.84	929.28	913.94	878.84	913.94	1030.15
Air Temperature (°C)	15.62	15.81	16.14	16.71	16.98	17.99	19.32	18.59	17.42	16.56	16.01	15.79
Radiant Temperature (°C)	13.21	13.82	14.56	15.85	16.35	17.90	19.63	18.61	17.05	15.38	14.22	13.47
Operative Temperature (°C)	14.41	14.82	15.35	16.28	16.67	17.95	19.48	18.60	17.24	15.97	15.11	14.63
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1106.46	-911.16	-990.46	-846.54	-659.48	-490.03	-424.44	-384.61	-447.73	-629.37	-852.29	-1030.49
External Vent. (kWh)	0.00	0.00	-1.25	-3.45	-4.00	-4.63	-5.87	-2.62	-0.77	0.00	0.00	0.00
General Lighting (kWh)	208.90	187.86	215.27	210.38	215.27	216.75	202.53	208.90	204.01	202.53	204.01	221.64
Occupancy (kWh)	55.52	49.77	58.10	56.95	57.85	58.50	48.87	52.71	54.18	52.71	54.51	61.02
Solar Gains Exterior Windows (kWh)	336.71	592.45	1090.23	1363.99	1539.24	1521.57	1602.13	1320.88	975.46	612.27	394.26	223.85
Zone Sensible Heating (kWh)	4562.36	3387.93	3087.13	1811.88	1305.50	522.86	78.83	294.84	734.33	2000.90	3158.19	4288.92
Zone Sensible Cooling (kWh)	0.00	0.00	-7.01	-12.20	-13.56	-47.15	-86.25	-36.70	-5.62	-0.01	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	-6.98	-11.70	-12.51	-43.61	-81.38	-33.57	-4.37	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	-6.98	-11.70	-12.51	-43.70	-83.52	-35.33	-4.38	0.00	0.00	0.00
Zone Heating (kWh)	4615.24	3430.54	3128.33	1839.70	1325.66	531.91	81.57	300.43	746.52	2026.96	3197.91	4339.68
Mech Vent + Nat Vent + Infiltration (ac/h)	1.07	1.06	1.06	1.06	1.05	1.05	1.05	1.04	1.04	1.05	1.06	1.06

Figure A114. The simulation detailed results of the house.

Case 39. A House Built in 1960

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are a mix of brick and timber frame with block/brick outer leaf rendered externally.	1.534	Increase 18 cm Insulation
	Flat 1.599	Increase 31 cm Insulation
	Pitched 1.447	Increase 32 cm Insulation
Floors are of a timber construction.	0.835	Increase 31 cm Insulation
Internal Walls are plasterboard finishing.	1.203	
Windows are of replacement u-PVC double glazed type.		

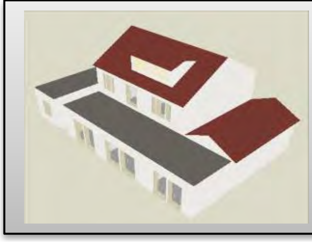
* As a basis for a theory of possibility

Description

The property comprises an extended three storey detached house.

Ground Floor: Entrance hall, bedroom/study, kitchen, living room, dining room and family room.

First Floor: Landing, three bedrooms and bathroom with WC.



Weather Dry and sunny.

Heating and hot water

The property benefits from a gas fired central heating system serving steel panel radiators. Domestic hot water is presumed to be provided via the boiler.

Gross internal floor area(m²) 180 m²

Address

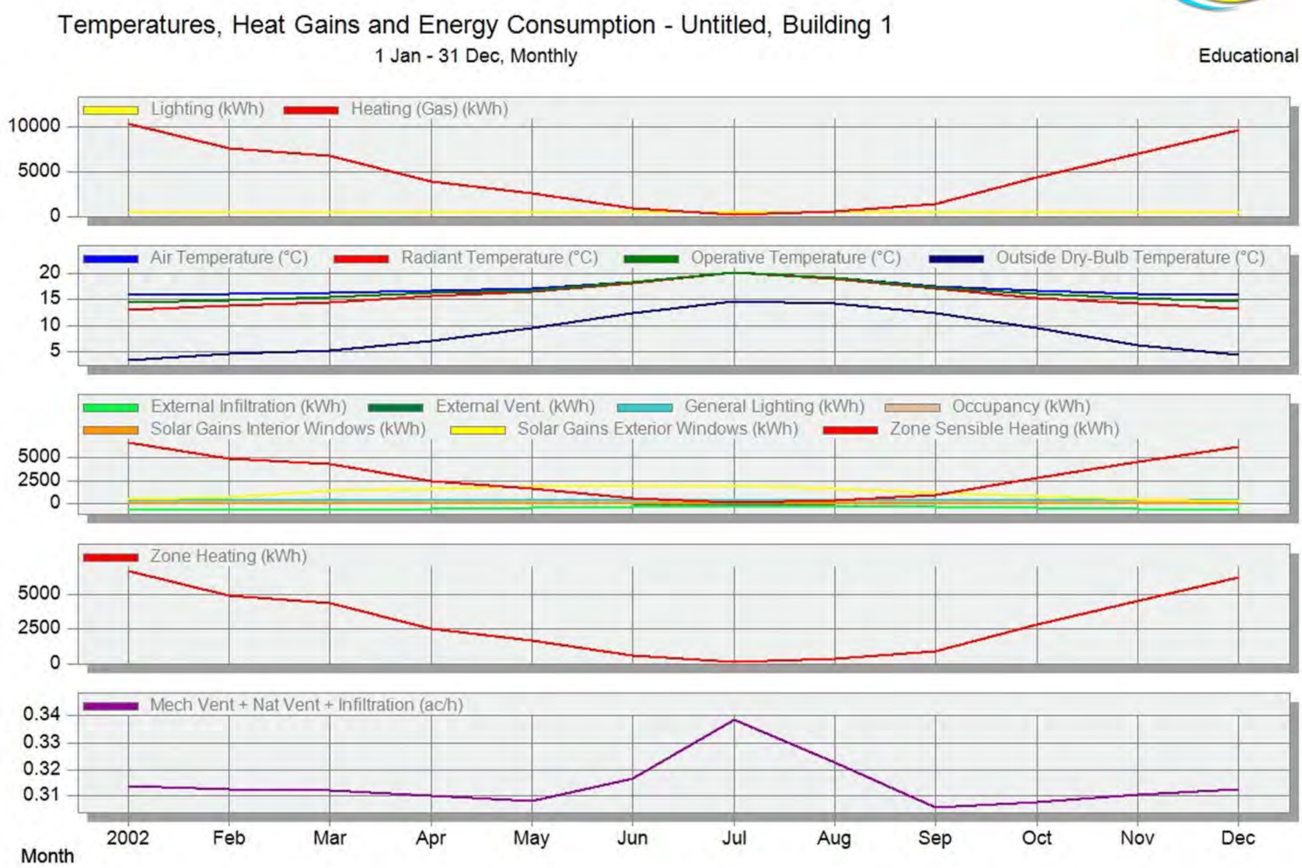
EDINBURGH EH4 6LH

Figure A115. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.44
Operative Temperature (°C)	15.22
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.13
Walls (kW)	-10.91
Ceilings (int) (kW)	-0.62
Floors (int) (kW)	0.52
Ground Floors (kW)	0.72
Partitions (int) (kW)	0.00
Roofs (kW)	-5.53
Floors (ext) (kW)	-0.03
External Infiltration (kW)	-1.87
External Vent. (kW)	-18.67
Zone Sensible Heating (kW)	39.44

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 49.300 (kW)				
Ground Floor Total Design Heating Capacity = 25.250 (kW)				
Game Room	14.55	6.84	**8.55**	236.3273
Dining Room	15.25	2.65	**3.31**	223.8311
Kitchen	14.77	2.45	**3.06**	264.0922
Sitting Room	16.61	3.29	**4.12**	158.9373
Hall	16.83	1.90	**2.38**	160.2766
Study Room	15.59	1.60	**2.00**	234.0720
Breakfast Room	16.17	1.47	**1.83**	193.6083
Garage Total Design Heating Capacity = 6.730 (kW)				
Zone 1	13.55	5.39	**6.73**	343.7987
First Floor Total Design Heating Capacity = 9.950 (kW)				
Bed Room	15.59	1.62	**2.03**	185.9704
Hall	16.26	1.72	**2.16**	151.6898
Bath Room	15.52	1.27	**1.59**	202.2808
Bed Room	15.63	1.86	**2.32**	177.5080
Bed Room	15.47	1.48	**1.85**	196.4551
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-7.06	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 6.640 (kW)				
Zone 1	14.57	5.31	**6.64**	111.6865
Window Roof Total Design Heating Capacity = 0.730 (kW)				
Zone 1	15.23	0.58	**0.73**	1.#INF
Roof 3 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-4.09	0.00	**0.00**	0.0000

Figure A116. The heating design simulation and data of the house.



Lighting (kWh)	419.62	378.68	422.17	409.38	422.17	411.94	417.06	419.62	406.82	417.06	406.82	424.73
Heating (Gas) (kWh)	10384.23	7616.92	6722.59	3847.18	2584.29	947.15	191.38	587.27	1424.77	4329.09	6994.85	9610.87
Air Temperature (°C)	15.83	16.01	16.28	16.75	17.14	18.44	20.17	19.12	17.59	16.64	16.18	15.86
Radiant Temperature (°C)	13.10	13.75	14.50	15.70	16.45	18.23	20.25	18.99	17.13	15.32	14.17	13.28
Operative Temperature (°C)	14.46	14.88	15.39	16.23	16.79	18.34	20.21	19.06	17.36	15.98	15.17	14.57
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-711.11	-584.90	-630.05	-530.05	-416.70	-321.83	-298.48	-259.62	-284.68	-398.98	-546.44	-654.01
External Vent. (kWh)	0.00	0.00	0.00	-0.01	-0.18	-11.60	-40.12	-17.43	-0.02	0.00	0.00	0.00
General Lighting (kWh)	419.62	378.68	422.17	409.38	422.17	411.94	417.06	419.62	406.82	417.06	406.82	424.73
Occupancy (kWh)	133.83	120.47	136.38	132.26	134.87	127.71	113.51	122.24	128.35	130.86	130.31	139.69
Solar Gains Interior Windows (kWh)	0.57	0.94	1.62	1.85	1.92	1.85	1.93	1.71	1.38	0.95	0.65	0.38
Solar Gains Exterior Windows (kWh)	443.71	765.44	1408.64	1710.93	1910.59	1907.95	1977.57	1647.63	1244.47	807.09	510.72	294.20
Zone Sensible Heating (kWh)	6725.13	4931.85	4352.25	2489.04	1670.76	611.70	123.47	379.45	921.16	2802.04	4528.20	6223.92
Zone Heating (kWh)	6749.75	4950.99	4369.69	2500.67	1679.79	615.65	124.40	381.73	926.10	2813.91	4546.65	6247.07
Mech Vent + Nat Vent + Infiltration (ac/h)	0.31	0.31	0.31	0.31	0.31	0.32	0.34	0.32	0.31	0.31	0.31	0.31

Figure A117. The simulation detailed results of the house.

Case 40. A House Built in 1959

Material	U-Value W/m^{2}K	How to reach Zero Carbon home (theoretically*)
Main Walls are of cavity brick construction externally rendered.	1.503	Increase 18 cm Insulation
	Flat 1.608	Increase 31 cm Insulation
	Pitched -	-
Floors are mainly of concrete.	0.858	Increase 30 cm Insulation
Internal Walls are a mixture of brick and plasterboard. **Windows** are of timber frame double glazed type.	1.221	

* As a basis for a theory of possibility

Description

Detached house.

GROUND FLOOR: Entrance Vestibule, Hall, Lounge open with Dining Room, Kitchen, Utility Room, Study, WC and also self-contained flat containing open plan Kitchen/Living Room, Bedroom and Bathroom with WC.

First Floor: Landing, Four Bedrooms, En Suite Bathroom.

Weather Dry and bright.

Heating and hot water

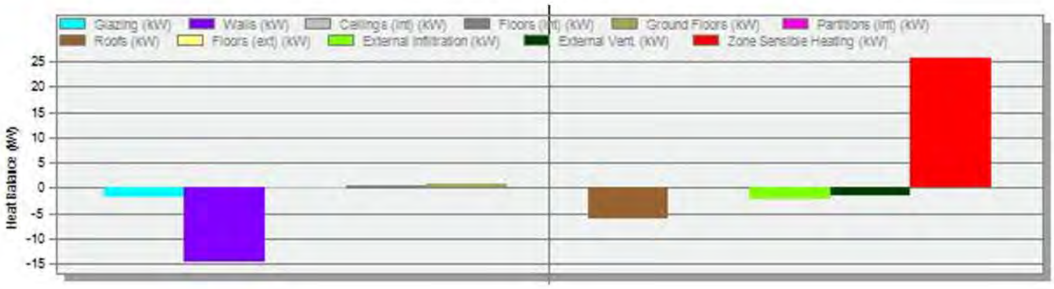
There is a gas fired central heating system from a boiler located in a cupboard off the landing with insulated hot water storage tank adjacent. This serves radiators throughout many of the main apartments while elsewhere within the main hall, kitchen, utility room, WC and the two en-suite shower rooms it is understood there is electric under floor heating.

Gross internal floor area(m²) 270 m^2

Address

STANDREWS KY16 9UD

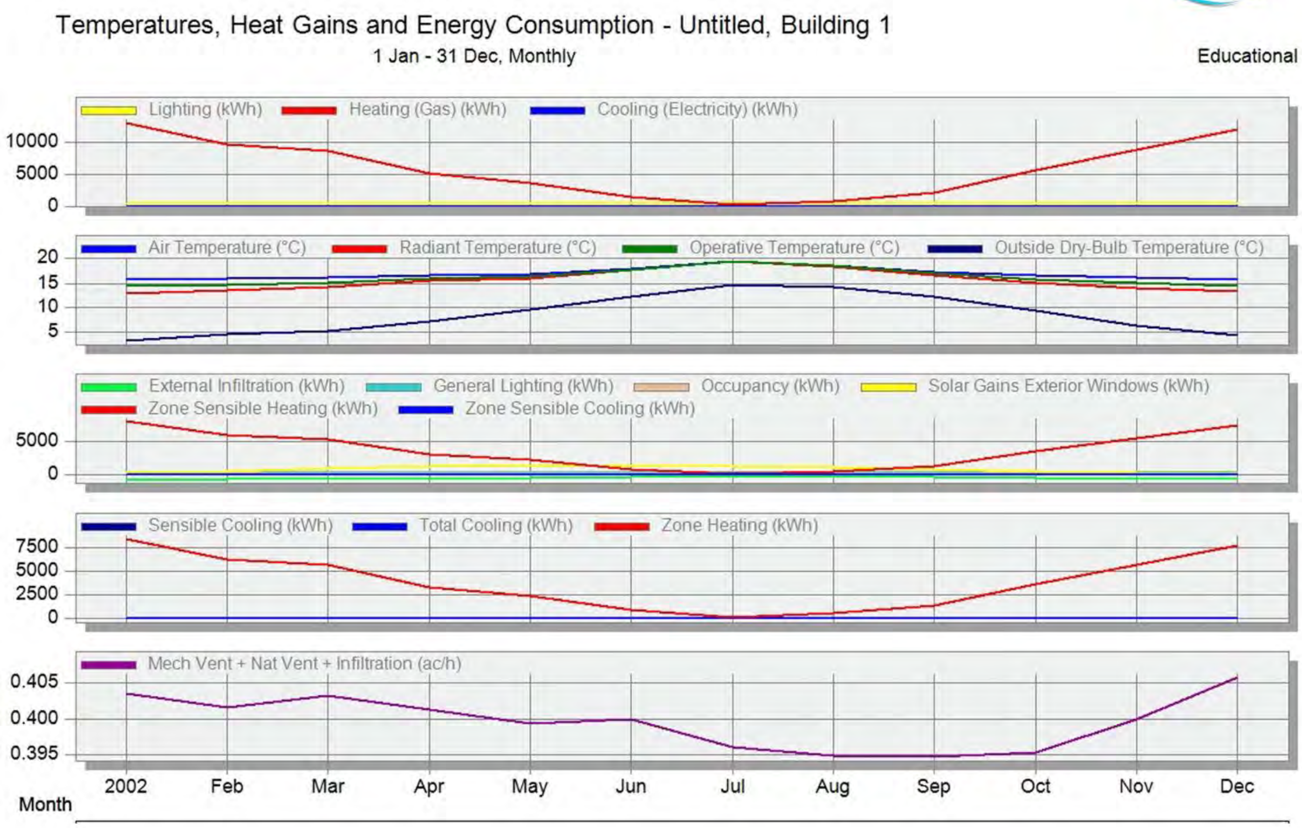
Figure A118. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.61
Operative Temperature (°C)	15.31
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.02
Walls (kW)	-14.75
Ceilings (int) (kW)	-0.36
Floors (int) (kW)	0.37
Ground Floors (kW)	0.75
Partitions (int) (kW)	0.06
Roofs (kW)	-6.17
Floors (ext) (kW)	-0.00
External Infiltration (kW)	-2.07
External Vent. (kW)	-1.66
Zone Sensible Heating (kW)	25.78

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 32.250 (kW)				
Ground Floor Total Design Heating Capacity = 18.210 (kW)				
Living Room	15.45	1.60	**2.00**	113.5424
Utility Room	16.49	0.57	**0.72**	78.8331
Landing	16.89	0.45	**0.57**	57.9094
Study Room	16.30	0.43	**0.54**	106.3292
Lounge	14.78	2.61	**3.26**	128.4239
Dining Room	16.00	1.39	**1.74**	79.3275
Vestibule	14.37	0.85	**1.06**	297.8670
Service	14.30	0.87	**1.09**	305.3297
Kitchen	15.84	1.32	**1.65**	88.9504
Bath Room	16.29	0.33	**0.41**	128.5930
Garage	13.84	2.90	**3.63**	179.2392
Bed Room	15.03	1.23	**1.54**	151.9678
First Floor Total Design Heating Capacity = 14.040 (kW)				
Hall	15.55	0.68	**0.85**	258.1870
HallWay	15.53	1.75	**2.19**	142.1402
Service	15.92	0.19	**0.24**	360.1791
Service	14.93	0.87	**1.09**	199.4302
Shower Room	16.63	0.17	**0.22**	144.7685
Bed Room	14.99	1.25	**1.56**	153.8929
Dressing Room	15.90	0.92	**1.15**	119.9115
Bed Room	14.94	1.41	**1.76**	148.2338
Cloak Room	15.73	0.45	**0.56**	179.8900
Shower Room	15.73	0.59	**0.74**	150.4003
Bed Room	14.91	1.18	**1.47**	164.7483
Bed Room	14.35	1.77	**2.21**	178.0548

Figure A119. The heating design simulation and data of the house.



Lighting (kWh)	385.96	348.31	388.32	376.55	388.32	378.90	383.61	385.96	374.19	383.61	374.19	390.67
Heating (Gas) (kWh)	12942.81	9634.27	8682.08	5097.75	3646.62	1368.18	214.63	765.39	2049.62	5677.37	8838.41	11982.54
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.76	15.93	16.16	16.65	16.94	17.99	19.44	18.64	17.33	16.60	16.13	15.82
Radiant Temperature (°C)	13.05	13.64	14.28	15.49	16.09	17.71	19.50	18.48	16.76	15.20	14.10	13.27
Operative Temperature (°C)	14.40	14.79	15.22	16.07	16.52	17.85	19.47	18.56	17.05	15.90	15.12	14.55
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-782.48	-642.32	-689.74	-582.43	-452.40	-336.96	-297.13	-266.26	-302.57	-438.75	-601.53	-721.12
General Lighting (kWh)	385.96	348.31	388.32	376.55	388.32	378.90	383.61	385.96	374.19	383.61	374.19	390.67
Occupancy (kWh)	123.09	110.83	125.75	122.46	125.60	121.60	109.86	116.36	119.53	120.40	119.90	128.49
Solar Gains Exterior Windows (kWh)	301.44	545.28	1000.10	1284.16	1365.50	1366.60	1382.75	1159.76	854.87	546.71	349.14	203.60
Zone Sensible Heating (kWh)	8126.93	6026.55	5399.36	3125.55	2231.02	830.89	131.28	465.09	1243.37	3533.47	5522.62	7510.42
Zone Sensible Cooling (kWh)	0.00	-0.28	-1.48	-4.57	-8.07	-41.17	-74.37	-44.05	-8.29	-0.17	-0.21	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.00	-0.60	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.00	-0.83	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	8412.83	6262.27	5643.35	3313.54	2370.30	889.31	139.51	497.50	1332.25	3690.29	5744.96	7788.65
Mech Vent + Nat Vent + Infiltration (ac/h)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.39	0.39	0.40	0.40	0.41

Figure A120. The simulation detailed results of the house.

Case 41. A House Built in 1951

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of cavity brick construction externally rendered.	1.537	Increase 18 cm Insulation
	Flat 1.688	Increase 31 cm Insulation
	Pitched 1.559	Increase 33 cm Insulation
Floors are of solid concrete construction and of suspended timber.	0.862	Increase 31 cm Insulation
Internal Walls are plasterboard on the hard and plasterboard.	1.324	
Windows are of u-PVC framed casement pattern.		

* As a basis for a theory of possibility

Description

The property comprises a two storey detached villa

On ground floor: entrance vestibule with WC apartment off, hallway, lounge, dining room, tv room, breakfast room, study, kitchen, rear hall, sun room and utility room.

Weather Overcast.

Heating and hot water

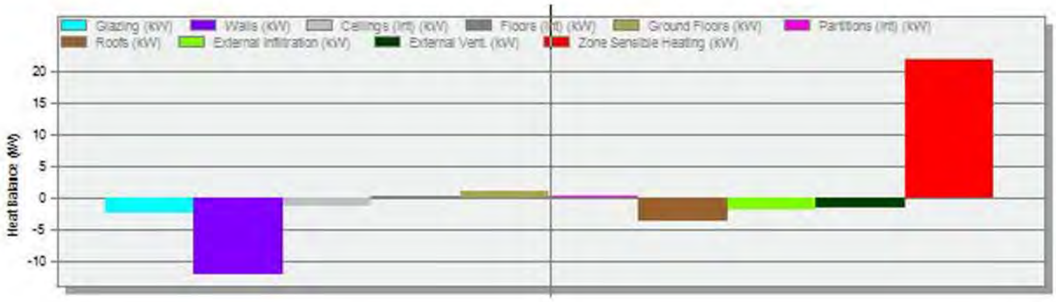
Central heating is from a gas fired Potterton Kingfisher CF boiler which is in a rear hall cupboard. The boiler serves radiators throughout and also supplies a hot water source to a circulating tank which is in a cupboard off the landing.

Gross internal floor area (m²) 208 m²

Address

GULLANE EH31 2DJ

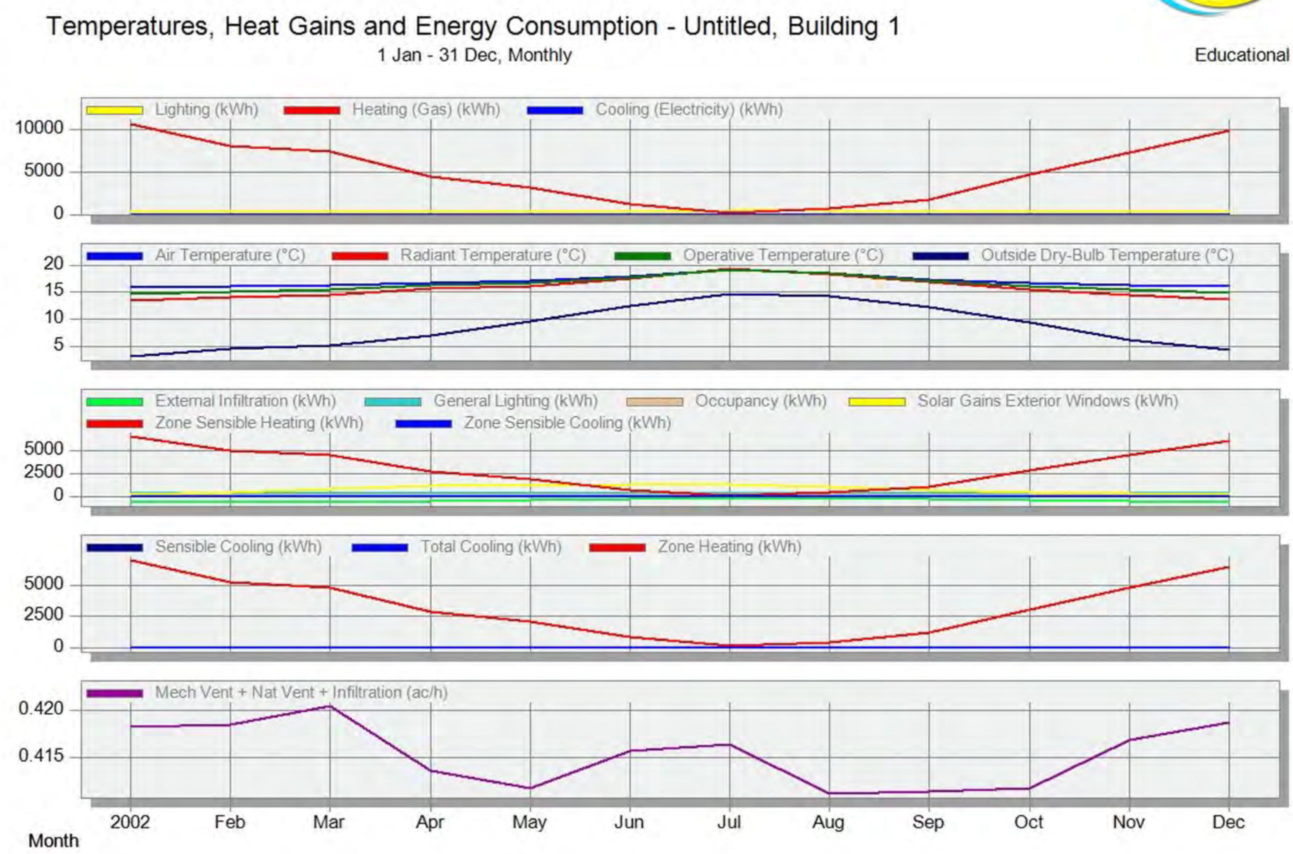
Figure A121. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.92
Operative Temperature (°C)	15.46
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.33
Walls (kW)	-12.16
Ceilings (int) (kW)	-1.42
Floors (int) (kW)	0.31
Ground Floors (kW)	0.87
Partitions (int) (kW)	0.08
Roofs (kW)	-3.71
External Infiltration (kW)	-1.80
External Vent. (kW)	-1.72
Zone Sensible Heating (kW)	21.78

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 27.200 (kW)				
Ground Floor Total Design Heating Capacity = 12.390 (kW)				
Vestibule	15.17	0.69	**0.87**	178.4537
Dining Room	15.82	1.09	**1.37**	87.7466
Hall	17.37	0.30	**0.37**	33.2148
Store	16.74	0.24	**0.30**	98.0254
Service	15.90	0.53	**0.66**	134.1650
Boiler Room	17.53	0.10	**0.12**	38.0293
Kitchen	14.81	1.30	**1.62**	149.2253
Store	17.27	0.09	**0.11**	67.4400
Breakfast Room	15.37	0.98	**1.22**	129.4170
Conservatory	15.18	0.98	**1.22**	139.5113
Study Room	14.73	1.10	**1.37**	173.5693
Family Room	17.11	0.45	**0.57**	39.6462
Landing	17.54	0.09	**0.12**	44.9926
Living Room	15.50	1.98	**2.47**	87.3165
Double Garage Total Design Heating Capacity = 4.820 (kW)				
Zone 1	13.59	3.86	**4.82**	152.5728
Garden Store Total Design Heating Capacity = 2.170 (kW)				
Store	13.98	1.05	**1.31**	260.6304
Garden Store	14.15	0.68	**0.86**	388.5150
First Floor Total Design Heating Capacity = 7.820 (kW)				
Bath Room	15.05	0.73	**0.91**	181.8312
Shower Room	15.24	0.77	**0.96**	155.4349
Hall	17.00	0.36	**0.45**	50.9867
Master BedRoom	15.39	1.17	**1.46**	109.1358
Landing	17.26	0.07	**0.08**	81.8851
Bed Room	15.78	0.75	**0.93**	107.8769
Bed Room	15.45	1.30	**1.62**	99.1405
Bed Room	15.50	1.13	**1.41**	105.7331

Figure A122. The heating design simulation and data of the house.



Lighting (kWh)	388.52	352.76	393.28	376.60	388.52	381.37	388.52	390.90	378.98	388.52	378.98	390.90
Heating (Gas) (kWh)	10674.09	8026.07	7370.16	4455.88	3158.86	1226.91	221.20	654.06	1759.33	4718.75	7313.99	9877.24
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.84	0.00	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.94	16.11	16.30	16.74	17.00	17.85	19.15	18.52	17.36	16.71	16.31	16.01
Radiant Temperature (°C)	13.41	13.95	14.50	15.59	16.15	17.54	19.17	18.36	16.80	15.40	14.41	13.63
Operative Temperature (°C)	14.67	15.03	15.40	16.17	16.57	17.69	19.16	18.44	17.08	16.06	15.36	14.82
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-689.83	-566.73	-606.92	-510.49	-395.87	-285.55	-242.97	-224.99	-263.83	-386.99	-531.81	-636.90
General Lighting (kWh)	388.52	352.76	393.28	376.60	388.52	381.37	388.52	390.90	378.98	388.52	378.98	390.90
Occupancy (kWh)	121.94	112.25	127.36	118.53	121.76	121.29	112.93	118.64	121.08	121.94	121.44	124.67
Solar Gains Exterior Windows (kWh)	245.71	460.99	842.08	1125.47	1231.41	1255.78	1271.73	1031.58	738.77	449.74	290.40	166.75
Zone Sensible Heating (kWh)	6656.79	4979.44	4544.54	2709.62	1913.47	737.91	136.52	393.98	1052.61	2908.82	4530.48	6149.82
Zone Sensible Cooling (kWh)	0.00	-0.01	-1.65	-4.55	-6.07	-37.53	-76.48	-44.63	-8.19	-0.05	-0.11	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-1.69	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-2.11	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	6938.16	5216.94	4790.60	2896.32	2053.26	797.49	143.78	425.14	1143.57	3067.19	4754.09	6420.21
Mech Vent + Nat Vent + Infiltration (ac/h)	0.42	0.42	0.42	0.41	0.41	0.42	0.42	0.41	0.41	0.41	0.42	0.42

Figure A123. The simulation detailed results of the house.

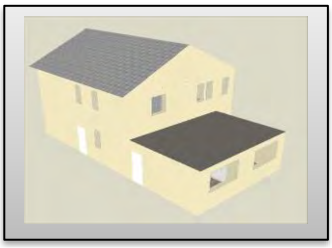
Case 42. A House Built in 1945

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional cavity construction with rendered finishes externally.	1.549	Increase 18.5 cm Insulation
	Flat 1.818	Increase 32 cm Insulation
	Pitched 1.574	Increase 32.3 cm Insulation
Floors are of suspended timber design.	0.889	Increase 30 cm Insulation
Internal Walls are a combination of brickwork and timber stud design with plaster finishes.	1.373	
Windows are of u-PVC framed casement pattern.		

* As a basis for a theory of possibility

Description

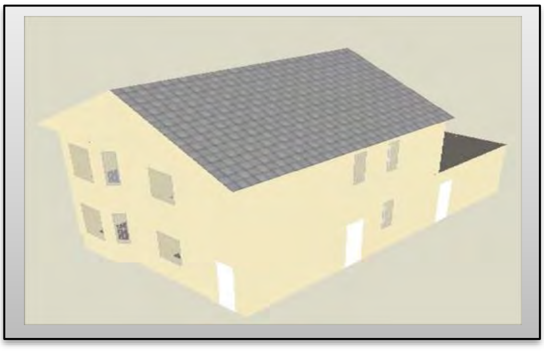
The subjects comprise an extended lower flatted villa within a two storey block containing four flats in total. Access is via private main door. Ground Floor: Entrance hall, lounge, kitchen, four bedrooms, bathroom and storage.



Weather Dry and sunny.

Heating and hot water

Central heating is by way of a gas fired boiler serving panel radiators located throughout the property. Domestic hot water is supplied on a direct demand basis via the central heating system.



Gross internal floor area(m²) 86 m^2

Address

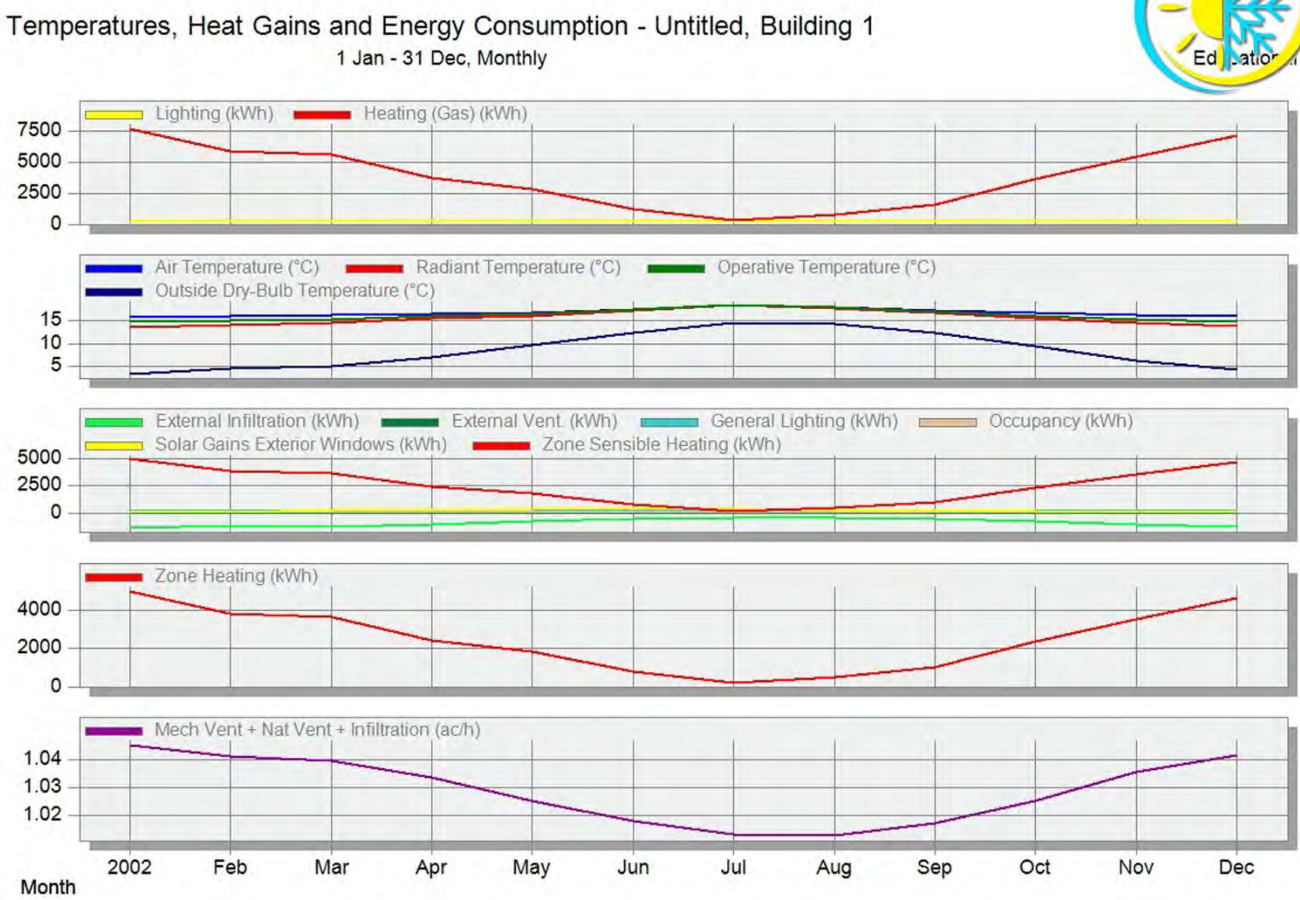
EDINBURGH EH12 7EP

Figure A124. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.39
Operative Temperature (°C)	15.69
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.28
Walls (kW)	-7.29
Ceilings (int) (kW)	-1.67
Floors (int) (kW)	0.26
Ground Floors (kW)	0.37
Partitions (int) (kW)	0.00
Roofs (kW)	-1.23
External Infiltration (kW)	-3.63
External Vent. (kW)	-10.88
Zone Sensible Heating (kW)	25.31

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 31.620 (kW)				
Block 1 Total Design Heating Capacity = 18.280 (kW)				
Bedroom4	14.75	2.19	**2.73**	285.9285
Bedroom3	16.07	1.15	**1.43**	211.1705
Box Room	16.75	0.47	**0.59**	202.7174
Living Room	15.68	2.69	**3.36**	203.6900
Corridor	16.77	1.65	**2.06**	181.4079
Bedroom1	15.83	2.43	**3.04**	208.4320
Service	16.74	0.55	**0.69**	196.8500
Bedroom2	14.70	2.02	**2.53**	275.7715
Kitchen	16.03	1.48	**1.85**	202.5103
Block 3 Total Design Heating Capacity = 13.340 (kW)				
Corridor	16.31	1.45	**1.81**	206.9084
2 Bedroom1	15.45	2.60	**3.24**	222.7002
2 Service 1	16.34	0.54	**0.67**	232.0630
2 Living Room	15.23	2.89	**3.61**	218.7250
2 Bedroom2	15.22	1.37	**1.72**	263.9075
2 Service	16.30	0.63	**0.78**	223.5750
Kitchen	15.07	1.21	**1.51**	272.7818

Figure A125. The heating design simulation and data of the house.



Lighting (kWh)	232.58	209.89	233.99	226.90	233.99	228.32	231.16	232.58	225.49	231.16	225.49	235.41
Heating (Gas) (kWh)	7701.65	5882.19	5573.33	3697.27	2813.25	1229.69	269.99	741.02	1559.32	3643.38	5395.38	7099.97
Air Temperature (°C)	15.78	15.94	16.10	16.51	16.77	17.46	18.38	17.97	17.19	16.60	16.16	15.86
Radiant Temperature (°C)	13.53	14.02	14.49	15.44	15.91	17.15	18.48	17.79	16.65	15.39	14.47	13.75
Operative Temperature (°C)	14.65	14.98	15.30	15.98	16.34	17.30	18.43	17.88	16.92	15.99	15.32	14.80
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1372.13	-1125.26	-1201.66	-1005.01	-773.74	-535.49	-407.76	-395.38	-515.28	-768.14	-1056.24	-1266.62
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.04	-0.21	0.00	0.00	0.00	0.00	0.00
General Lighting (kWh)	232.58	209.89	233.99	226.90	233.99	228.32	231.16	232.58	225.49	231.16	225.49	235.41
Occupancy (kWh)	74.18	66.79	75.80	73.88	75.80	74.86	69.91	72.37	72.23	72.55	72.25	77.43
Solar Gains Exterior Windows (kWh)	67.03	135.00	263.57	335.14	382.19	393.16	397.61	322.13	237.02	139.95	79.59	43.53
Zone Sensible Heating (kWh)	4990.74	3811.01	3610.69	2395.43	1822.85	796.89	174.89	480.19	1010.68	2361.11	3495.71	4601.03
Zone Heating (kWh)	5006.07	3823.42	3622.67	2403.23	1828.61	799.30	175.50	481.66	1013.56	2368.20	3507.00	4614.98
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A126. The simulation detailed results of the house.

Case 43. A House Built in 1936

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional brick construction facing brick.	1.540	Increase 18.5 cm Insulation
	Flat 1.756	Increase 32 cm Insulation
	Pitched 1.636	Increase 33 cm Insulation
Floors are mainly timber suspended with timber concrete sections.	0.907	Increase 32 cm Insulation
Internal Walls are plaster on the hard and plasterboard construction.	1.388	
Windows are of metal casement style single glazed lead lined panes.		

* As a basis for a theory of possibility

Description

Detached two storey dwelling house.

Ground Floor: Entrance Vestibule, Reception Hall, Livingroom, Conservatory, Kitchen/Dining room, Utility Room, Study/Sitting room, Bedroom with En-Suite Bathroom, Cloakroom with WC and WHB, Boiler Room

First Floor: Master Bedroom with En-Suite Bathroom.

Weather Dry.

Heating and hot water

Boiler to hot water radiators. Hot water supplemented by copper foam lagged tanks (x2).

Gross internal floor area(m²) 300 m²

Address

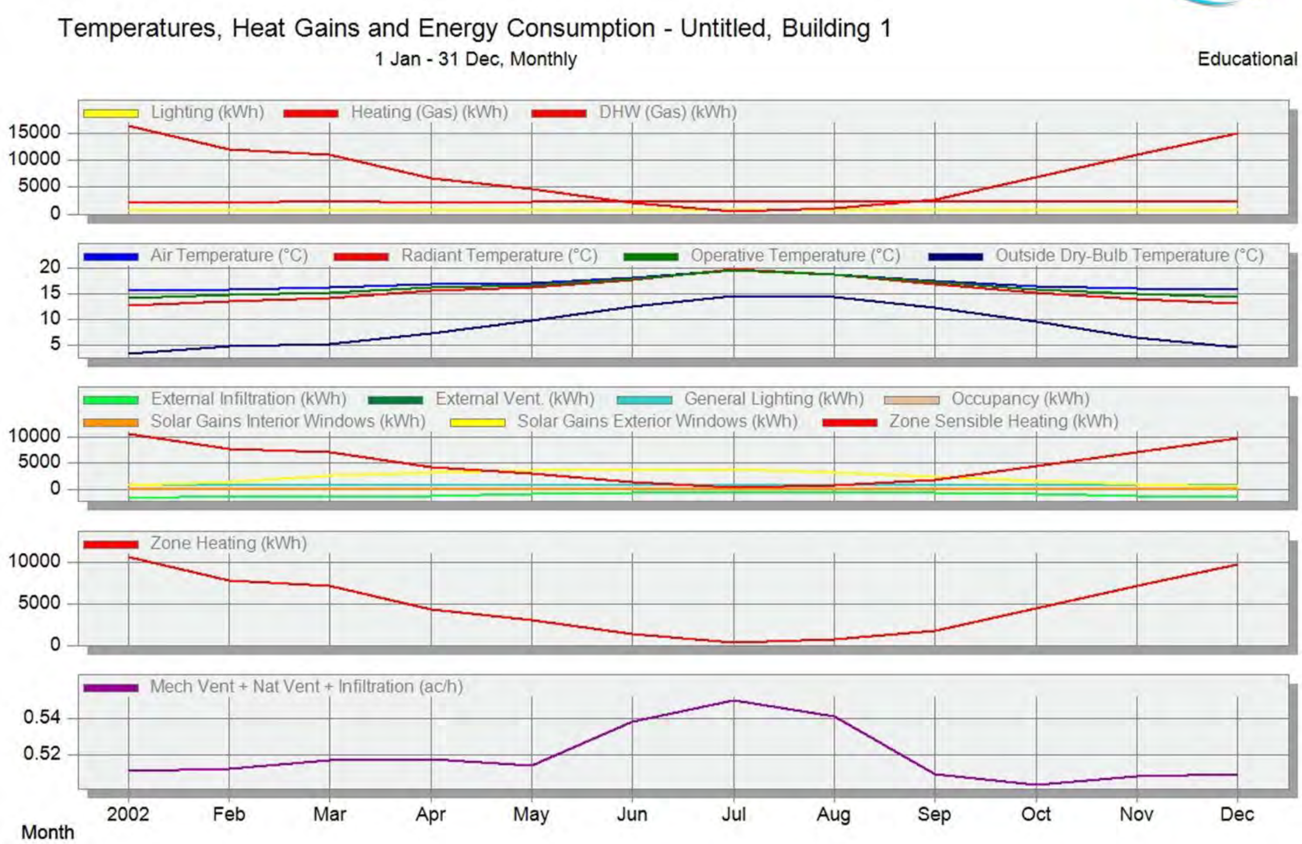
KIRKNEWTON EH27 8EB

Figure A127. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.05
Operative Temperature (°C)	15.02
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-11.39
Walls (kW)	-9.68
Ceilings (int) (kW)	-0.60
Floors (int) (kW)	0.57
Ground Floors (kW)	0.94
Partitions (int) (kW)	0.05
Roofs (kW)	-8.90
Floors (ext) (kW)	-0.07
External Infiltration (kW)	-4.36
External Vent. (kW)	-26.71
Zone Sensible Heating (kW)	60.06

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 75.080 (kW)				
Ground Floor Total Design Heating Capacity = 25.260 (kW)				
Service	15.26	1.45	**1.82**	246.9508
HallWay	16.64	0.28	**0.34**	236.5844
Utility Room	15.95	1.54	**1.93**	189.1619
Kitchen	15.85	4.61	**5.76**	163.8189
Entrance Hall	16.92	1.82	**2.28**	135.0031
Drawing Room	15.82	4.78	**5.97**	160.9677
Bed Room	15.73	2.64	**3.30**	176.0173
Drying Room	16.45	0.75	**0.93**	182.1455
Family Room	16.20	1.15	**1.44**	182.8326
Vestibule	14.91	1.19	**1.49**	305.4027
First Floor Total Design Heating Capacity = 17.920 (kW)				
Double BedRoom	15.73	1.12	**1.40**	126.4750
HallWay	16.38	2.31	**2.88**	115.0316
Double BedRoom	16.18	0.99	**1.24**	113.3692
Service	14.90	0.96	**1.20**	245.7922
Service	16.17	0.84	**1.05**	118.9928
Master BedRoom	15.82	2.83	**3.54**	110.2917
Office	15.42	0.79	**0.98**	162.9225
Double BedRoom	15.64	1.79	**2.24**	120.4549
Bath Room	15.74	1.09	**1.36**	126.0839
Double BedRoom	14.82	1.62	**2.03**	161.2359
Dining Conservatory Total Design Heating Capacity = 8.740 (kW)				
Zone 1	11.63	7.00	**8.74**	341.9576
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-2.48	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 23.160 (kW)				
Zone 1	14.17	18.53	**23.16**	127.8795

Figure A128. The heating design simulation and data of the house.



Lighting (kWh)	757.15	697.33	791.89	737.21	757.15	771.94	757.15	774.52	754.58	757.15	754.58	774.52
Heating (Gas) (kWh)	16230.65	12038.63	11074.67	6631.54	4666.74	2014.99	590.27	1176.27	2619.47	6856.59	10884.59	14973.11
DHW (Gas) (kWh)	2180.22	2066.10	2430.47	2142.18	2180.22	2392.43	2180.22	2305.35	2267.31	2180.22	2267.31	2305.35
Air Temperature (°C)	15.68	15.91	16.27	16.79	17.02	18.10	19.66	18.85	17.50	16.55	16.08	15.76
Radiant Temperature (°C)	12.74	13.45	14.24	15.57	16.14	17.78	19.72	18.68	16.91	15.10	13.91	12.99
Operative Temperature (°C)	14.21	14.68	15.25	16.18	16.58	17.94	19.69	18.77	17.21	15.82	14.99	14.37
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1629.20	-1336.86	-1448.10	-1224.01	-945.19	-713.07	-637.25	-565.96	-637.86	-894.08	-1241.77	-1500.21
External Vent. (kWh)	0.00	-11.63	-41.27	-52.95	-40.88	-95.21	-124.33	-93.27	-30.61	-7.02	-4.82	0.00
General Lighting (kWh)	757.15	697.33	791.89	737.21	757.15	771.94	757.15	774.52	754.58	757.15	754.58	774.52
Occupancy (kWh)	204.06	190.61	219.34	196.61	200.42	202.59	180.78	194.18	203.48	203.73	207.76	212.53
Solar Gains Interior Windows (kWh)	3.78	6.81	13.19	16.91	20.10	19.75	21.28	17.29	12.32	7.43	4.48	2.49
Solar Gains Exterior Windows (kWh)	846.01	1452.80	2640.62	3285.99	3699.80	3605.17	3854.77	3186.99	2359.72	1493.14	990.31	561.84
Zone Sensible Heating (kWh)	10513.63	7797.18	7173.05	4294.18	3019.26	1300.17	378.52	758.53	1693.99	4439.75	7048.56	9698.71
Zone Heating (kWh)	10549.92	7825.11	7198.54	4310.50	3033.38	1309.74	383.67	764.58	1702.65	4456.78	7074.98	9732.52
Mech Vent + Nat Vent + Infiltration (ac/h)	0.51	0.51	0.52	0.52	0.51	0.54	0.55	0.54	0.51	0.50	0.51	0.51

Figure A129. The simulation detailed results of the house.

Case 44. A House Built in 1935

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls 300mm cavity brick construction roughcast externally and mainly plastered on the hard internally.	1.573	Increase 18.5 cm Insulation
	Flat 1.797	Increase 32 cm Insulation
	Pitched 1.652	Increase 32 cm Insulation
Floors are timber suspended construction.	0.983	Increase 30 cm Insulation
Internal Walls are Brickwork plastered on the hard and timber framing.	1.393	
Windows are of a modern replacement type which are u-PVC framed and double glazed.		

* As a basis for a theory of possibility

Description

Detached two storey and attic villa with surrounding garden grounds and integral garage.

Ground floor entrance vestibule, hallway, lounge, sitting room, dining room, study, WC compartment , kitchen/breakfast room, side vestibule , bathroom and boiler room

First floor landing, rear bedroom with en suite bathroom, gable bedroom , centre rear bedroom.

Weather Dry and overcast.

Heating and hot water

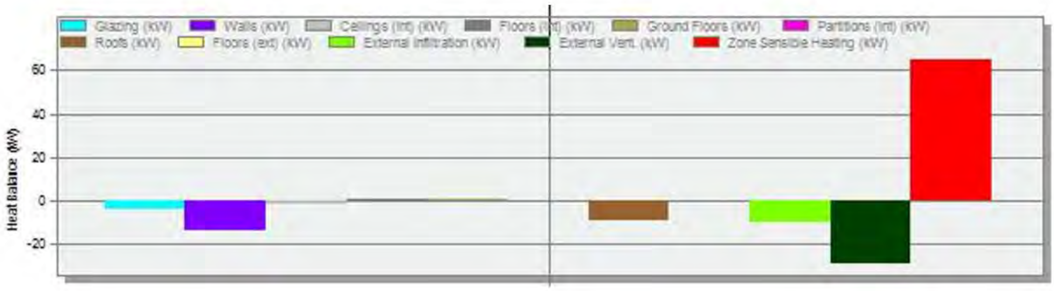
The property has gas fired central heating to radiator outlets. Domestic hot water is provided indirectly by the gas central heating boiler to a modern insulated hot water tank located in the cupboard off the gable vestibule.

Gross internal floor area(m²) 464 m^2

Address

EDINBURGH EH4 6LF

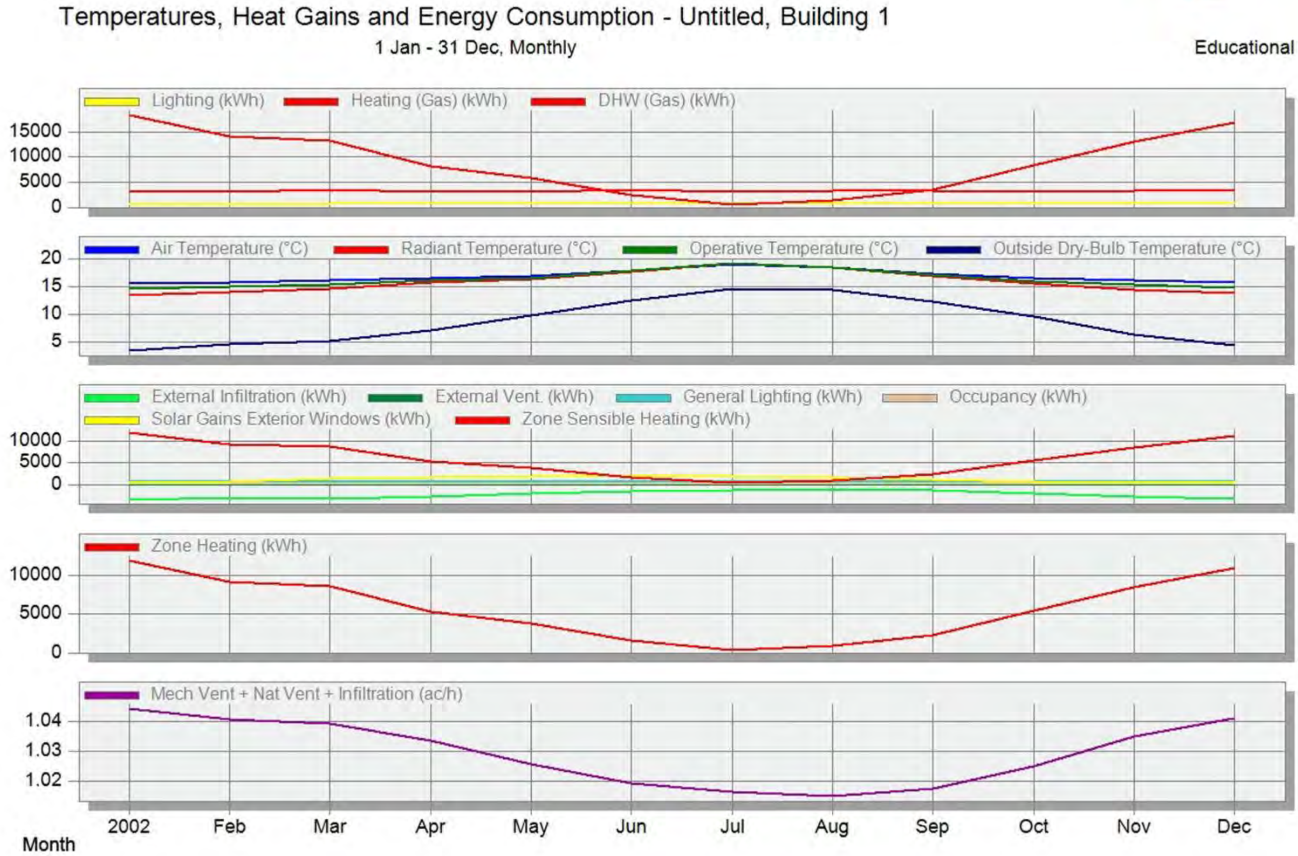
Figure A130. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.53
Operative Temperature (°C)	15.76
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.70
Walls (kW)	-13.65
Ceilings (int) (kW)	-1.49
Floors (int) (kW)	0.95
Ground Floors (kW)	0.73
Partitions (int) (kW)	0.00
Roofs (kW)	-9.23
Floors (ext) (kW)	-0.26
External Infiltration (kW)	-9.70
External Vent. (kW)	-29.10
Zone Sensible Heating (kW)	65.01

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 81.260 (kW)				
Ground Floor Total Design Heating Capacity = 36.730 (kW)				
Hall	15.39	1.05	**1.31**	317.3216
Living Room	16.54	4.29	**5.36**	161.3180
Garage	14.96	3.04	**3.80**	229.5969
Garage	15.91	3.46	**4.32**	183.3876
Study Room	16.13	2.38	**2.97**	183.2846
Sitting Room	16.70	3.50	**4.38**	158.3488
Service	16.28	0.31	**0.39**	251.6573
Hall	16.87	1.90	**2.38**	159.9293
Vestibule	15.97	0.35	**0.44**	263.2016
Dining Room	16.52	2.13	**2.67**	168.2461
Kitchen	16.02	3.29	**4.12**	186.2194
Storage	14.75	1.03	**1.29**	314.9224
Hall	15.76	0.68	**0.84**	254.7322
Service	15.79	0.72	**0.90**	247.0249
Storage	14.61	1.25	**1.56**	305.2953
First Floor Total Design Heating Capacity = 27.340 (kW)				
Lounge	15.91	5.81	**7.26**	161.1136
Study Room	15.29	1.28	**1.60**	229.0912
Hall	16.51	3.14	**3.93**	162.7532
Bed Room	15.29	1.67	**2.09**	224.0770
Bed Room	15.58	1.12	**1.40**	217.0652
Service	17.26	0.70	**0.88**	136.1756
Bed Room	16.44	2.18	**2.72**	158.5787
Bed Room	15.89	2.42	**3.02**	178.7893
Bed Room	15.02	2.33	**2.91**	217.3805
Service	14.99	1.22	**1.53**	257.5073

Figure A131. The heating design simulation and data of the house.



Lighting (kWh)	669.84	622.48	714.95	654.06	669.84	699.16	669.84	692.40	676.61	669.84	676.61	692.40
Heating (Gas) (kWh)	18417.79	14016.53	13322.24	8201.65	5816.43	2429.58	439.82	1444.56	3486.80	8466.31	12990.38	16978.87
DHW (Gas) (kWh)	3140.38	2976.01	3500.85	3085.59	3140.38	3446.06	3140.38	3320.62	3265.83	3140.38	3265.83	3320.62
Air Temperature (°C)	15.52	15.77	16.03	16.44	16.75	17.73	18.90	18.28	17.25	16.48	15.98	15.68
Radiant Temperature (°C)	13.46	14.03	14.58	15.65	16.20	17.67	19.21	18.28	16.87	15.43	14.42	13.74
Operative Temperature (°C)	14.49	14.90	15.30	16.05	16.48	17.70	19.05	18.28	17.06	15.96	15.20	14.71
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3600.46	-2975.74	-3206.09	-2681.49	-2077.15	-1511.54	-1235.38	-1146.98	-1404.62	-2035.50	-2784.49	-3343.24
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.51	-3.36	-1.32	0.00	0.00	0.00	0.00
General Lighting (kWh)	669.84	622.48	714.95	654.06	669.84	699.16	669.84	692.40	676.61	669.84	676.61	692.40
Occupancy (kWh)	161.56	153.10	179.99	158.50	161.35	174.78	152.90	164.52	167.67	161.56	168.01	170.83
Solar Gains Exterior Windows (kWh)	387.19	724.81	1288.22	1711.16	1857.70	1867.52	1930.87	1573.86	1138.84	683.10	463.12	262.63
Zone Sensible Heating (kWh)	11929.66	9078.34	8628.84	5311.86	3767.12	1573.69	284.92	936.19	2259.95	5484.67	8413.18	10998.00
Zone Heating (kWh)	11971.57	9110.75	8659.46	5331.07	3780.68	1579.23	285.88	938.96	2266.42	5503.10	8443.74	11036.26
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.01	1.02	1.03	1.04	1.04

Figure A132. The simulation detailed results of the house.

Case 45. A House Built in 1931

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are traditional brickwork cavity and are rough casted "wet dash" and painted over.	1.589	Increase 18.8 cm Insulation
	Flat 1.991	Increase 32 cm Insulation
	Pitched 1.766	Increase 32 cm Insulation
Floors are timber suspended construction.	1.040	Increase 31 cm Insulation
Internal Walls solid and plastered on the hard.	1.418	
Windows mainly are u-PVC framed and double glazed.		

* As a basis for a theory of possibility

Description

The subjects comprise a Detached Bungalow with accommodation on ground and attic floors

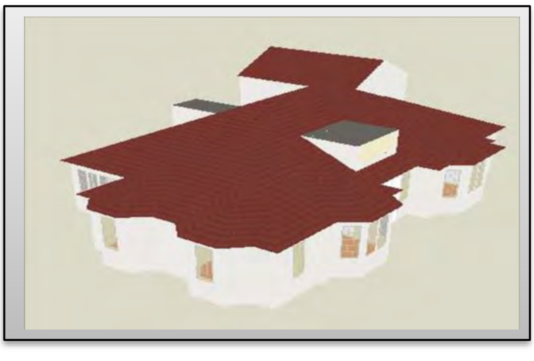
On Ground Floor: Entrance porch, hall, lounge, dining room, kitchen/family room, utility room, two bedrooms, two en-suite bathrooms with w.cs and shower room with WC.

On Attic Floor: Landing and two bedrooms.

Weather Dry and overcast.

Heating and hot water

Gas fired central heating is provided by Worcester Green Star boiler which is located behind panelling in utility room and supplies radiators throughout the property which are fitted with thermostatic valves. There is a 210 litre unvented hot water cylinder.



Gross internal floor area(m²) 218 m^2

Address

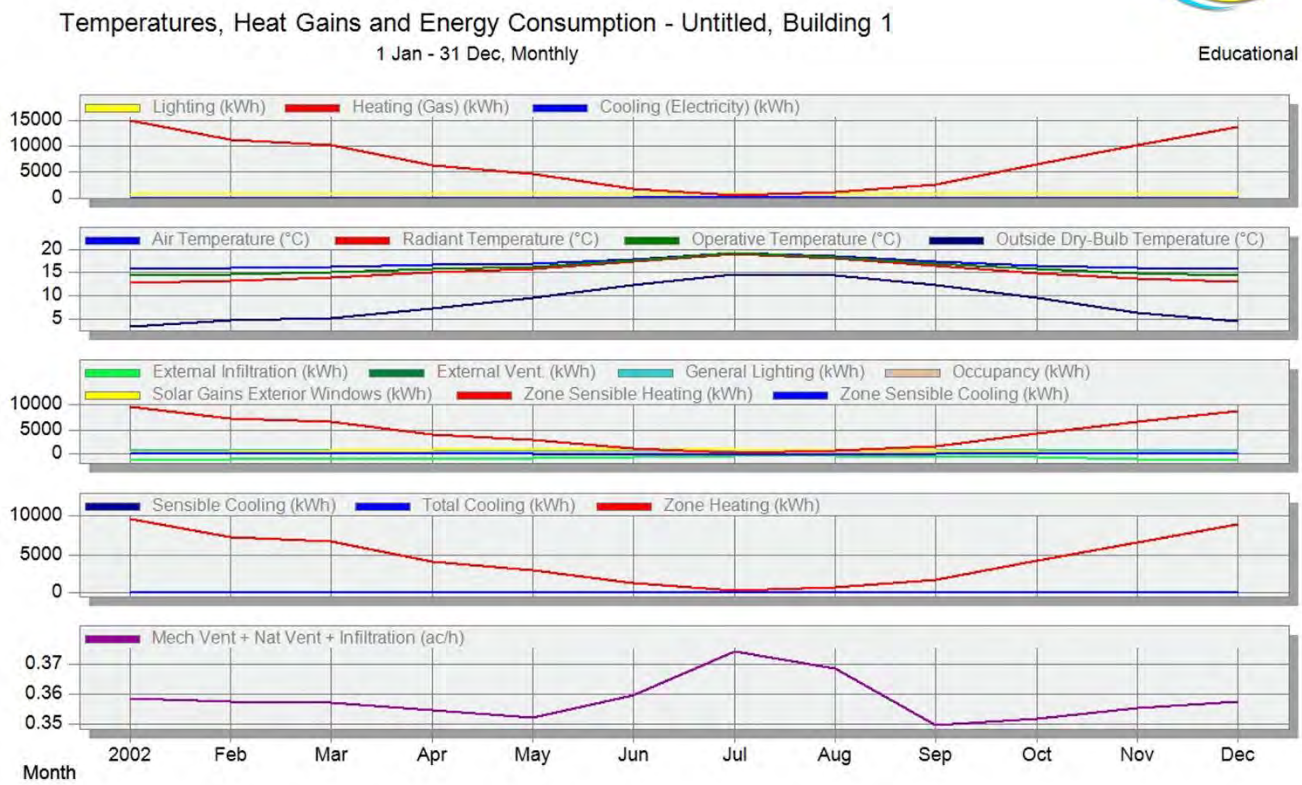
NORTH BERWICK EH39 5DF

Figure A133. The software visualization of the

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.04
Operative Temperature (°C)	15.02
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.36
Walls (kW)	-10.69
Ceilings (int) (kW)	-1.43
Floors (int) (kW)	1.44
Ground Floors (kW)	1.18
Partitions (int) (kW)	0.07
Roofs (kW)	-12.58
Floors (ext) (kW)	-1.23
External Infiltration (kW)	-3.21
External Vent. (kW)	-28.05
Zone Sensible Heating (kW)	57.67

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 72.090 (kW)				
Ground Floor Total Design Heating Capacity = 35.840 (kW)				
Master BedRoom	16.10	3.15	**3.94**	205.2279
Hall	17.28	1.35	**1.69**	146.5882
Bed Room	16.05	3.46	**4.32**	181.2694
Utility Room	16.12	1.06	**1.32**	217.2734
Vestibule	15.68	0.99	**1.23**	274.9888
Bath Room	15.41	1.23	**1.54**	266.8944
Bath Room	15.45	1.80	**2.25**	238.0407
Sitting Room	17.14	2.14	**2.67**	153.8639
Shower Room	17.31	0.41	**0.51**	159.1103
Kitchen	15.94	5.77	**7.22**	181.2563
Dressing Room	15.40	1.98	**2.47**	236.1896
Sun Room	15.43	2.90	**3.62**	244.6870
Dining Room	16.07	2.22	**2.78**	194.3350
Service	17.53	0.13	**0.16**	165.2952
Cloak Room	17.56	0.10	**0.12**	167.9094
Garage Total Design Heating Capacity = 9.860 (kW)				
Zone 1	14.80	7.89	**9.86**	208.6332
Garage Roof Total Design Heating Capacity = 4.580 (kW)				
Zone 1	13.77	3.66	**4.58**	87.4433
Main Roof Total Design Heating Capacity = 20.370 (kW)				
Zone 1	14.43	16.30	**20.37**	98.2316
Window Roof Total Design Heating Capacity = 0.920 (kW)				
Zone 1	13.91	0.74	**0.92**	1.#INF
Window Roof Total Design Heating Capacity = 0.520 (kW)				
Zone 1	13.77	0.41	**0.52**	1.#INF

Figure A134. The heating design simulation and data of the house.



Lighting (kWh)	767.94	697.27	777.36	744.39	767.94	753.81	767.94	772.65	749.10	767.94	749.10	772.65
Heating (Gas) (kWh)	15054.24	11316.51	10385.61	6403.80	4594.35	1864.90	471.21	1120.28	2540.75	6594.04	10256.67	13869.58
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.50	3.48	0.24	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.78	15.91	16.11	16.54	16.86	17.88	19.19	18.48	17.26	16.47	16.06	15.83
Radiant Temperature (°C)	12.73	13.28	13.90	15.07	15.74	17.34	19.01	18.08	16.47	14.87	13.76	12.97
Operative Temperature (°C)	14.26	14.60	15.00	15.80	16.30	17.61	19.10	18.28	16.87	15.67	14.91	14.40
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1222.34	-1001.18	-1071.52	-897.70	-694.42	-501.72	-419.08	-387.98	-462.72	-676.18	-935.20	-1127.00
External Vent. (kWh)	0.00	0.00	-0.31	-0.46	-0.16	-2.83	-24.03	-15.51	-0.25	0.00	0.00	0.00
General Lighting (kWh)	767.94	697.27	777.36	744.39	767.94	753.81	767.94	772.65	749.10	767.94	749.10	772.65
Occupancy (kWh)	250.12	230.26	260.95	242.17	247.93	242.21	227.03	239.12	246.25	250.10	249.08	255.73
Solar Gains Exterior Windows (kWh)	253.58	439.21	772.82	929.15	965.59	941.01	978.49	841.97	658.73	432.49	293.24	168.93
Zone Sensible Heating (kWh)	9700.17	7286.25	6681.96	4113.50	2949.19	1194.78	298.87	715.92	1628.03	4240.86	6601.45	8934.47
Zone Sensible Cooling (kWh)	0.00	0.00	-1.89	-4.41	-4.87	-22.84	-37.13	-21.23	-3.97	-0.25	-0.12	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-1.23	-7.53	-0.51	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-1.24	-8.69	-0.59	0.00	0.00	0.00	0.00
Zone Heating (kWh)	9785.26	7355.73	6750.64	4162.47	2986.32	1212.19	306.29	728.18	1651.49	4286.13	6666.84	9015.23
Mech Vent + Nat Vent + Infiltration (ac/h)	0.36	0.36	0.36	0.35	0.35	0.36	0.37	0.37	0.35	0.35	0.36	0.36

Figure A135. The simulation detailed results of the house.

Case 46. A House Built in 1930

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls, the main walls of the original part of the property are of cavity masonry, with a textured render external finish.	1.595	Increase 18.7 cm Insulation
	Flat -	-
	Pitched 1.969	Increase 32 cm Insulation
Floors are timber suspended construction.	0.994	Increase 30 cm Insulation
Internal Walls are plastered finish.	1.398	
Windows are timber framed and double glazed.		

* As a basis for a theory of possibility

Description

The subjects form a semi-detached bungalow over two storeys.

The accommodation within comprises:

GROUND FLOOR: Hall, living / dining room, kitchen / dining room, two bedrooms, bathroom (with WC) and utility room.

FIRST FLOOR: Upper hall, two bedrooms and shower room.

Weather Dry and sunny.

Heating and hot water

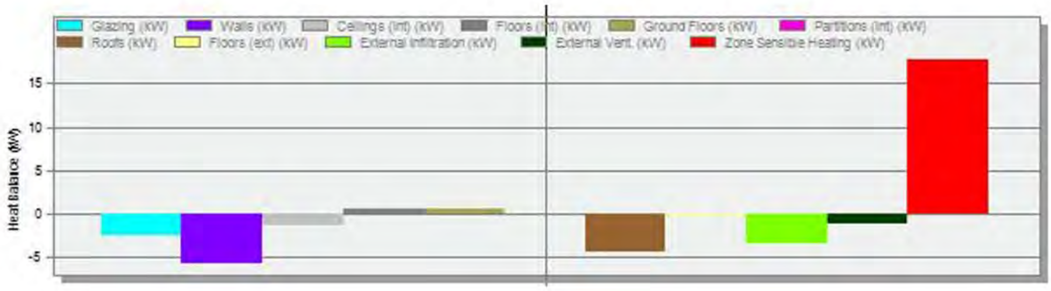
The property has full oil fired central heating. A Grant boiler, located within the utility room, serves panel radiators throughout the property and, in conjunction with an immersion system, provides hot water. An unvented hot water cylinder is located within the under stair cupboard.

Gross internal floor area(m²) 155 m^2

Address

EAST LOTHIAN EH39 5AR

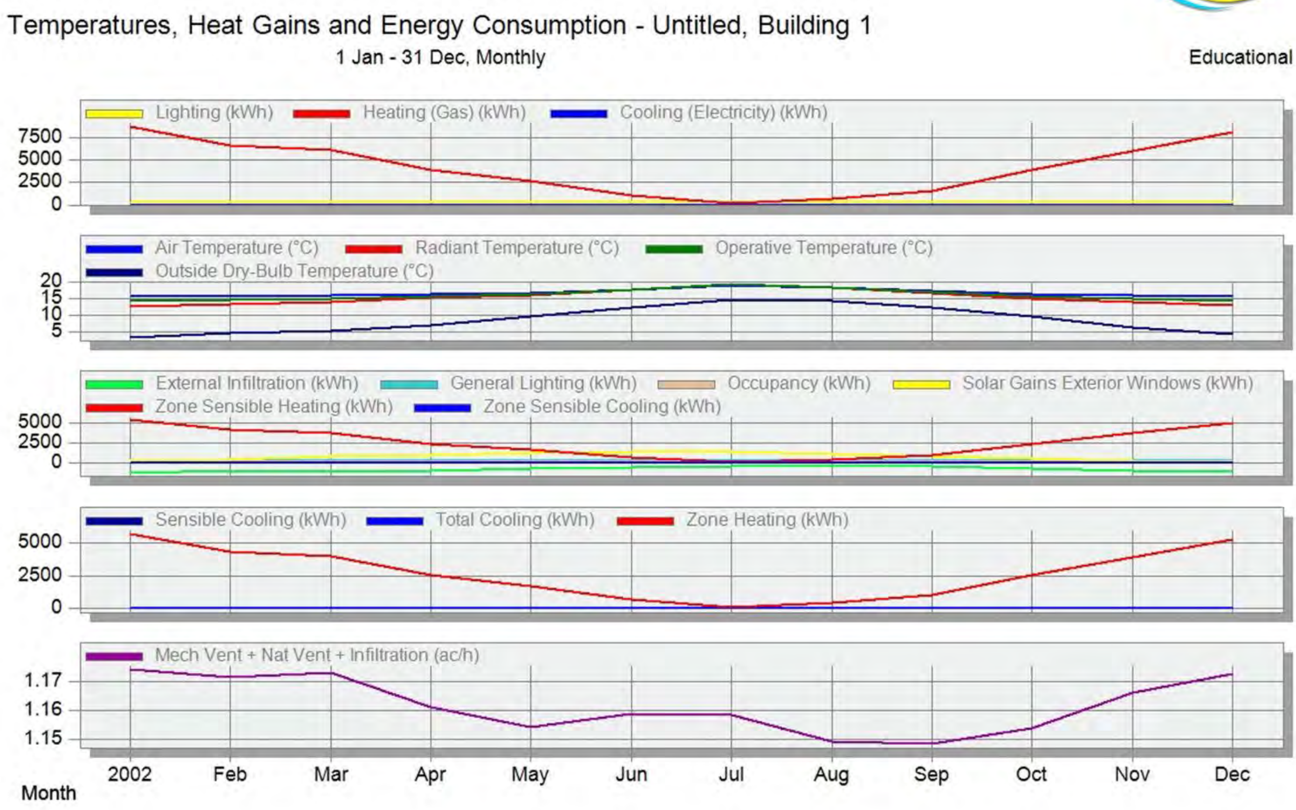
Figure A136. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.07
Operative Temperature (°C)	15.03
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.42
Walls (kW)	-5.82
Ceilings (int) (kW)	-1.44
Floors (int) (kW)	0.60
Ground Floors (kW)	0.50
Partitions (int) (kW)	0.03
Roofs (kW)	-4.36
Floors (ext) (kW)	-0.17
External Infiltration (kW)	-3.52
External Vent. (kW)	-1.25
Zone Sensible Heating (kW)	17.81

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 22.280 (kW)				
Ground Floor Total Design Heating Capacity = 12.600 (kW)				
Service	16.41	0.62	**0.78**	133.1965
Double BedRoom	15.81	1.11	**1.39**	115.4352
Hall	16.84	0.54	**0.67**	100.6515
Landing	17.26	0.17	**0.22**	87.8537
Dining Room	16.31	0.83	**1.04**	95.8508
Master BedRoom	15.68	1.34	**1.68**	120.8029
Living Room	15.63	1.49	**1.87**	114.8042
Kitchen	14.79	3.42	**4.27**	142.3269
Utility Room	15.02	0.54	**0.68**	204.4210
First Floor Roof Total Design Heating Capacity = 9.680 (kW)				
Bed Room	13.82	2.80	**3.51**	146.6147
Landing	14.99	0.95	**1.18**	140.7587
Bed Room	13.92	3.11	**3.89**	135.9205
Service	15.20	0.88	**1.10**	132.6355
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-7.25	0.00	**0.00**	0.0000
Roof 3 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.73	0.00	**0.00**	0.0000

Figure A137. The heating design simulation and data of the house.



Lighting (kWh)	277.90	252.33	281.31	269.37	277.90	272.78	277.90	279.60	271.08	277.90	271.08	279.60
Heating (Gas) (kWh)	8795.29	6654.03	6171.20	3886.78	2674.98	1060.81	185.56	633.82	1593.30	3927.28	6060.05	8141.87
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	1.52	0.00	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.69	15.81	15.99	16.40	16.79	17.76	19.02	18.33	17.18	16.44	16.00	15.75
Radiant Temperature (°C)	12.76	13.36	14.00	15.20	16.01	17.65	19.34	18.30	16.63	14.98	13.84	12.99
Operative Temperature (°C)	14.23	14.59	14.99	15.80	16.40	17.70	19.18	18.32	16.90	15.71	14.92	14.37
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1326.94	-1085.55	-1159.37	-968.56	-754.78	-540.80	-444.12	-412.24	-499.57	-735.21	-1015.05	-1222.77
General Lighting (kWh)	277.90	252.33	281.31	269.37	277.90	272.78	277.90	279.60	271.08	277.90	271.08	279.60
Occupancy (kWh)	87.22	80.29	91.12	84.87	87.01	86.44	81.15	85.10	86.61	87.22	86.86	89.17
Solar Gains Exterior Windows (kWh)	232.97	412.63	765.47	1007.03	1289.32	1359.15	1365.14	1078.22	744.52	464.41	275.62	159.27
Zone Sensible Heating (kWh)	5508.94	4149.69	3828.81	2386.69	1634.76	639.70	110.48	381.10	965.73	2435.74	3773.98	5092.56
Zone Sensible Cooling (kWh)	0.00	0.00	-0.44	-1.51	-4.43	-24.57	-53.64	-25.50	-3.59	-0.01	-0.04	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-2.96	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-3.81	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	5716.94	4325.12	4011.28	2526.41	1738.74	689.53	120.62	411.98	1035.64	2552.73	3939.03	5292.22
Mech Vent + Nat Vent + Infiltration (ac/h)	1.17	1.17	1.17	1.16	1.15	1.16	1.16	1.15	1.15	1.15	1.17	1.17

Figure A138. The simulation detailed results of the house.

Case 47. A House Built in 1930

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are traditional brickwork cavity rough casted and painted over.	1.608	Increase 19 cm Insulation
	Flat -	-
	Pitched 2.061	Increase 32 cm Insulation
Floors are timber suspended construction.	1.002	Increase 30 cm Insulation
Internal Walls are solid and plastered on the hard.	1.395	
Windows are replacement u-PVC framed double glazed windows.		

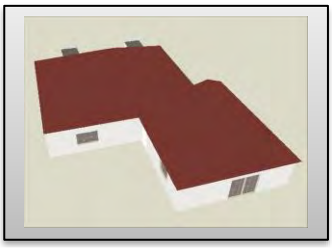
* As a basis for a theory of possibility

Description

The subjects comprise an extended semi-detached chalet bungalow.

On ground floor: entrance hall, lounge, kitchen/breakfast room, living room, two bedrooms and bathroom with WC.

On attic floor: landing and two bedrooms.



Weather Overcast and raining.

Heating and hot water

Gas fired central heating is provided by wall mounted Saunier Duval boiler which is located in kitchen cupboard and supplies radiators throughout the property which are fitted with thermostatic valves. The boiler is combination type and also provides instantaneous domestic hot water.

Gross internal floor area(m²) 142 m^2

Address

LONGNIDDRY EH32 0LP

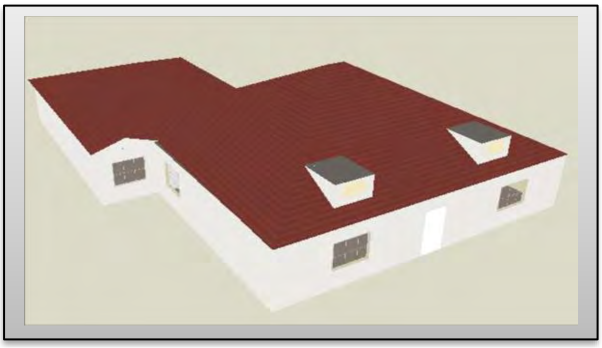
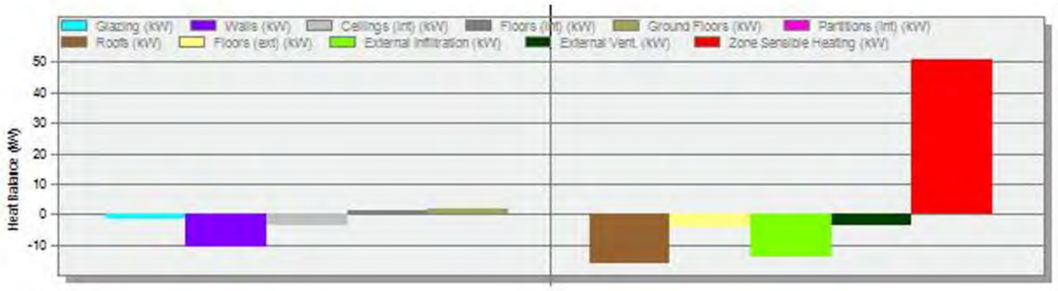


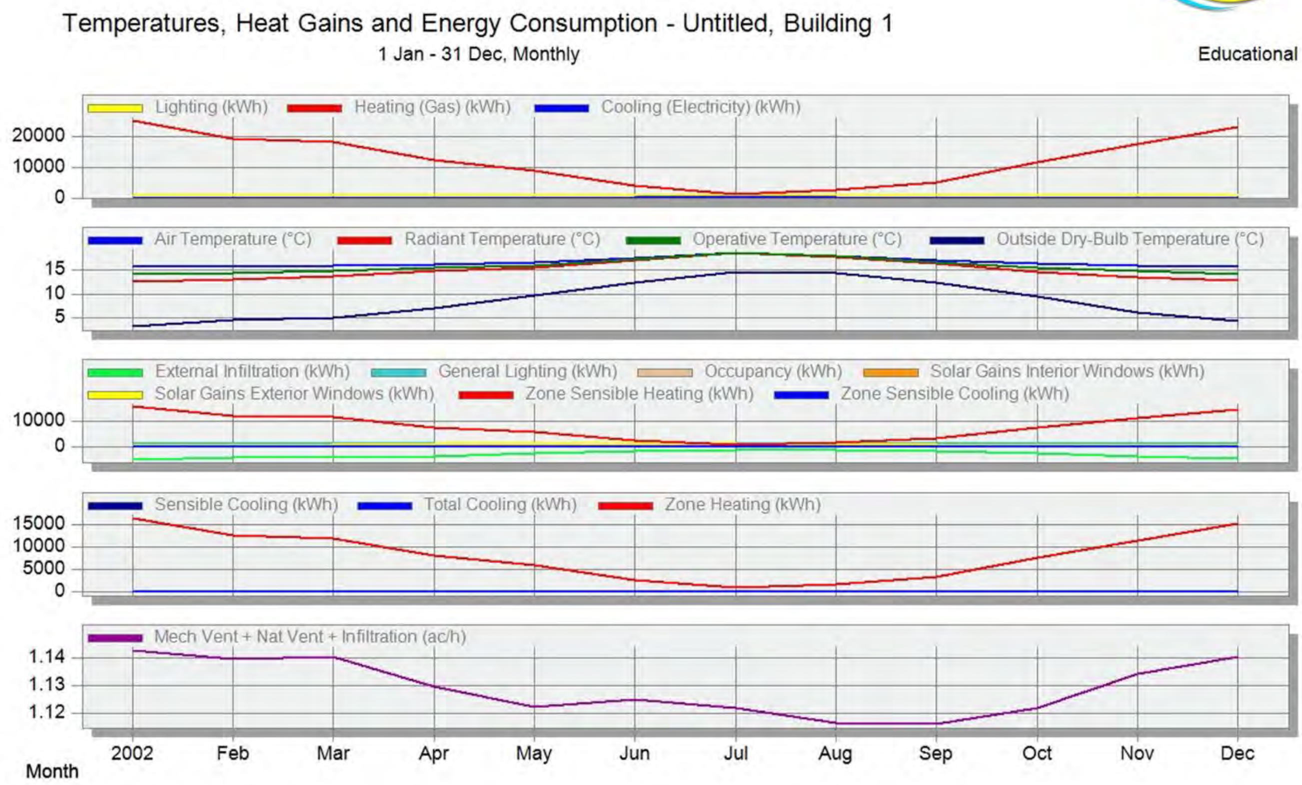
Figure A139. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.83
Operative Temperature (°C)	14.91
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.43
Walls (kW)	-10.60
Ceilings (int) (kW)	-3.77
Floors (int) (kW)	1.40
Ground Floors (kW)	1.69
Partitions (int) (kW)	0.00
Roofs (kW)	-16.37
Floors (ext) (kW)	-4.28
External Infiltration (kW)	-13.92
External Vent. (kW)	-3.73
Zone Sensible Heating (kW)	50.98

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 63.730 (kW)				
Ground Floor Total Design Heating Capacity = 37.880 (kW)				
Bed Room	15.57	4.02	**5.02**	103.9546
Hall	16.02	4.13	**5.16**	110.3376
Kitchen	14.92	3.92	**4.90**	136.4588
Service	16.33	2.29	**2.86**	85.7417
Dining Room	16.34	1.39	**1.73**	93.5583
Sitting Room	15.80	4.17	**5.21**	93.8147
Bed Room	15.74	3.34	**4.18**	99.8473
Lounge	14.89	7.05	**8.82**	115.3912
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.92	0.00	**0.00**	0.0000
First Floor Roof Total Design Heating Capacity = 25.050 (kW)				
Bed Room	14.82	4.23	**5.29**	83.0229
Hall Corridor	12.88	11.69	**14.61**	129.1069
Bed Room	14.84	4.12	**5.15**	82.1303

Figure A140. The heating design simulation and data of the house.



Lighting (kWh)	971.70	882.28	983.62	941.89	971.70	953.81	971.70	977.66	947.85	971.70	947.85	977.66
Heating (Gas) (kWh)	25201.45	19311.21	18392.97	12235.54	8942.43	4163.14	1370.43	2707.15	5206.31	11637.49	17693.59	23248.80
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.22	7.51	0.08	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.60	15.70	15.85	16.20	16.51	17.42	18.46	17.93	16.97	16.27	15.86	15.66
Radiant Temperature (°C)	12.51	13.05	13.64	14.78	15.43	17.04	18.57	17.66	16.26	14.65	13.54	12.76
Operative Temperature (°C)	14.05	14.38	14.74	15.49	15.97	17.23	18.52	17.80	16.61	15.46	14.70	14.21
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-5199.69	-4238.60	-4514.12	-3742.86	-2875.91	-2029.22	-1565.63	-1488.50	-1900.56	-2835.15	-3949.92	-4788.20
General Lighting (kWh)	971.70	882.28	983.62	941.89	971.70	953.81	971.70	977.66	947.85	971.70	947.85	977.66
Occupancy (kWh)	304.97	280.75	318.62	296.63	304.52	303.03	288.37	299.67	302.65	304.97	303.73	311.80
Solar Gains Interior Windows (kWh)	0.28	0.53	0.97	1.22	1.30	1.28	1.30	1.12	0.84	0.54	0.33	0.19
Solar Gains Exterior Windows (kWh)	243.79	418.22	736.22	876.21	909.71	878.72	918.29	792.59	625.88	412.59	282.15	163.28
Zone Sensible Heating (kWh)	15740.53	12010.71	11391.87	7519.41	5485.66	2535.89	829.47	1648.11	3169.29	7201.14	10989.62	14497.26
Zone Sensible Cooling (kWh)	0.00	0.00	-1.64	-5.97	-10.13	-61.01	-126.56	-59.96	-12.96	-0.10	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.53	-15.23	-0.19	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.55	-18.77	-0.21	0.00	0.00	0.00	0.00
Zone Heating (kWh)	16380.94	12552.29	11955.43	7953.10	5812.58	2706.04	890.78	1759.65	3384.10	7564.37	11500.83	15111.72
Mech Vent + Nat Vent + Infiltration (ac/h)	1.14	1.14	1.14	1.13	1.12	1.13	1.12	1.12	1.12	1.12	1.13	1.14

Figure A141. The simulation detailed results of the house.

Case 48. A House Built in 1925

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional cavity brickwork having been rendered externally.	1.632	Increase 18.8 cm Insulation
	Flat 1.982	Increase 32 cm Insulation
	Pitched 2.176	Increase 32 cm Insulation
Floors are timber suspended construction.	1.032	Increase 30 cm Insulation
Internal Walls have plaster finishes.	1.412	
Windows are of timber sash and casement single glazed type.		

* As a basis for a theory of possibility

Description

The subject property comprises a detached bungalow.

Ground Floor: Entrance porch, internal hallway, living room, three bedrooms, kitchen, sun room and bathroom with WC.

First Floor: Two bedrooms with bathroom and WC

Weather Dry and sunny.

Heating and hot water

The property benefits from a gas fired central heating system with the gas boiler located within the hall cupboard at ground floor level.

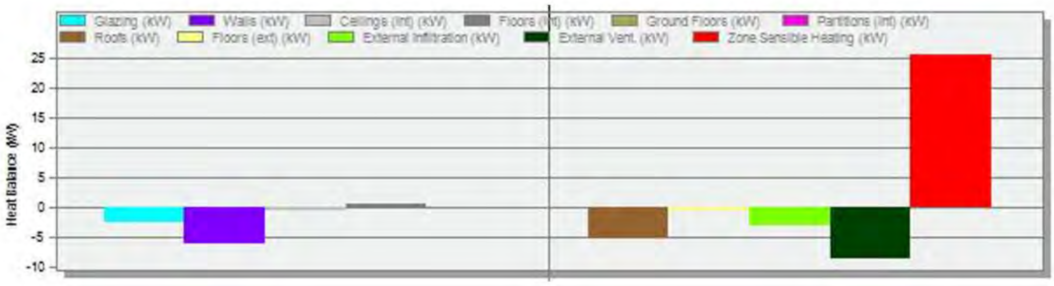
Hot water is provided by hot water cylinder located within the bedroom cupboard at first floor level.

Gross internal floor area(m²) 148 m^2

Address

Edinburgh, EH13 0NQ

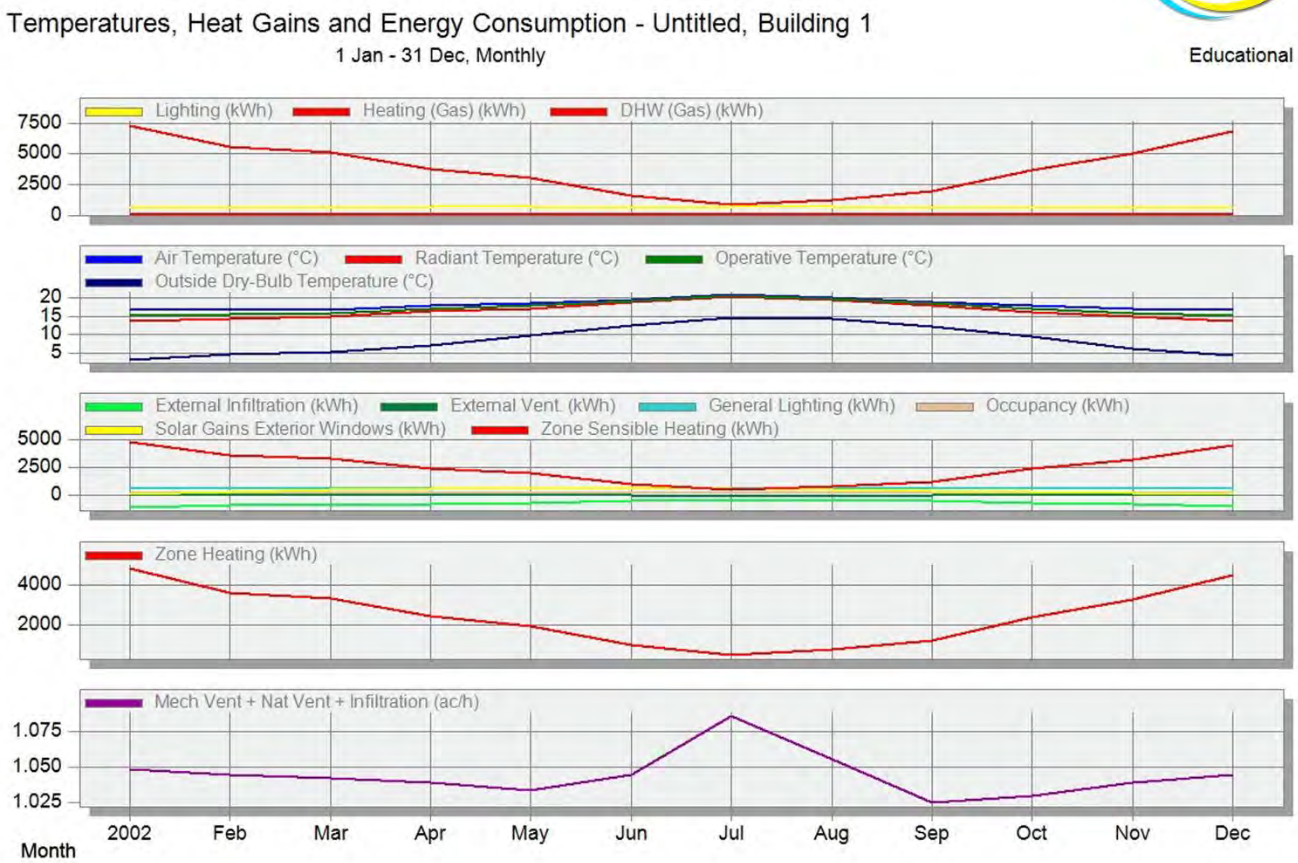
Figure A142. The software visualization of the



Air Temperature (°C)	21.74
Radiant Temperature (°C)	14.69
Operative Temperature (°C)	18.22
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.55
Walls (kW)	-6.04
Ceilings (int) (kW)	-0.57
Floors (int) (kW)	0.57
Ground Floors (kW)	0.06
Partitions (int) (kW)	0.00
Roofs (kW)	-5.14
Floors (ext) (kW)	-0.60
External Infiltration (kW)	-2.87
External Vent. (kW)	-8.61
Zone Sensible Heating (kW)	25.56

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 31.960 (kW)				
First Floor Roof Total Design Heating Capacity = 9.490 (kW)				
Bed Room	17.09	3.19	**3.99**	157.1790
Landing Hall	18.46	1.50	**1.88**	135.1060
Bed Room	17.51	2.20	**2.75**	157.6948
Service	15.31	0.70	**0.87**	103.6862
Ground Floor Total Design Heating Capacity = 21.850 (kW)				
Kitchen	20.65	0.55	**0.69**	252.9424
Bed Room	18.52	1.65	**2.07**	386.2258
BathRoom	19.55	0.66	**0.82**	360.8739
Dining Room	18.65	2.85	**3.56**	320.7226
Store	17.02	0.97	**1.22**	1027.2385
HallWay	20.14	3.19	**3.98**	247.7181
Vestibule	16.85	0.64	**0.81**	1282.6467
Bed Room	19.09	2.08	**2.60**	307.2007
Lounge	19.20	2.83	**3.54**	285.4369
Garage	17.85	2.05	**2.56**	446.4860

Figure A143. The heating design simulation and data of the house.



Lighting (kWh)	690.73	601.16	632.03	660.87	690.73	602.17	690.73	661.38	631.52	690.73	631.52	661.38
Heating (Gas) (kWh)	7344.17	5562.74	5084.99	3751.63	3068.86	1591.26	892.26	1245.70	1930.75	3688.22	5018.41	6872.98
DHW (Gas) (kWh)	62.36	54.22	56.93	59.64	62.36	54.22	62.36	59.64	56.93	62.36	56.93	59.64
Air Temperature (°C)	16.66	16.72	16.81	17.76	18.42	19.32	20.73	20.08	18.82	17.78	16.93	16.59
Radiant Temperature (°C)	13.67	14.19	14.77	16.21	17.11	18.61	20.27	19.43	17.86	16.10	14.79	13.76
Operative Temperature (°C)	15.17	15.45	15.79	16.99	17.76	18.97	20.50	19.76	18.34	16.94	15.86	15.17
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1012.49	-831.22	-884.64	-788.74	-660.91	-494.09	-435.93	-420.63	-478.21	-627.21	-791.44	-927.97
External Vent. (kWh)	0.00	0.00	0.00	-0.46	-1.54	-10.07	-31.53	-12.76	-0.88	0.00	0.00	0.00
General Lighting (kWh)	690.73	601.16	632.03	660.87	690.73	602.17	690.73	661.38	631.52	690.73	631.52	661.38
Occupancy (kWh)	221.36	192.71	202.68	211.45	220.43	188.25	208.80	204.68	201.08	221.32	202.47	212.02
Solar Gains Exterior Windows (kWh)	185.24	312.89	535.69	637.78	656.73	637.87	659.63	571.20	451.10	305.55	213.36	124.21
Zone Sensible Heating (kWh)	4760.28	3604.84	3294.23	2428.99	1986.34	1029.86	577.18	806.12	1249.58	2388.63	3251.63	4455.12
Zone Heating (kWh)	4773.71	3615.78	3305.25	2438.56	1994.76	1034.32	579.97	809.71	1254.98	2397.35	3261.97	4467.43
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.04	1.03	1.04	1.09	1.06	1.03	1.03	1.04	1.04

Figure A144. The simulation detailed results of the house.

Case 49. A House Built in 1923

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of a lighter weight construction.	1.632	Increase 18.8 cm Insulation
	Flat 1.982	Increase 32 cm Insulation
	Pitched 2.176	Increase 32 cm Insulation
Floors are timber suspended construction.	1.032	Increase 30 cm Insulation
Internal Walls are of plaster on brick.	1.412	
Windows are of PVC framed double glazed.		

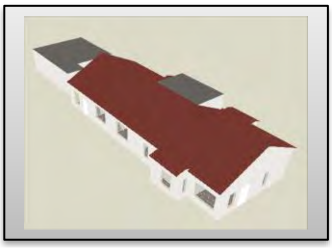
* As a basis for a theory of possibility

Description

The subject form a superior detached bungalow with garage and further outbuildings all set in good sized garden grounds.

Ground Floor: Entrance porch, hall, living room, family room, kitchen, sun room and bathroom with WC.

First Floor: three bedrooms with bathroom.



Weather Dull and raining.

Heating and hot water

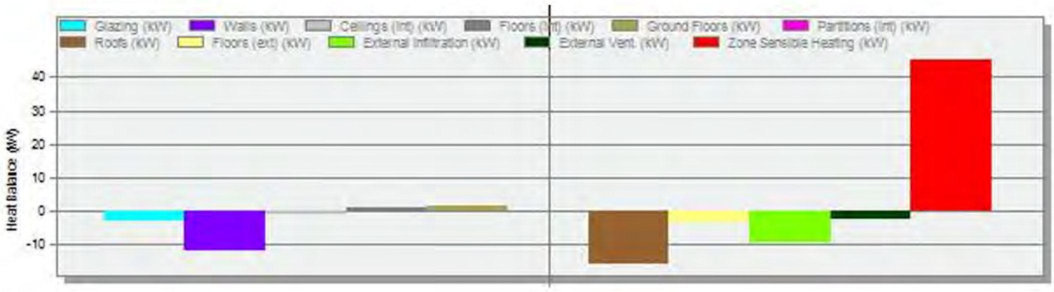
The subject benefits from a full gas fired central heating system sourced from the boiler located within the side extension. This boiler feeds panel radiators in each of the rooms.

Gross internal floor area(m²) 205 m^2

Address

EDINBURGH, EH4 8DZ

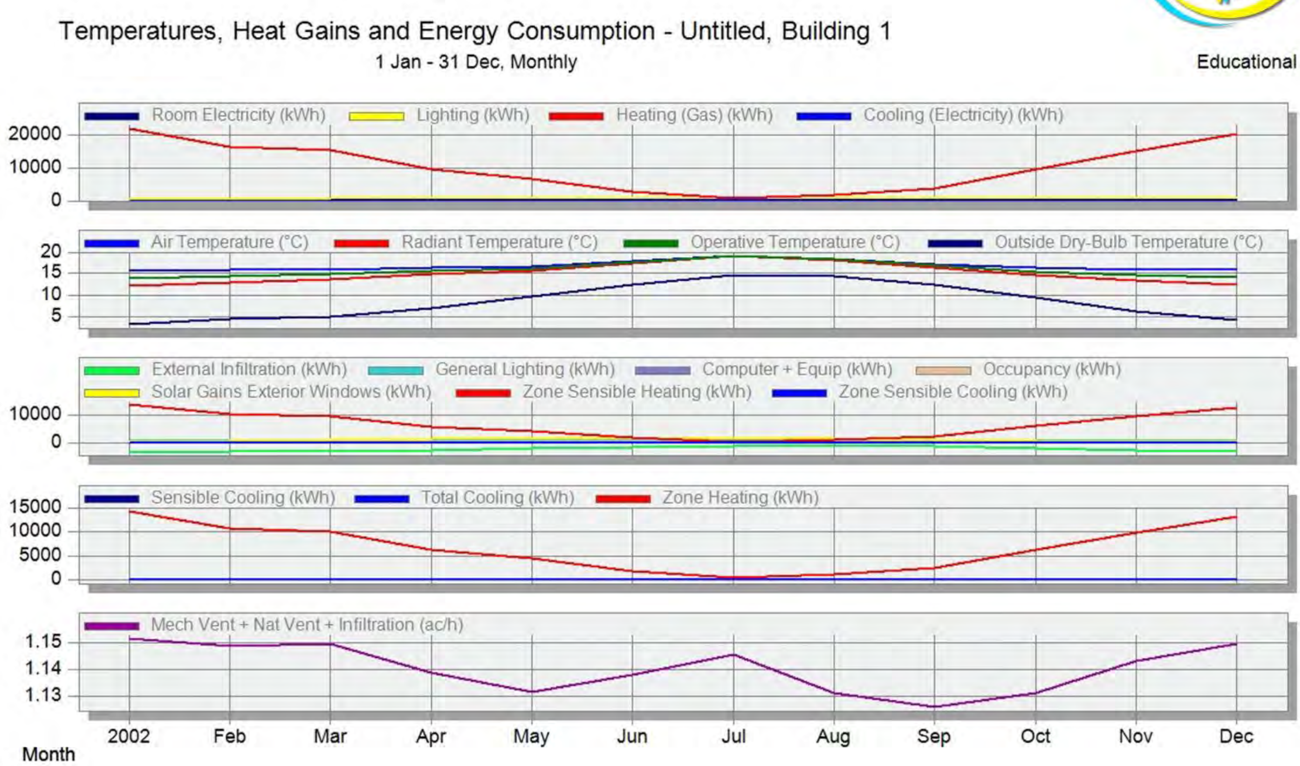
Figure A145. The software visualization of the



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.21
Operative Temperature (°C)	14.61
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.05
Walls (kW)	-11.81
Ceilings (int) (kW)	-1.16
Floors (int) (kW)	0.92
Ground Floors (kW)	1.45
Partitions (int) (kW)	0.00
Roofs (kW)	-16.16
Floors (ext) (kW)	-3.49
External Infiltration (kW)	-9.44
External Vent. (kW)	-2.76
Zone Sensible Heating (kW)	45.36

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 56.690 (kW)				
Ground Floor Total Design Heating Capacity = 24.270 (kW)				
Garage	15.01	3.50	**4.37**	132.7928
Bed Room	16.26	1.33	**1.66**	94.7504
Bed Room	16.23	1.04	**1.30**	101.8156
Landing	16.37	0.68	**0.84**	106.7932
Service	15.95	0.74	**0.92**	137.5563
Kitchen	16.04	1.18	**1.48**	111.8545
Dining Room	14.91	2.79	**3.49**	150.9166
Sitting Room	14.99	2.85	**3.56**	140.1109
Hall	17.06	1.04	**1.30**	72.0866
Living Room	14.94	2.77	**3.47**	142.2681
Vestibule	15.55	0.67	**0.83**	184.4588
Store	14.27	0.84	**1.05**	387.3198
Main Roof Total Design Heating Capacity = 20.520 (kW)				
Roof	13.94	2.78	**3.48**	113.3479
Storage	13.90	1.79	**2.24**	125.1992
Bed Room	14.73	2.03	**2.54**	96.3305
Bed Room	13.35	2.23	**2.79**	131.5301
Bed Room	13.92	2.95	**3.68**	101.8350
Service	13.39	2.72	**3.40**	133.7491
Landing	14.16	1.91	**2.39**	113.4151

Figure A146. The heating design simulation and data of the house.



Room Electricity (kWh)	474.77	428.82	474.77	459.45	474.77	459.45	474.77	474.77	459.45	474.77	459.45	474.77
Lighting (kWh)	692.88	629.12	701.38	671.63	692.88	680.13	692.88	697.13	675.88	692.88	675.88	697.13
Heating (Gas) (kWh)	21966.28	16504.60	15312.26	9550.10	6765.69	2887.77	789.11	1840.92	3873.13	9610.98	15069.77	20277.23
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.05	6.07	0.06	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.63	15.73	15.90	16.27	16.59	17.70	18.99	18.29	17.11	16.28	15.87	15.68
Radiant Temperature (°C)	12.21	12.84	13.51	14.79	15.48	17.28	19.01	17.96	16.34	14.54	13.34	12.47
Operative Temperature (°C)	13.92	14.29	14.70	15.53	16.03	17.49	19.00	18.13	16.72	15.41	14.60	14.07
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3537.70	-2884.98	-3080.22	-2562.61	-1977.20	-1459.56	-1218.30	-1113.78	-1326.40	-1927.05	-2683.39	-3254.24
General Lighting (kWh)	692.88	629.12	701.38	671.63	692.88	680.13	692.88	697.13	675.88	692.88	675.88	697.13
Computer + Equip (kWh)	474.77	428.82	474.77	459.45	474.77	459.45	474.77	474.77	459.45	474.77	459.45	474.77
Occupancy (kWh)	217.46	200.19	227.05	211.28	216.86	213.57	200.13	210.08	215.05	217.45	216.55	222.34
Solar Gains Exterior Windows (kWh)	384.01	675.85	1186.47	1472.98	1554.13	1542.69	1551.20	1324.10	1010.26	664.95	445.52	258.65
Zone Sensible Heating (kWh)	13818.86	10339.18	9550.77	5900.10	4169.56	1770.32	483.19	1127.83	2369.49	5984.57	9427.31	12738.34
Zone Sensible Cooling (kWh)	0.00	-0.26	-4.71	-10.18	-15.63	-70.31	-133.29	-70.04	-19.20	-0.45	-0.67	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.11	-12.50	-0.11	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.12	-15.17	-0.15	0.00	0.00	0.00	0.00
Zone Heating (kWh)	14278.08	10727.99	9952.97	6207.57	4397.70	1877.05	512.92	1196.60	2517.54	6247.14	9795.35	13180.20
Mech Vent + Nat Vent + Infiltration (ac/h)	1.15	1.15	1.15	1.14	1.13	1.14	1.15	1.13	1.13	1.13	1.14	1.15

Figure A147. The simulation detailed results of the house.

Case 50. A House Built in 1920

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional masonry construction with some stone work to the front elevation.	1.644	Increase 18.8 cm Insulation
	Flat 2.082	Increase 32.3 cm Insulation
	Pitched 2.184	Increase 33 cm Insulation
Floors are timber suspended construction.	1.054	Increase 30 cm Insulation
Internal Walls are plastered and decorated.	1.403	
Windows are replacement u-PVC double glazed windows.		

* As a basis for a theory of possibility

Description

Detached villa. Ground Floor: Entrance vestibule, hallway, living room, dining room, kitchen/dining room, bedroom and WC apartment.

First Floor: Landing, master bedroom with en-suite shower room, four further bedrooms and bathroom.

Weather Dry and bright.

Heating and hot water

Gas fired boiler located in kitchen cupboard serving panel radiators throughout property via thermal store which supplies hot water.

Gross internal floor area(m²) 238 m²

Address

BONNYRIGG EH19 2HZ

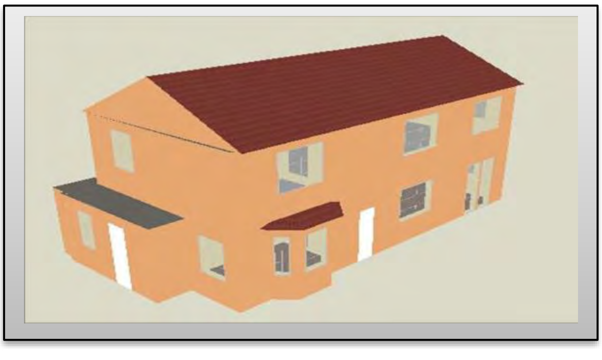
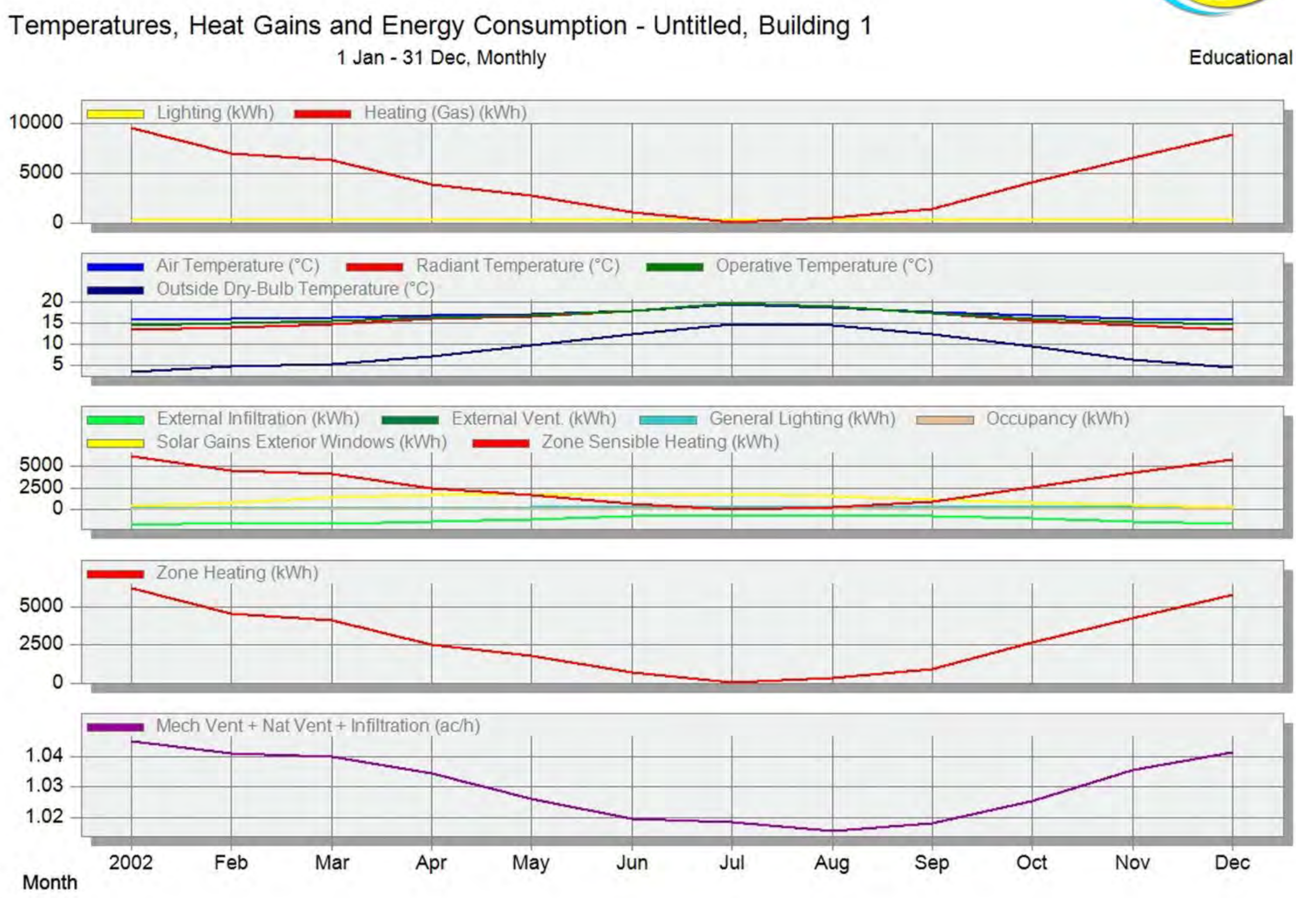


Figure A148. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.68
Operative Temperature (°C)	15.34
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.85
Walls (kW)	-9.12
Ceilings (int) (kW)	-2.56
Floors (int) (kW)	0.32
Ground Floors (kW)	0.48
Partitions (int) (kW)	0.06
Roofs (kW)	-0.43
External Infiltration (kW)	-4.68
External Vent. (kW)	-14.04
Zone Sensible Heating (kW)	32.76

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 40.930 (kW)				
Block 1 Total Design Heating Capacity = 20.760 (kW)				
Cupboard3	14.74	0.36	**0.45**	1037.2745
Dining Room	15.54	2.69	**3.36**	246.7648
Hall	17.28	0.74	**0.92**	190.8748
Sitting Room	15.27	6.29	**7.86**	238.2774
Kitchen	15.58	3.57	**4.46**	242.6834
Service	16.39	0.43	**0.54**	296.6715
Family Room	16.24	1.62	**2.02**	221.1989
Storm Porch	15.56	0.22	**0.27**	1084.5619
Cupboard4	14.71	0.27	**0.34**	2165.9245
Cupboard2	14.71	0.27	**0.34**	2165.9198
Cupboard1	16.13	0.16	**0.20**	768.9386
Block 2 Total Design Heating Capacity = 20.170 (kW)				
Cupboard	15.83	0.18	**0.23**	888.0507
Cupboard	15.63	0.20	**0.25**	1023.0832
Bedroom1	14.90	2.94	**3.67**	292.7684
Bedroom2	14.65	6.66	**8.32**	252.2908
Bedroom4	15.62	1.77	**2.21**	241.9553
Hall	16.72	0.88	**1.09**	225.7916
Service	15.94	0.49	**0.62**	336.9778
Bedroom3	14.89	3.03	**3.78**	262.2057
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.19	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.49	0.00	**0.00**	0.0000

Figure A149. The heating design simulation and data of the house.



Lighting (kWh)	258.08	234.33	261.24	250.16	258.08	253.33	258.08	259.66	251.74	258.08	251.74	259.66
Heating (Gas) (kWh)	9571.13	7009.94	6273.82	3809.77	2715.83	1029.26	105.58	470.46	1411.04	4093.19	6475.12	8912.17
Air Temperature (°C)	15.72	15.90	16.16	16.70	16.99	17.87	19.30	18.67	17.46	16.65	16.12	15.77
Radiant Temperature (°C)	13.29	13.98	14.74	15.98	16.51	17.94	19.75	18.88	17.26	15.56	14.40	13.46
Operative Temperature (°C)	14.50	14.94	15.45	16.34	16.75	17.91	19.53	18.77	17.36	16.10	15.26	14.61
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1762.62	-1446.78	-1558.50	-1322.53	-1028.78	-745.94	-653.51	-605.31	-701.19	-998.61	-1357.24	-1621.83
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-1.82	0.00	0.00	0.00	0.00	0.00
General Lighting (kWh)	258.08	234.33	261.24	250.16	258.08	253.33	258.08	259.66	251.74	258.08	251.74	259.66
Occupancy (kWh)	81.00	74.57	84.53	78.69	80.81	80.50	74.52	78.32	80.24	81.00	80.66	82.81
Solar Gains Exterior Windows (kWh)	481.26	826.12	1446.46	1701.57	1798.29	1755.24	1818.71	1564.15	1240.07	818.32	556.64	318.33
Zone Sensible Heating (kWh)	6201.22	4540.95	4063.70	2468.05	1759.52	666.88	68.43	304.85	914.49	2652.28	4194.42	5773.91
Zone Heating (kWh)	6221.24	4556.46	4077.98	2476.35	1765.29	669.02	68.63	305.80	917.18	2660.58	4208.83	5792.91
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.02	1.03	1.04	1.04

Figure A150. The simulation detailed results of the house.

Case 51. A House Built in 1915

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone.	1.641	Increase 18.9 cm Insulation
	Flat -	-
	Pitched 2.002	Increase 32.8 cm Insulation
Floors are timber suspended construction.	1.071	Increase 30 cm Insulation
Internal Walls are solid partitions.	1.411	
Windows are replacement u-PVC double glazed windows.		

* As a basis for a theory of possibility

Description

Two storey semidetached house. The frontage points approximately to the East Livingroom kitchen dining room 4 bedrooms box room bathroom and separate WC.

Weather Raining.

Heating and hot water

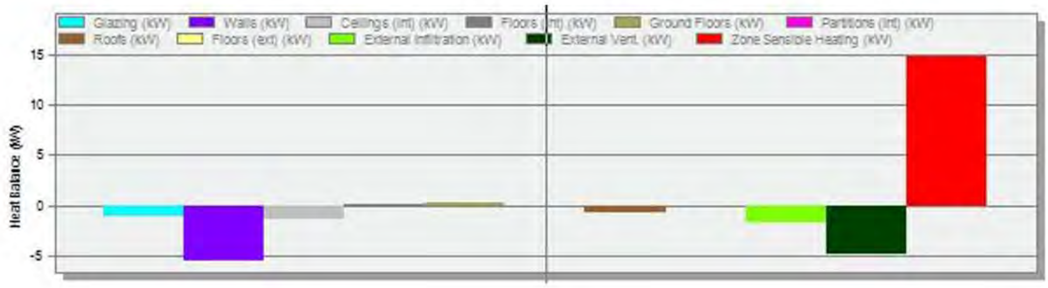
From a gas fired radiator central heating system, supplying domestic hot water.

Gross internal floor area(m²) 103 m^2

Address

KINROSS KY13 8DE

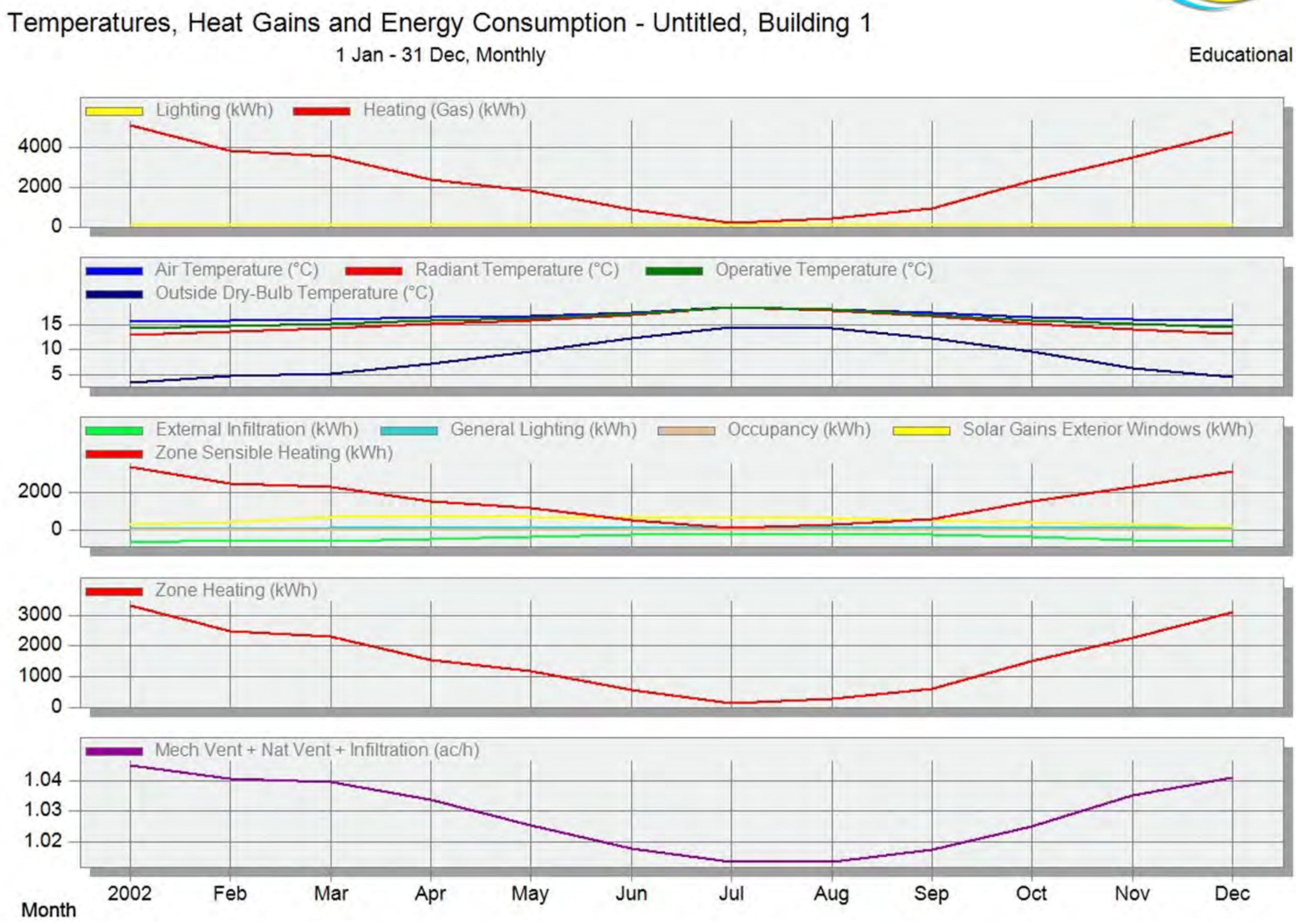
Figure A151. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.35
Operative Temperature (°C)	15.17
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.08
Walls (kW)	-5.60
Ceilings (int) (kW)	-1.32
Floors (int) (kW)	0.12
Ground Floors (kW)	0.34
Partitions (int) (kW)	0.00
Roofs (kW)	-0.76
Floors (ext) (kW)	-0.05
External Infiltration (kW)	-1.65
External Vent. (kW)	-4.95
Zone Sensible Heating (kW)	14.91

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 18.640 (kW)				
Ground Floor Total Design Heating Capacity = 12.220 (kW)				
Corridor	15.77	0.74	**0.92**	303.3297
Kitchen	14.99	1.20	**1.51**	297.7749
Dining Room	15.86	1.64	**2.05**	212.2432
Hall	16.59	0.50	**0.62**	211.5208
Lounge	14.97	1.91	**2.39**	278.0435
Bed Room	15.16	1.55	**1.94**	258.0549
Veslibule	15.88	0.28	**0.34**	414.3731
Service	14.76	0.97	**1.22**	356.0952
Bed Room	14.71	0.98	**1.23**	359.3178
First Floor Total Design Heating Capacity = 6.420 (kW)				
Bed Room 1	14.51	1.90	**2.38**	277.0549
Landing	16.45	0.49	**0.62**	179.3338
Bed Room	14.45	1.97	**2.46**	276.7347
Study Room	15.63	0.38	**0.48**	291.0492
Service	13.67	0.38	**0.48**	2500.9741
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	0.17	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-3.27	0.00	**0.00**	0.0000

Figure A152. The heating design simulation and data of the house.



Lighting (kWh)	109.64	99.55	110.99	106.28	109.64	107.62	109.64	110.31	106.95	109.64	106.95	110.31
Heating (Gas) (kWh)	5101.18	3801.73	3521.18	2341.71	1804.19	836.96	171.55	431.37	922.57	2299.35	3473.51	4744.12
Air Temperature (°C)	15.72	15.87	16.10	16.52	16.79	17.39	18.48	18.13	17.30	16.60	16.11	15.76
Radiant Temperature (°C)	13.03	13.64	14.25	15.25	15.76	16.94	18.54	17.94	16.73	15.22	14.14	13.21
Operative Temperature (°C)	14.37	14.75	15.18	15.89	16.27	17.17	18.51	18.03	17.02	15.91	15.12	14.49
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-620.80	-508.47	-546.09	-457.59	-352.73	-240.43	-190.68	-187.40	-239.52	-349.15	-477.65	-570.84
General Lighting (kWh)	109.64	99.55	110.99	106.28	109.64	107.62	109.64	110.31	106.95	109.64	106.95	110.31
Occupancy (kWh)	34.41	31.68	35.93	33.46	34.39	34.80	33.07	34.13	34.19	34.41	34.26	35.18
Solar Gains Exterior Windows (kWh)	279.52	426.29	683.94	733.98	704.89	636.19	699.99	643.14	560.23	406.24	318.10	185.26
Zone Sensible Heating (kWh)	3308.00	2465.01	2283.03	1518.42	1170.04	542.83	111.27	279.79	598.44	1491.28	2252.25	3076.30
Zone Heating (kWh)	3315.77	2471.12	2288.77	1522.11	1172.72	544.03	111.51	280.39	599.67	1494.58	2257.78	3083.68
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A153. The simulation detailed results of the house.

Case 52. A House Built in 1910

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional rendered brick construction with a stone frontage.	1.655	Increase 18.9 cm Insulation
	Flat 1.985	Increase 32 cm Insulation
	Pitched 2.185	Increase 33 cm Insulation
Floors are timber suspended construction.	1.090	Increase 30 cm Insulation
Internal Walls are of solid masonry as well as timber stud construction.	1.413	
Windows are of timber framed single glazed and double glazed type.		

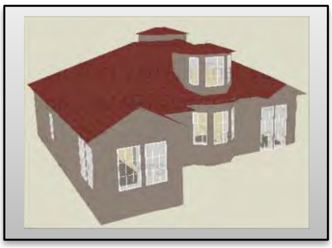
* As a basis for a theory of possibility

Description

The property comprises a detached villa with attic accommodation.

Ground Floor: Entrance Hall, Livingroom, Kitchen/Diningroom, Further Public Room, Three Bedrooms and Shower Room with WC.

Attic Level: Bedroom and Bathroom.



Weather Dry and overcast.

Heating and hot water

Full gas fired central heating with boiler located within the storage cupboard at first floor level.

Gross internal floor area(m²) 190 m^2

Address

EDINBURGH EH2 4AR

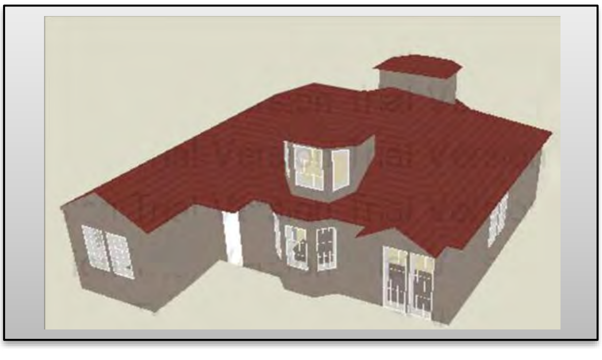
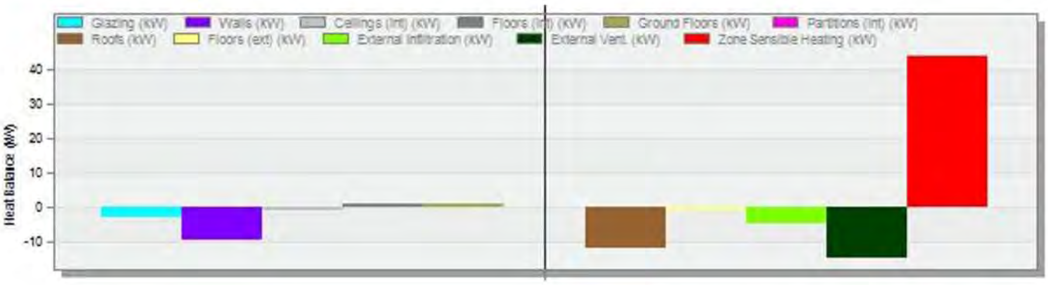


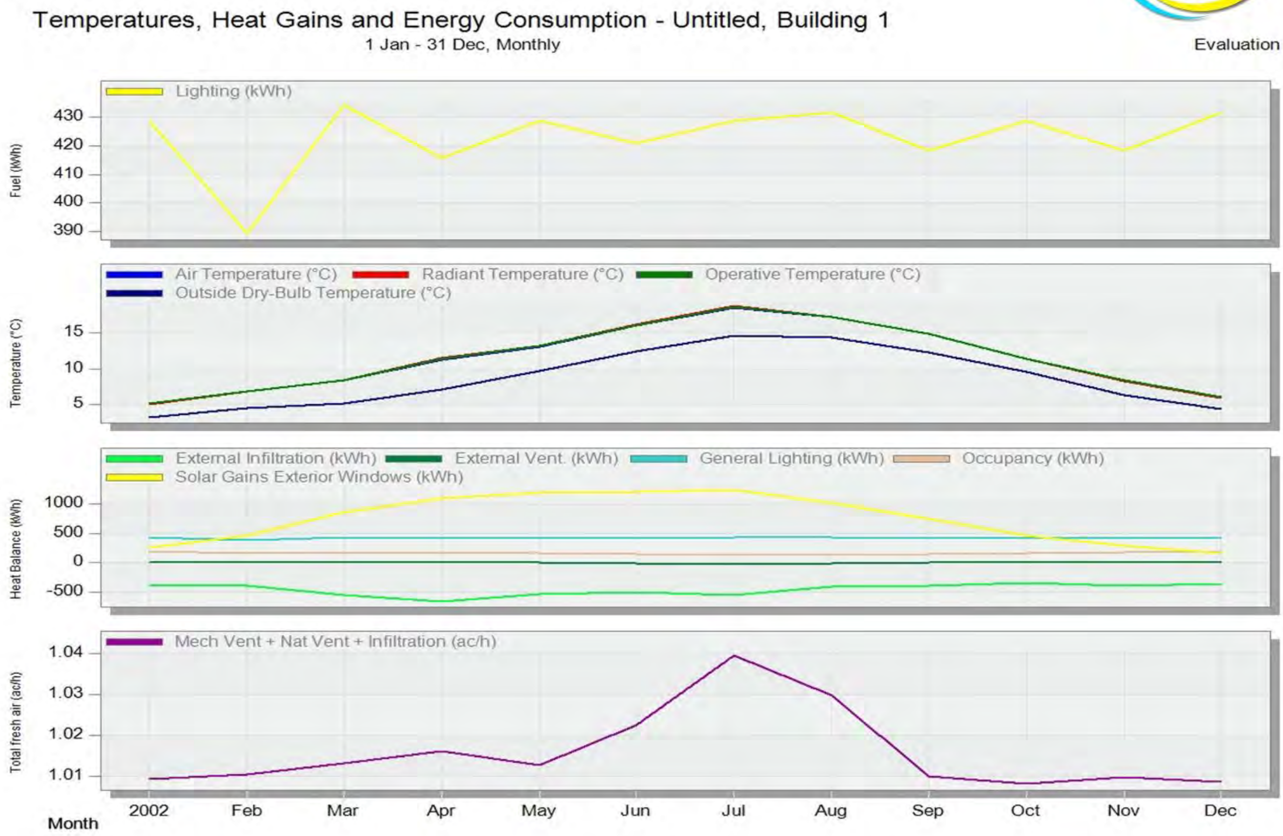
Figure A154. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	10.17
Operative Temperature (°C)	14.09
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.89
Walls (kW)	-9.36
Ceilings (int) (kW)	-0.99
Floors (int) (kW)	0.99
Ground Floors (kW)	0.92
Partitions (int) (kW)	0.00
Roofs (kW)	-11.76
Floors (ext) (kW)	-1.02
External Infiltration (kW)	-4.99
External Vent. (kW)	-14.97
Zone Sensible Heating (kW)	44.06

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 55.080 (kW)				
Ground Floor Total Design Heating Capacity = 26.870 (kW)				
Landing	16.13	0.74	**0.92**	271.2447
Kitchen	14.66	4.14	**5.18**	292.6005
Vestibule Hall	16.78	2.43	**3.04**	197.9972
Shower Room	16.08	0.90	**1.13**	263.8416
Bed Room	15.27	1.93	**2.42**	288.9937
Bed Room	16.12	2.34	**2.92**	216.9054
Bed Room	15.26	2.52	**3.15**	269.6905
Bed Room	15.88	1.86	**2.33**	240.4243
Sitting Room	15.27	4.62	**5.78**	247.5848
Garage Total Design Heating Capacity = 7.120 (kW)				
Zone 1	13.34	5.69	**7.12**	376.8916
Main Roof Total Design Heating Capacity = 18.000 (kW)				
Zone 1	13.02	14.40	**18.00**	133.7971
Roof 2 Total Design Heating Capacity = 0.160 (kW)				
Zone 1	11.78	0.13	**0.16**	72.2958

Figure A155. The heating design simulation and data of the house.



Lighting (kWh)	428.98	389.50	434.24	415.82	428.98	421.08	428.98	431.61	418.45	428.98	418.45	431.61
Air Temperature (°C)	5.19	6.87	8.35	11.27	13.05	15.98	18.43	17.10	14.82	11.41	8.38	6.12
Radiant Temperature (°C)	5.08	6.81	8.38	11.43	13.14	16.11	18.62	17.17	14.83	11.34	8.32	6.00
Operative Temperature (°C)	5.14	6.84	8.36	11.35	13.10	16.04	18.53	17.13	14.83	11.37	8.35	6.06
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-391.80	-395.23	-555.89	-657.88	-532.40	-513.78	-548.00	-418.34	-392.00	-346.56	-401.35	-364.54
External Vent. (kWh)	0.00	0.00	0.00	-0.00	-0.00	-9.22	-28.68	-18.28	-0.58	0.00	0.00	0.00
General Lighting (kWh)	428.98	389.50	434.24	415.82	428.98	421.08	428.98	431.61	418.45	428.98	418.45	431.61
Occupancy (kWh)	188.83	168.55	183.81	159.24	154.97	140.16	125.85	136.06	146.99	165.32	176.72	190.01
Solar Gains Exterior Windows (kWh)	254.00	465.09	864.57	1094.04	1200.29	1219.02	1236.86	1016.88	751.28	470.94	293.92	169.70
Mech Vent + Nat Vent + Infiltration (ac/h)	1.01	1.01	1.01	1.02	1.01	1.02	1.04	1.03	1.01	1.01	1.01	1.01

Figure A156. The simulation detailed results of the house.

Case 53. A House Built in 1906

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls of solid stone/brick construction finished externally to all elevations with a harling finish.	1.705	Increase 19 cm Insulation
	Flat 2.130	Increase 32 cm Insulation
	Pitched 2.210	Increase 32 cm Insulation
Floors are timber suspended construction.	1.202	Increase 32 cm Insulation
Internal Walls are of brickwork plastered on the hard.	1.402	
Windows are of its original windows which are mainly of timber sash and case construction.		

* As a basis for a theory of possibility

Description

The subjects comprise a two storey and attics detached villa. There is a small one storey side off shoot to the building which is in separate ownership.

Ground floor: entrance vestibule, hallway, drawing room ,dining room, sitting room, kitchen/breakfast room, side hall, utility room and WC compartment.

Weather Dry and overcast.

Heating and hot water

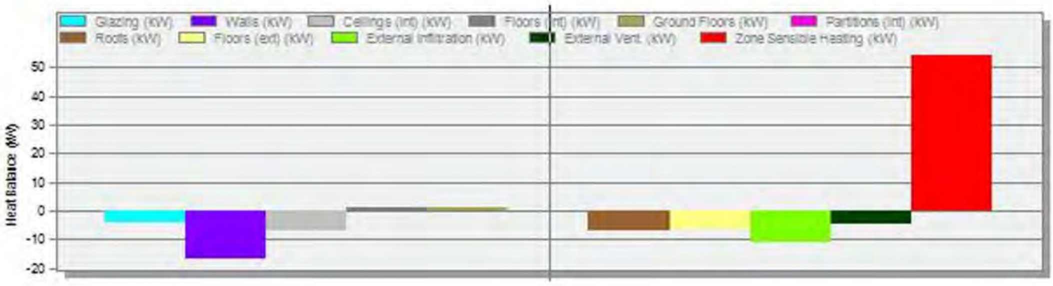
The property has gas fired central heating to radiator outlets. Domestic hot water appears to be provided indirectly by the gas central heating boiler to a hot water tank boxed on the wall in the utility room.

Gross internal floor area(m²) 530 m^2

Address

EDINBURGH EH13 0LW

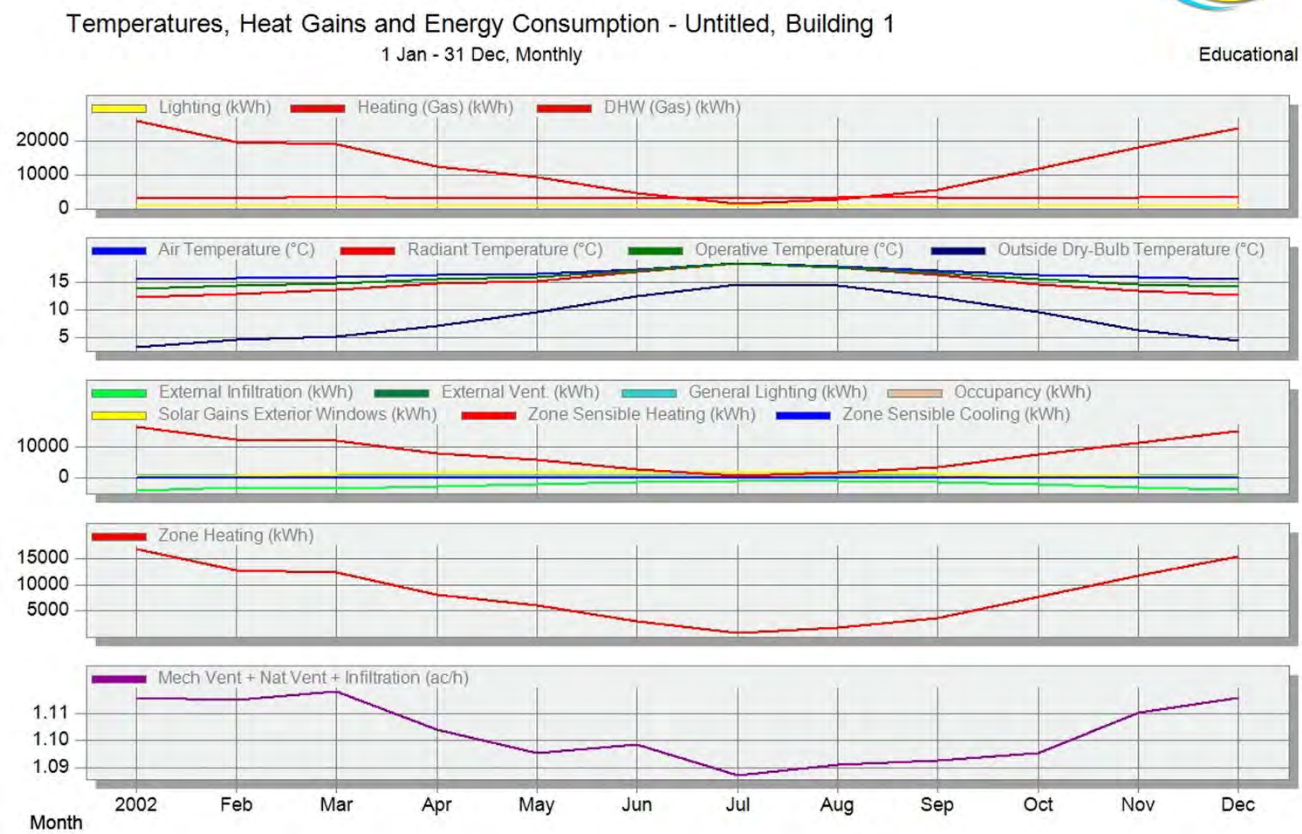
Figure A157. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.47
Operative Temperature (°C)	14.74
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-4.21
Walls (kW)	-16.96
Ceilings (int) (kW)	-6.79
Floors (int) (kW)	1.04
Ground Floors (kW)	0.88
Partitions (int) (kW)	-0.02
Roofs (kW)	-7.12
Floors (ext) (kW)	-6.41
External Infiltration (kW)	-10.86
External Vent. (kW)	-4.36
Zone Sensible Heating (kW)	54.48

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 68.110 (kW)				
Ground Floor Total Design Heating Capacity = 16.780 (kW)				
Utility Room	16.35	0.48	**0.60**	108.9398
Service	15.27	0.56	**0.70**	232.1695
Vestibule	15.85	0.41	**0.52**	189.1036
Dining Room	16.53	1.07	**1.34**	78.1277
Hall	15.60	1.12	**1.40**	147.3715
Sitting Room	15.68	1.99	**2.49**	104.5365
Kitchen	15.40	3.45	**4.31**	104.3859
Landing	17.37	0.13	**0.16**	65.3116
Hall	16.81	1.53	**1.91**	74.4901
Drawing Room	15.69	2.68	**3.35**	96.8959
First Floor Total Design Heating Capacity = 24.840 (kW)				
Double BedRoom	14.23	1.22	**1.52**	188.6730
Service	15.88	0.38	**0.48**	191.0198
Double BedRoom	15.34	2.15	**2.69**	111.4499
Kitchen	16.11	0.64	**0.81**	122.2751
Bath Room	14.35	1.19	**1.49**	184.1736
Dressing Room	15.78	1.24	**1.55**	107.6594
Master BedRoom	14.73	2.80	**3.50**	135.4476
Bath Room	15.83	0.63	**0.79**	129.1613
Double BedRoom	15.70	1.66	**2.07**	100.1340
Sitting Room	12.93	2.63	**3.29**	231.2000
Hall	16.07	3.03	**3.79**	105.2479
Double BedRoom	14.85	2.29	**2.86**	134.0557
Second Floor Total Design Heating Capacity = 16.020 (kW)				
Service	14.78	0.36	**0.46**	235.1863
Games Room	12.93	5.16	**6.45**	143.1380
Store	14.22	0.39	**0.48**	256.3110
Landing Hall	14.16	1.04	**1.30**	162.5633

Figure A158. The heating design simulation and data of the house.



Lighting (kWh)	768.22	711.69	814.24	749.38	768.22	795.40	768.22	791.23	772.39	768.22	772.39	791.23
Heating (Gas) (kWh)	25883.31	19845.13	19122.55	12448.09	9331.83	4481.85	1306.94	2780.21	5470.06	11907.67	18128.93	23846.56
DHW (Gas) (kWh)	3135.98	2971.83	3495.94	3081.26	3135.98	3441.22	3135.98	3315.96	3261.24	3135.98	3261.24	3315.96
Air Temperature (°C)	15.46	15.64	15.86	16.18	16.40	17.29	18.28	17.85	17.03	16.24	15.81	15.58
Radiant Temperature (°C)	12.25	12.90	13.51	14.65	15.20	16.76	18.29	17.52	16.24	14.61	13.40	12.57
Operative Temperature (°C)	13.85	14.27	14.69	15.41	15.80	17.02	18.28	17.68	16.63	15.43	14.61	14.07
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-4005.51	-3291.89	-3534.82	-2922.32	-2221.53	-1561.21	-1188.65	-1154.82	-1511.86	-2213.36	-3069.80	-3707.86
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-1.75	-6.80	-5.83	-0.07	0.00	0.00	0.00
General Lighting (kWh)	768.22	711.69	814.24	749.38	768.22	795.40	768.22	791.23	772.39	768.22	772.39	791.23
Occupancy (kWh)	192.83	181.85	212.65	188.97	192.57	206.25	186.09	196.79	198.48	192.82	199.09	202.75
Solar Gains Exterior Windows (kWh)	470.91	844.59	1464.51	1789.45	1841.57	1841.62	1892.57	1583.31	1236.82	807.93	550.33	313.11
Zone Sensible Heating (kWh)	16447.99	12569.75	12075.55	7833.01	5871.26	2791.35	807.54	1734.39	3413.10	7518.28	11479.00	15123.17
Zone Sensible Cooling (kWh)	0.00	0.00	-0.59	-1.24	-0.79	-9.48	-39.44	-20.45	-2.01	0.00	-0.07	0.00
Zone Heating (kWh)	16824.15	12899.34	12429.66	8091.26	6065.69	2913.20	849.51	1807.14	3555.54	7739.98	11783.80	15500.26
Mech Vent + Nat Vent + Infiltration (ac/h)	1.12	1.11	1.12	1.10	1.10	1.10	1.09	1.09	1.09	1.10	1.11	1.12

Figure A159. The simulation detailed results of the house.

Case 54. A House Built in 1905

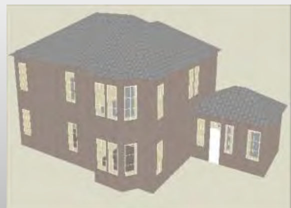
Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are of stone construction.	1.695	Increase 19 cm Insulation
	Flat 2.167	Increase 32 cm Insulation
	Pitched 2.223	Increase 33 cm Insulation
Floors are timber construction.	1.325	Increase 31.4 cm Insulation
Internal Walls are a mix of lath and plaster and plastered on hard.	1.507	
Windows are of timber framed windows, mainly single glazed.		

* As a basis for a theory of possibility

Description

Detached villa. On ground floor: Vestibule, hall, lounge, living room, dining room, kitchen, rear hall, utility room, study and two toilets.

On first floor: Master bedroom with en-suite bathroom, three further bedrooms and bathroom.



Weather Dry.

Heating and hot water

Gas fired central heating with boiler at utility room and pre insulated hot water cylinder in loft.

Gross internal floor area(m²) 263 m^2

Address

BO'NESS EH51 9EA

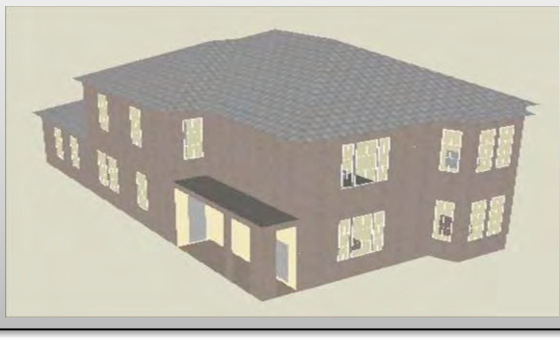
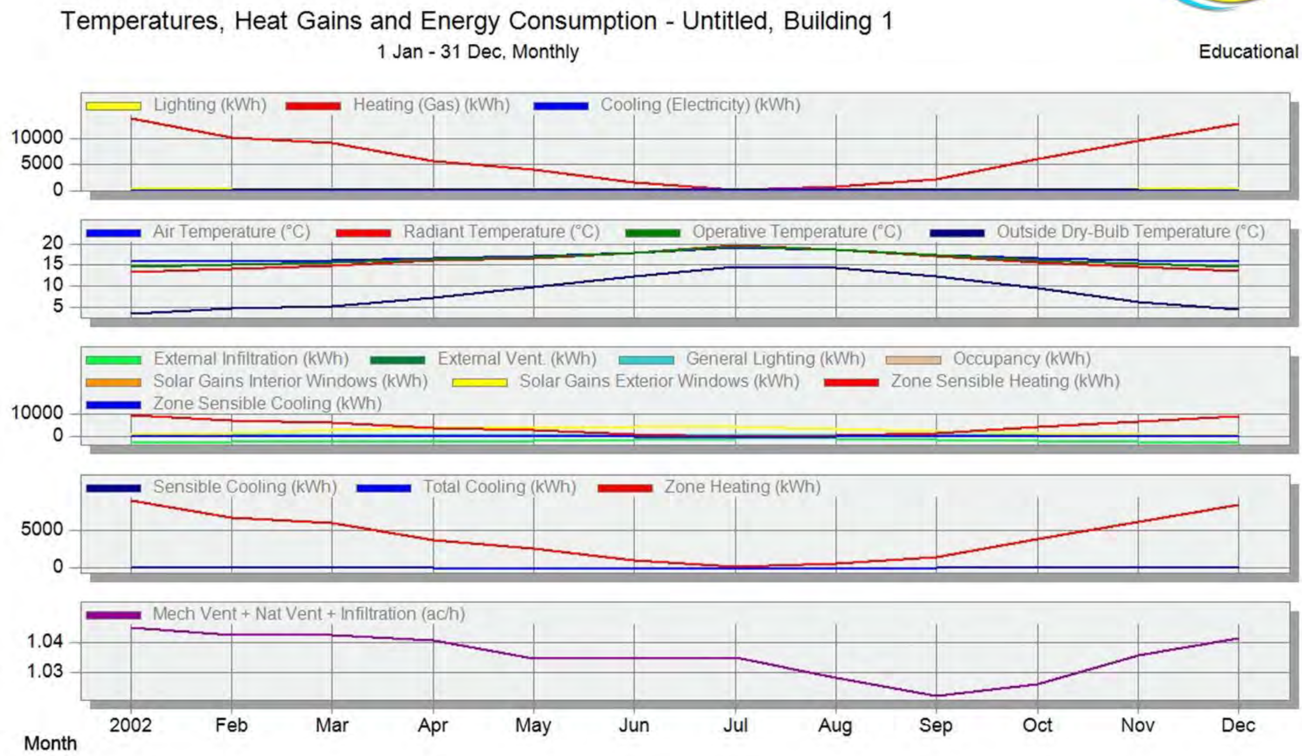


Figure A160. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.87
Operative Temperature (°C)	15.44
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-6.58
Walls (kW)	-11.19
Ceilings (int) (kW)	-4.09
Floors (int) (kW)	0.55
Ground Floors (kW)	0.94
Partitions (int) (kW)	0.00
Roofs (kW)	-0.51
External Infiltration (kW)	-7.11
External Vent. (kW)	-21.33
Zone Sensible Heating (kW)	49.21

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 61.510 (kW)				
Ground Floor Total Design Heating Capacity = 33.650 (kW)				
Entrance	16.25	3.31	**4.13**	202.7051
Drawing Room	15.34	5.70	**7.12**	233.1000
Hall 1	17.08	2.77	**3.46**	175.0281
Dining Room	15.29	4.88	**6.10**	239.1663
Kitchen	15.94	2.15	**2.69**	229.1427
Service 1	15.81	0.44	**0.55**	393.9924
Vestibule	16.08	0.51	**0.64**	306.1302
Laundry	15.20	1.15	**1.44**	354.0734
Study Room	14.54	1.07	**1.33**	457.5257
Hall	15.18	1.47	**1.83**	317.0058
Pantry	15.40	1.06	**1.32**	311.3133
Service	14.83	0.27	**0.34**	2232.8356
Family Room	15.44	2.16	**2.70**	657.8456
First Floor Total Design Heating Capacity = 27.860 (kW)				
Bed Room	14.89	4.10	**5.12**	266.6042
Bed Room	14.55	4.67	**5.84**	264.8240
Cupboard	16.68	0.33	**0.42**	225.5178
Service	15.58	1.13	**1.41**	271.6767
Hall	16.50	1.76	**2.20**	184.7022
Bed Room	14.56	5.22	**6.52**	255.7185
Laundry	15.56	1.45	**1.81**	259.6009
Bed Room	14.82	2.45	**3.06**	287.3194
Service	14.61	1.19	**1.48**	428.0752

Figure A161. The heating design simulation and data of the house.



Lighting (kWh)	390.34	354.42	395.13	378.37	390.34	383.16	390.34	392.74	380.76	390.34	380.76	392.74
Heating (Gas) (kWh)	13930.07	10241.92	9209.17	5650.73	3919.58	1466.74	171.01	766.73	2079.73	6038.09	9490.83	12935.84
Cooling (Electricity) (kWh)	0.00	1.50	6.43	17.21	19.25	29.86	43.65	24.77	9.36	0.89	0.23	0.00
Air Temperature (°C)	15.73	15.92	16.16	16.69	17.01	17.88	19.23	18.53	17.43	16.64	16.13	15.79
Radiant Temperature (°C)	13.43	14.08	14.79	15.99	16.58	18.01	19.74	18.75	17.25	15.59	14.48	13.60
Operative Temperature (°C)	14.58	15.00	15.48	16.34	16.79	17.95	19.48	18.64	17.34	16.11	15.30	14.70
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2680.28	-2203.14	-2371.63	-2014.70	-1576.88	-1146.75	-990.80	-900.91	-1065.19	-1516.76	-2064.29	-2467.61
External Vent. (kWh)	0.00	-4.48	-8.49	-20.02	-20.38	-29.80	-35.04	-20.75	-6.86	-1.30	-0.78	0.00
General Lighting (kWh)	390.34	354.42	395.13	378.37	390.34	383.16	390.34	392.74	380.76	390.34	380.76	392.74
Occupancy (kWh)	122.51	112.73	127.83	118.81	121.98	121.75	113.29	119.31	121.39	122.46	121.98	125.25
Solar Gains Interior Windows (kWh)	0.73	1.51	2.81	3.92	4.28	4.35	4.47	3.66	2.56	1.47	0.90	0.50
Solar Gains Exterior Windows (kWh)	784.35	1488.83	2728.74	3493.04	3825.56	3844.88	3972.77	3252.38	2405.05	1463.04	933.20	519.78
Zone Sensible Heating (kWh)	9024.79	6634.14	5964.47	3659.95	2538.89	950.06	110.75	496.73	1347.65	3912.07	6147.57	8380.32
Zone Sensible Cooling (kWh)	0.00	-6.71	-28.90	-77.33	-86.34	-133.81	-191.51	-107.17	-41.89	-3.94	-1.05	0.00
Sensible Cooling (kWh)	0.00	-6.74	-28.93	-77.45	-86.56	-134.02	-192.01	-107.45	-42.00	-3.97	-1.06	0.00
Total Cooling (kWh)	0.00	-6.74	-28.93	-77.45	-86.61	-134.37	-196.40	-111.45	-42.11	-3.98	-1.06	0.00
Zone Heating (kWh)	9054.54	6657.25	5985.96	3672.97	2547.72	953.38	111.16	498.37	1351.82	3924.76	6169.04	8408.30
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.02	1.03	1.04	1.04

Figure A162. The simulation detailed results of the house.

Case 55. A House Built in 1903

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone or brick construction with a mostly roughcast finish externally.	1.692	Increase 19 cm Insulation
	Flat -	-
	Pitched 2.209	Increase 33 cm Insulation
Floors are suspended timber construction.	1.355	Increase 31 cm Insulation
Internal Walls are mostly plaster on the hard.	1.517	
Windows are predominantly traditional timber sash and case single-glazed design.		

* As a basis for a theory of possibility

Description

The property comprises a two-storey, detached house.

Ground Floor: Entrance Vestibules, Hall, Lounge, Living Room, Dining Room, Kitchen, Two Utility Rooms, Cloakroom with WC, Rear and Side Porches.

First Floor: Six Bedrooms, Dressing Room, Study, Two Bathrooms and Cloakroom.

Weather Dry.

Heating and hot water

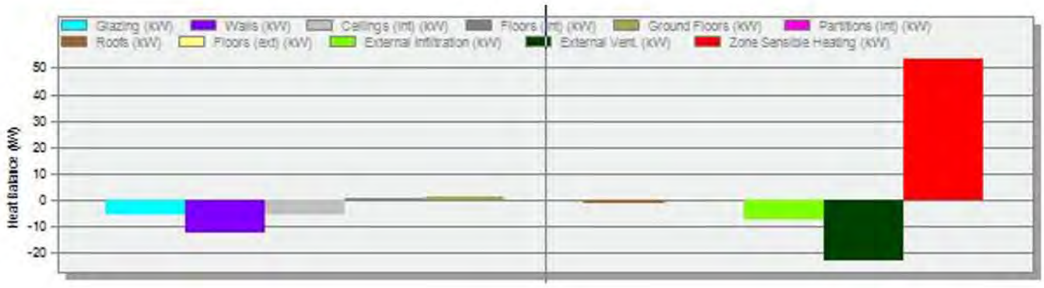
Hot water is provided by the gas fired central heating boiler through the hot water cylinder, both of which are located within the kitchen. There was a limited inspection of the hot water cylinder due to its location within a cupboard. The central heating boiler is floor mounted and also provides the hot water for a series of radiators throughout the property. Temperature control of the system is on the boiler itself and there are no individual thermostats on the radiators.

Gross internal floor area(m²) 380 m^2

Address

EDINBURGH EH3 1TD

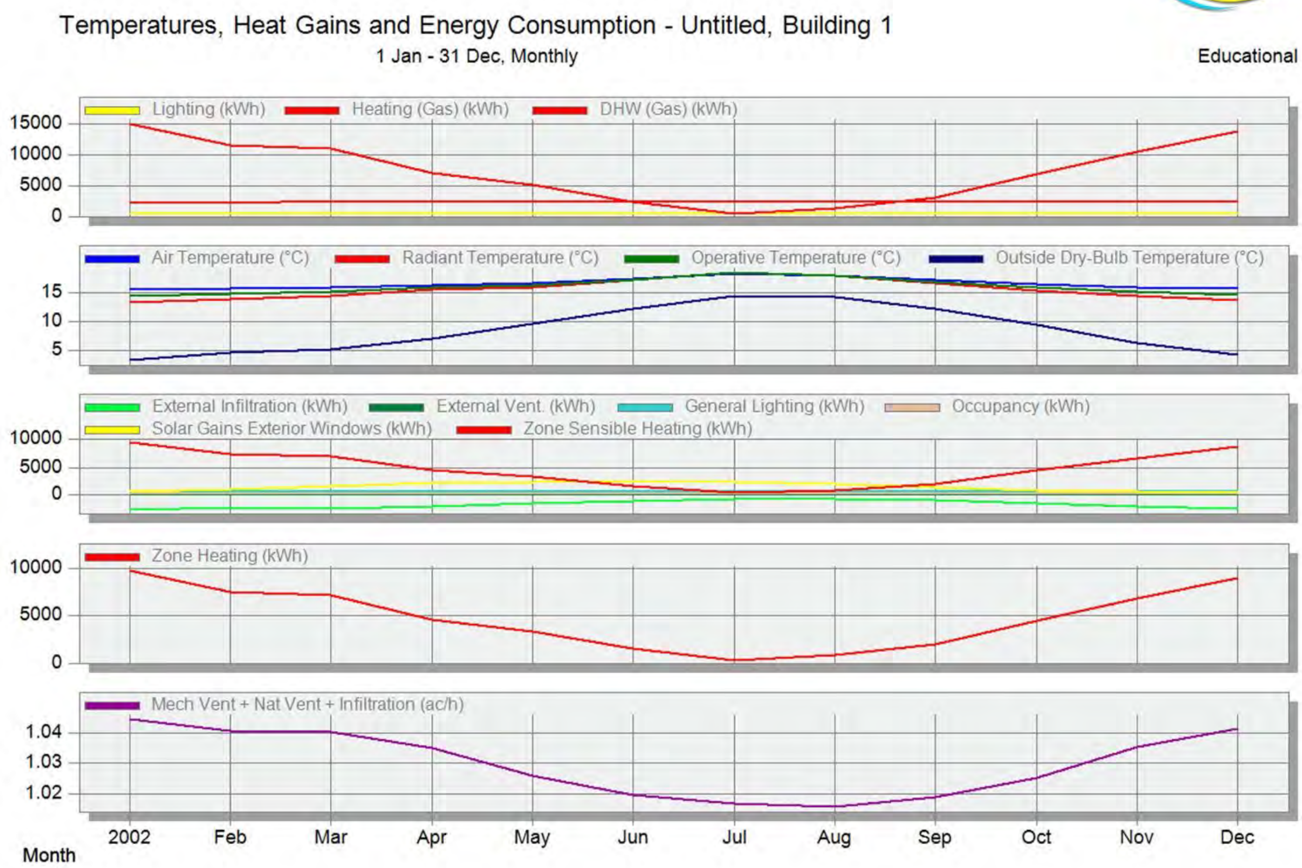
Figure A163. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.27
Operative Temperature (°C)	15.63
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-5.75
Walls (kW)	-12.51
Ceilings (int) (kW)	-5.78
Floors (int) (kW)	0.69
Ground Floors (kW)	1.51
Partitions (int) (kW)	0.00
Roofs (kW)	-1.06
Floors (ext) (kW)	-0.01
External Infiltration (kW)	-7.71
External Vent. (kW)	-23.12
Zone Sensible Heating (kW)	53.57

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 66.960 (kW)				
Garage Total Design Heating Capacity = 4.490 (kW)				
Zone 1	13.50	3.59	**4.49**	422.0603
Ground Floor Total Design Heating Capacity = 34.610 (kW)				
Kitchen	15.53	2.62	**3.27**	214.1365
Utility Room	16.72	1.56	**1.95**	170.7926
Entrance	13.52	0.91	**1.13**	1038.7331
Sitting	16.53	2.56	**3.19**	167.6465
Sum Room	14.02	3.28	**4.10**	325.5030
Drawing Room	15.30	7.10	**8.87**	199.0449
Cloak Room	16.15	0.39	**0.49**	281.5801
Hall	17.41	2.87	**3.59**	141.9257
Dining Room	15.65	3.60	**4.50**	198.0885
Vestibule	16.39	0.66	**0.82**	211.5005
Service	16.48	0.52	**0.65**	226.1125
Store	16.41	0.74	**0.92**	218.4554
Landing	17.42	0.25	**0.31**	158.4245
Store	17.54	0.46	**0.57**	146.5029
Store	17.22	0.20	**0.25**	178.3980
First Floor Total Design Heating Capacity = 27.860 (kW)				
Dressing Room	15.54	1.31	**1.64**	188.2829
Double BedRoom	14.66	4.45	**5.56**	191.9727
Store	16.81	0.13	**0.16**	196.4623
Hall	16.44	2.60	**3.25**	134.5381
Storage	15.94	0.92	**1.15**	180.9307
Master BedRoom	15.05	2.31	**2.89**	197.0191
Double BedRoom	15.63	1.77	**2.21**	173.7338
Double BedRoom	15.58	1.55	**1.94**	180.2492
Landing	15.84	0.65	**0.81**	254.2090
Double BedRoom	14.80	2.60	**3.26**	204.5661

Figure A164. The heating design simulation and data of the house.



Lighting (kWh)	493.90	458.98	527.16	482.26	493.90	515.52	493.90	510.53	498.89	493.90	498.89	510.53
Heating (Gas) (kWh)	15038.93	11483.04	11005.17	6932.92	5093.70	2283.37	443.73	1307.09	2967.29	6871.94	10421.59	13819.67
DHW (Gas) (kWh)	2330.79	2208.80	2598.33	2290.13	2330.79	2557.67	2330.79	2464.56	2423.90	2330.79	2423.90	2464.56
Air Temperature (°C)	15.59	15.84	16.08	16.46	16.73	17.49	18.45	18.04	17.25	16.54	16.06	15.75
Radiant Temperature (°C)	13.48	14.04	14.56	15.56	16.06	17.31	18.69	17.98	16.81	15.47	14.49	13.76
Operative Temperature (°C)	14.54	14.94	15.32	16.01	16.40	17.40	18.57	18.01	17.03	16.00	15.27	14.75
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2874.41	-2372.17	-2551.35	-2124.65	-1636.94	-1145.62	-881.28	-854.02	-1108.80	-1621.36	-2223.24	-2668.04
External Vent. (kWh)	0.00	0.00	-2.84	-3.76	-0.59	-2.11	-6.37	-2.85	-1.65	0.00	0.00	0.00
General Lighting (kWh)	493.90	458.98	527.16	482.26	493.90	515.52	493.90	510.53	498.89	493.90	498.89	510.53
Occupancy (kWh)	119.12	112.86	132.70	116.86	118.99	129.88	115.07	122.75	123.71	119.11	123.86	125.96
Solar Gains Exterior Windows (kWh)	494.81	889.00	1602.99	2110.98	2294.71	2309.62	2378.94	1928.99	1389.13	853.68	579.79	336.93
Zone Sensible Heating (kWh)	9735.19	7433.17	7124.40	4488.31	3297.37	1477.81	287.09	846.22	1921.52	4449.96	6746.37	8946.71
Zone Heating (kWh)	9775.30	7463.98	7153.36	4506.40	3310.91	1484.19	288.43	849.61	1928.74	4466.76	6774.03	8982.79
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.02	1.03	1.04	1.04

Figure A165. The simulation detailed results of the house.

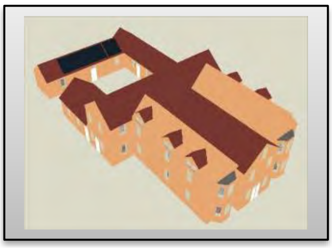
Case 56. A House Built in 1902

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are to 600mm solid stonework, part pointed, part rendered externally.	1.656	Increase 19 cm Insulation
	Flat -	-
	Pitched 2.043	Increase 32.8 cm Insulation
Floors are to a mixture of solid screed and suspended timber overlaid in boarding.	1.322	Increase 31.4 cm Insulation
Internal Walls are to a mixture of plasterboard and, lath and plaster.	1.521	
Windows are to a mixture of single glazed and double glazed units and are to timber frame, PVC frame and velux frame units.		

* As a basis for a theory of possibility

Description

The subjects comprise an extended two and half storey detached villa with attached single storey cottage. At date of inspection the property was owner occupied, fully furnished with floors covered.



Weather Dry.

Heating and hot water

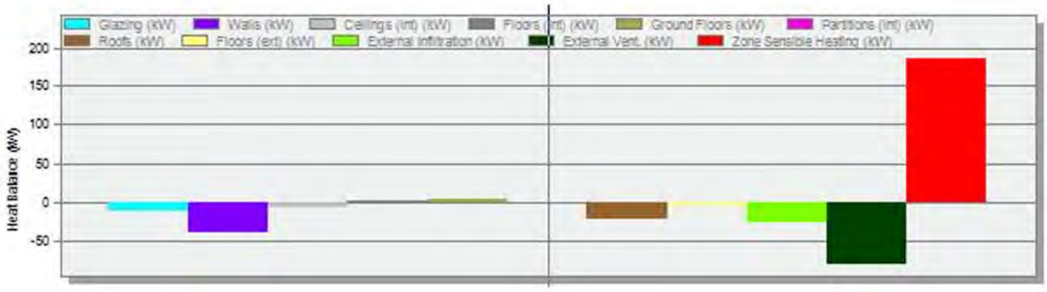
The property has an oil fired central heating system with the boiler floor mounted to the ground floor boiler room and ventilated externally. Hot water is augmented by roof mounted solar panels on the linked cottage. Partial electric storage panel radiators were also noted and heating is augmented by the open fires and multi fuel burning stoves.

Gross internal floor area(m²) 883 m²

Address

DUNS TD11 3PG

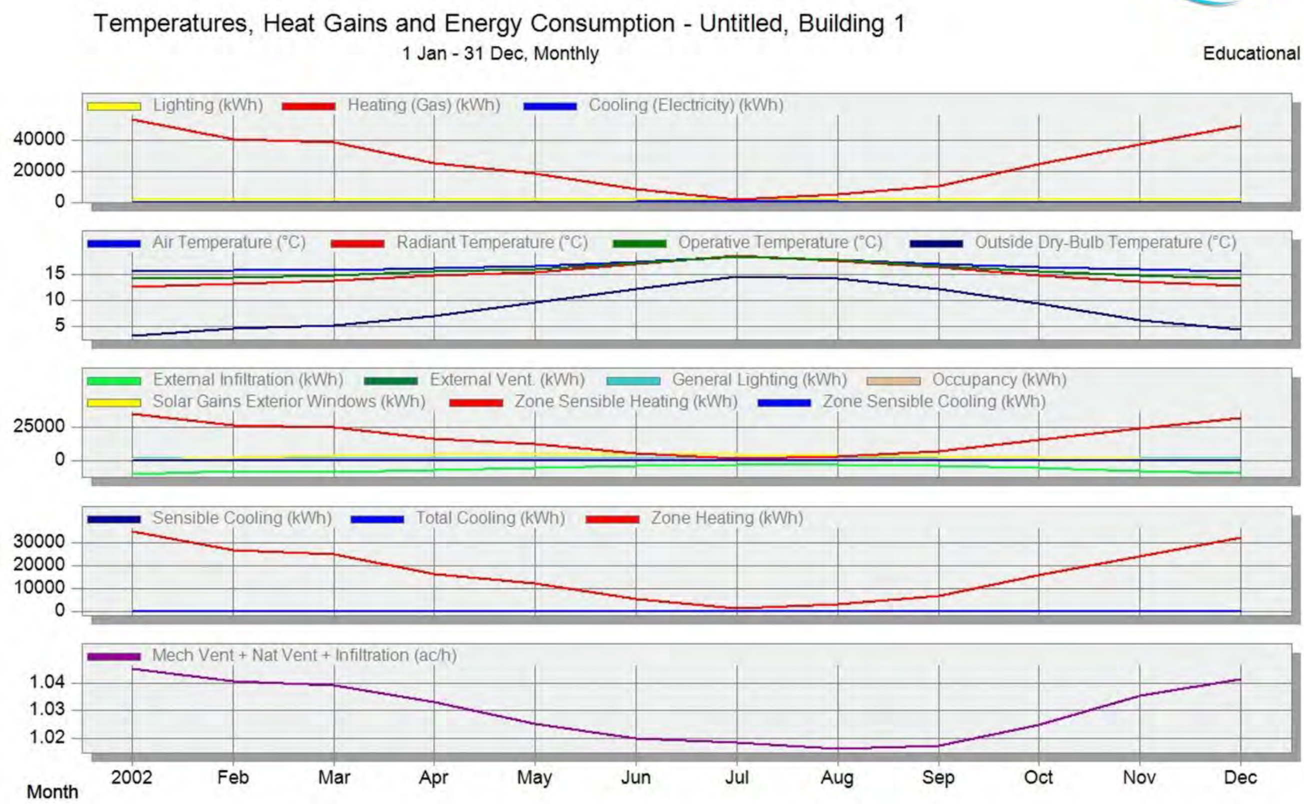
Figure A166. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.00
Operative Temperature (°C)	15.00
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-11.14
Walls (kW)	-38.62
Ceilings (int) (kW)	-7.42
Floors (int) (kW)	2.92
Ground Floors (kW)	3.22
Partitions (int) (kW)	-0.27
Roofs (kW)	-22.73
Floors (ext) (kW)	-4.20
External Infiltration (kW)	-26.85
External Vent. (kW)	-80.54
Zone Sensible Heating (kW)	185.49

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 231.890 (kW)				
Ground Floor Total Design Heating Capacity = 111.730 (kW)				
Sitting Room	14.18	4.74	**5.93**	311.1989
Kitchen	15.22	1.73	**2.16**	287.1678
Bed Room	15.24	2.24	**2.80**	273.0078
Hall	14.94	4.14	**5.17**	321.1874
Service	15.54	1.12	**1.40**	291.4830
Bed Room	14.74	3.72	**4.66**	294.6353
Bed Room	14.84	4.26	**5.33**	267.8523
Boiler Room	15.08	2.99	**3.74**	271.8589
Hall	15.56	1.19	**1.49**	329.2347
Utility Room	15.30	2.68	**3.35**	263.9164
Kitchen	16.10	5.06	**6.32**	201.1989
Utility Room	16.04	4.05	**5.07**	212.0591
Office	16.38	2.74	**3.43**	199.8703
Summer Room	15.54	6.15	**7.69**	224.7964
Landing	17.39	2.47	**3.09**	166.0193
Store	15.76	2.67	**3.34**	261.5026
Hall	17.27	9.98	**12.47**	162.1483
Dining Room	16.24	3.36	**4.21**	204.4099
Service	17.48	0.43	**0.54**	170.8640
Sitting Room	15.12	3.09	**3.86**	270.1492
Vestibule	15.24	2.51	**3.13**	289.0315
Drawing Room	15.57	5.27	**6.59**	224.4015
Study Room	16.20	3.58	**4.47**	202.9822
Bed Room	16.54	2.94	**3.68**	192.7647
Bar GamesRoom	14.41	6.25	**7.81**	278.5106
First Floor Total Design Heating Capacity = 69.840 (kW)				
Library	15.21	3.27	**4.09**	237.7583
Bed Room	14.99	4.57	**5.71**	240.5057

Figure A167. The heating design simulation and data of the house.



Lighting (kWh)	1801.86	1636.04	1823.97	1746.59	1801.86	1768.70	1801.86	1812.91	1757.64	1801.86	1757.64	1812.91
Heating (Gas) (kWh)	53993.25	41161.59	38777.20	25453.52	18783.35	8236.36	2007.23	4920.23	10346.22	24490.11	37393.54	49667.39
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	3.60	8.77	3.34	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.68	15.79	15.93	16.29	16.60	17.39	18.46	17.97	17.06	16.37	15.97	15.74
Radiant Temperature (°C)	12.71	13.25	13.82	14.91	15.55	17.03	18.61	17.76	16.41	14.86	13.76	12.96
Operative Temperature (°C)	14.19	14.52	14.87	15.60	16.07	17.21	18.54	17.86	16.73	15.62	14.86	14.35
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-10105.36	-8262.13	-8811.22	-7336.67	-5661.34	-3929.14	-3071.40	-2941.44	-3768.12	-5592.36	-7729.62	-9314.23
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-9.30	-21.79	-13.46	-0.81	0.00	0.00	0.00
General Lighting (kWh)	1801.86	1636.04	1823.97	1746.59	1801.86	1768.70	1801.86	1812.91	1757.64	1801.86	1757.64	1812.91
Occupancy (kWh)	565.52	520.60	590.71	549.95	564.52	565.84	537.33	558.24	561.47	565.51	563.21	578.19
Solar Gains Exterior Windows (kWh)	964.87	1824.41	3459.24	4372.95	4776.66	4779.68	4902.82	4056.39	3018.01	1845.60	1132.63	638.21
Zone Sensible Heating (kWh)	34981.06	26663.68	25116.08	16481.71	12161.82	5331.83	1298.87	3185.89	6701.07	15862.30	24220.33	32176.87
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-15.90	-34.12	-11.93	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-16.02	-34.30	-11.99	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-16.19	-39.44	-15.05	0.00	0.00	0.00	0.00
Zone Heating (kWh)	35095.61	26755.03	25205.18	16544.79	12209.18	5353.63	1304.70	3198.15	6725.04	15918.57	24305.80	32283.81
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.04	1.04

Figure A168. The simulation detailed results of the house.

Case 57. A House Built in 1900

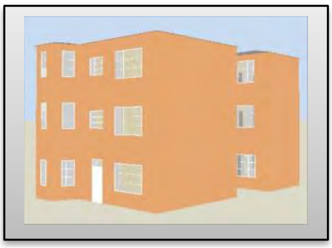
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of stone construction pointed externally.	1.659	Increase 19 cm Insulation
	Flat 2.173	Increase 32 cm Insulation
	Pitched 2.066	Increase 32 cm Insulation
Floors are a mixture of solid concrete and timber construction.	1.354	Increase 31 cm Insulation
Internal Walls have plaster finishes.	1.579	
Windows are timber sash and case single glazed type.		

* As a basis for a theory of possibility

Description

The property comprises a purpose built main door flat with a four storey tenement block.

Entrance Hall, Two Bedrooms, Kitchen, Living Room, Box Room and Bathroom with WC.



Weather **Dry and Clear**

Heating and hot water

The property benefits from a gas fired central heating system serving steel panel radiators. Domestic hot water is presumed to be provided by the central heating boiler.

Gross internal floor area (m²) 104 m^2 **approx.**

Address

EDINBURGH EH10 5JX

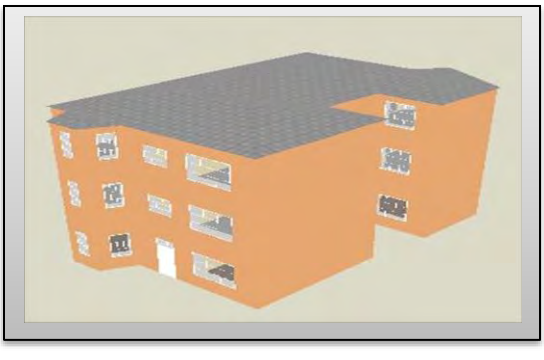
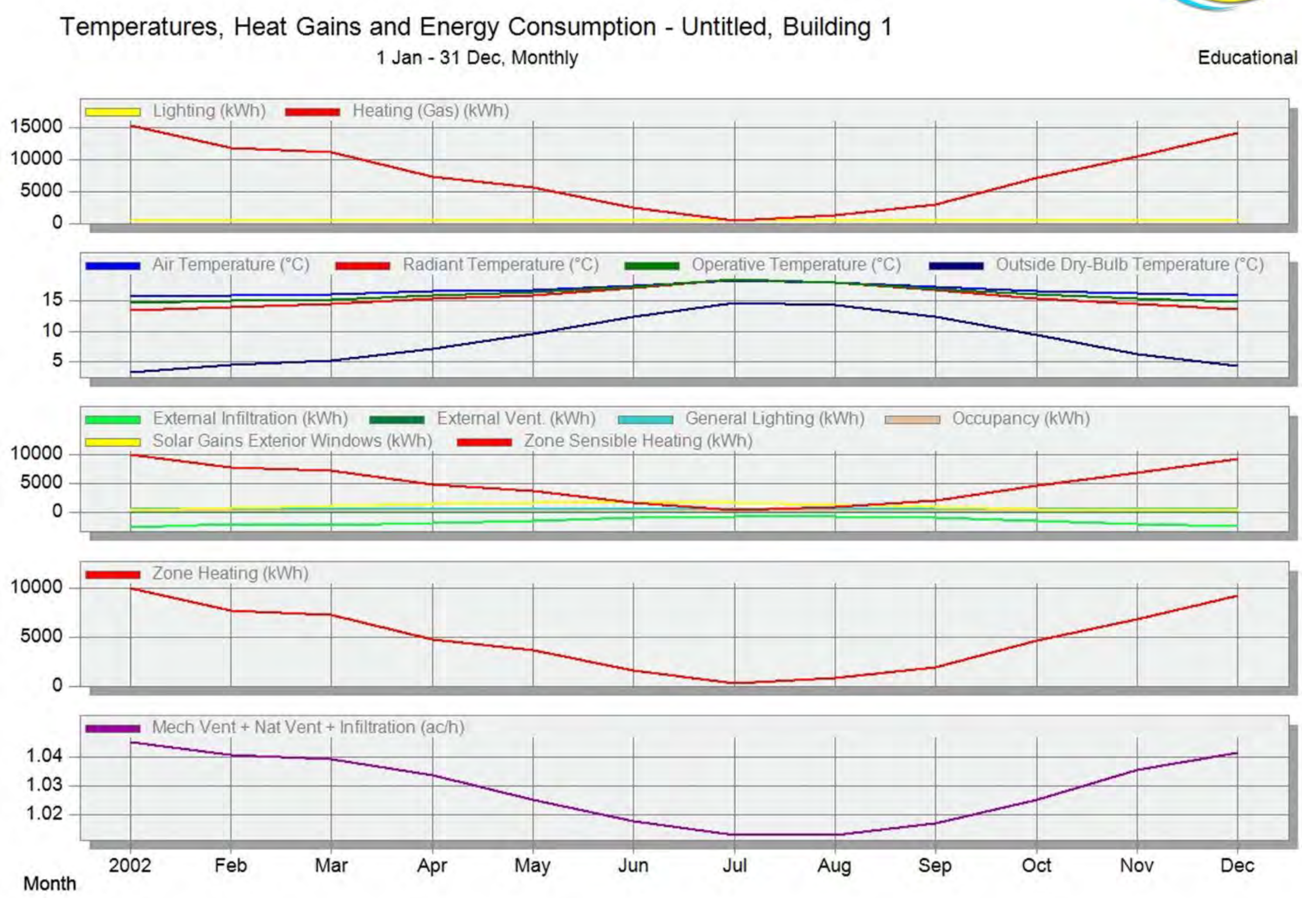


Figure A169. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.10
Operative Temperature (°C)	15.55
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-4.02
Walls (kW)	-16.33
Ceilings (int) (kW)	-3.07
Floors (int) (kW)	0.52
Ground Floors (kW)	0.69
Partitions (int) (kW)	0.00
Roofs (kW)	-0.12
External Infiltration (kW)	-7.17
External Vent. (kW)	-21.51
Zone Sensible Heating (kW)	50.90

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 63.620 (kW)				
Ground Floor Total Design Heating Capacity = 20.760 (kW)				
Bed Room	15.13	3.00	**3.76**	233.3566
Service	16.62	0.50	**0.62**	215.6325
Hall	17.09	1.92	**2.40**	156.7536
Kitchen DiningRoom	15.80	2.80	**3.50**	200.9186
Service	17.43	0.12	**0.15**	165.4479
Box Room	16.62	0.93	**1.16**	187.1333
Sitting Room	15.53	2.91	**3.64**	214.6594
Vestibule	15.62	0.42	**0.52**	390.1456
Utility	16.06	0.33	**0.42**	301.0646
Store	16.17	0.49	**0.61**	356.8981
Bed Room	15.22	3.18	**3.98**	229.1543
First Floor Total Design Heating Capacity = 20.170 (kW)				
Bed Room 1	14.93	2.93	**3.67**	227.8796
Service 1	16.52	0.48	**0.60**	208.6872
Hall	16.96	1.81	**2.27**	148.2386
Kitchen DiningRoom	15.61	2.71	**3.38**	194.3249
Service	17.36	0.12	**0.15**	158.8557
Box Room	16.48	0.89	**1.12**	180.3063
Sitting Room	15.32	2.83	**3.54**	208.8400
Vestibule	15.47	0.42	**0.53**	396.1103
Utility	15.98	0.33	**0.41**	295.0985
Store	16.04	0.47	**0.59**	342.3232
Bed Room	14.99	3.13	**3.91**	225.0425
Secons Floor Total Design Heating Capacity = 22.690 (kW)				
Bed Room 1	14.47	3.23	**4.04**	250.8327
Service 1	16.10	0.56	**0.70**	242.9928
Hall	16.37	2.13	**2.66**	174.1284
Kitchen DiningRoom	15.08	3.03	**3.79**	217.8775

Figure A170. The heating design simulation and data of the house.



Lighting (kWh)	477.13	433.23	482.99	462.50	477.13	468.35	477.13	480.06	465.43	477.13	465.43	480.06
Heating (Gas) (kWh)	15398.72	11791.85	11159.87	7347.18	5583.16	2382.56	393.78	1249.59	2966.15	7084.06	10573.56	14166.38
Air Temperature (°C)	15.76	15.91	16.08	16.49	16.76	17.35	18.31	17.98	17.20	16.60	16.15	15.84
Radiant Temperature (°C)	13.42	13.91	14.40	15.39	15.87	17.04	18.49	17.87	16.67	15.38	14.44	13.65
Operative Temperature (°C)	14.59	14.91	15.24	15.94	16.32	17.19	18.40	17.93	16.93	15.99	15.30	14.74
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2711.17	-2221.33	-2371.71	-1984.04	-1530.51	-1036.81	-792.83	-785.09	-1021.35	-1520.84	-2088.31	-2501.44
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.24	0.00	0.00	0.00	0.00	0.00
General Lighting (kWh)	477.13	433.23	482.99	462.50	477.13	468.35	477.13	480.06	465.43	477.13	465.43	480.06
Occupancy (kWh)	149.75	137.86	156.46	145.76	149.74	151.90	145.00	149.59	149.11	149.75	149.14	153.11
Solar Gains Exterior Windows (kWh)	294.25	563.81	1047.22	1397.97	1554.33	1580.77	1588.48	1294.84	922.83	550.30	349.34	199.67
Zone Sensible Heating (kWh)	9979.16	7640.97	7231.08	4760.75	3618.38	1544.24	255.10	809.93	1922.90	4591.73	6851.56	9180.27
Zone Heating (kWh)	10009.17	7664.70	7253.92	4775.67	3629.05	1548.66	255.96	812.23	1928.00	4604.64	6872.81	9208.15
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A171. The simulation detailed results of the house.

Case 58. A House Built in 1900

Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are built of traditional solid stone rendered externally.	1.663	Increase 19 cm Insulation
	Flat -	-
	Pitched 2.153	Increase 32 cm Insulation
Floor is of solid masonry and suspended timber at ground floor and suspended timber at upper floors.	1.377	Increase 31.5 cm Insulation
Internal Walls have plaster finishes.	1.538	
Windows are of timber single glazed style.		

* As a basis for a theory of possibility

Description

Detached villa.

Ground Floor - Entrance Hall, Living Room, Dining Room, Kitchen, Utility Room and 2 WC Compartments.

First Floor - Five Bedrooms, Bathroom with WC, Shower Room with WC

Attic Floor – Bedroom.

Weather **Dry and Sunny**

Heating and hot water

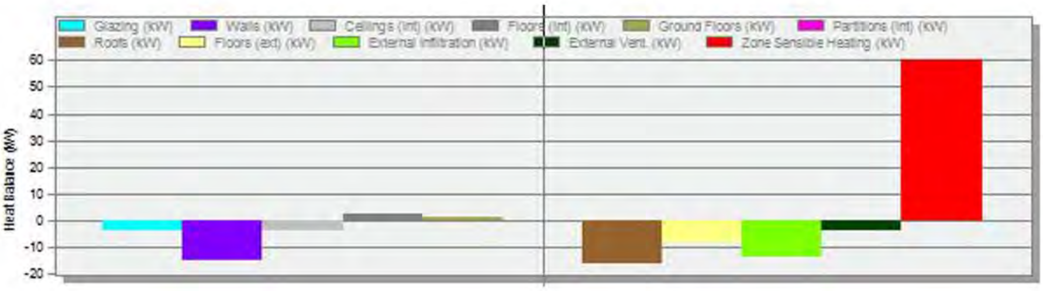
The property benefits from a gas fired boiler which appears to serve the central heating system and hot water supply. There is an electric heater within the ground floor WC.

Gross internal floor area (m²) 256 m^2 **approx.**

Address

EDINBURGH, EH12 6BR

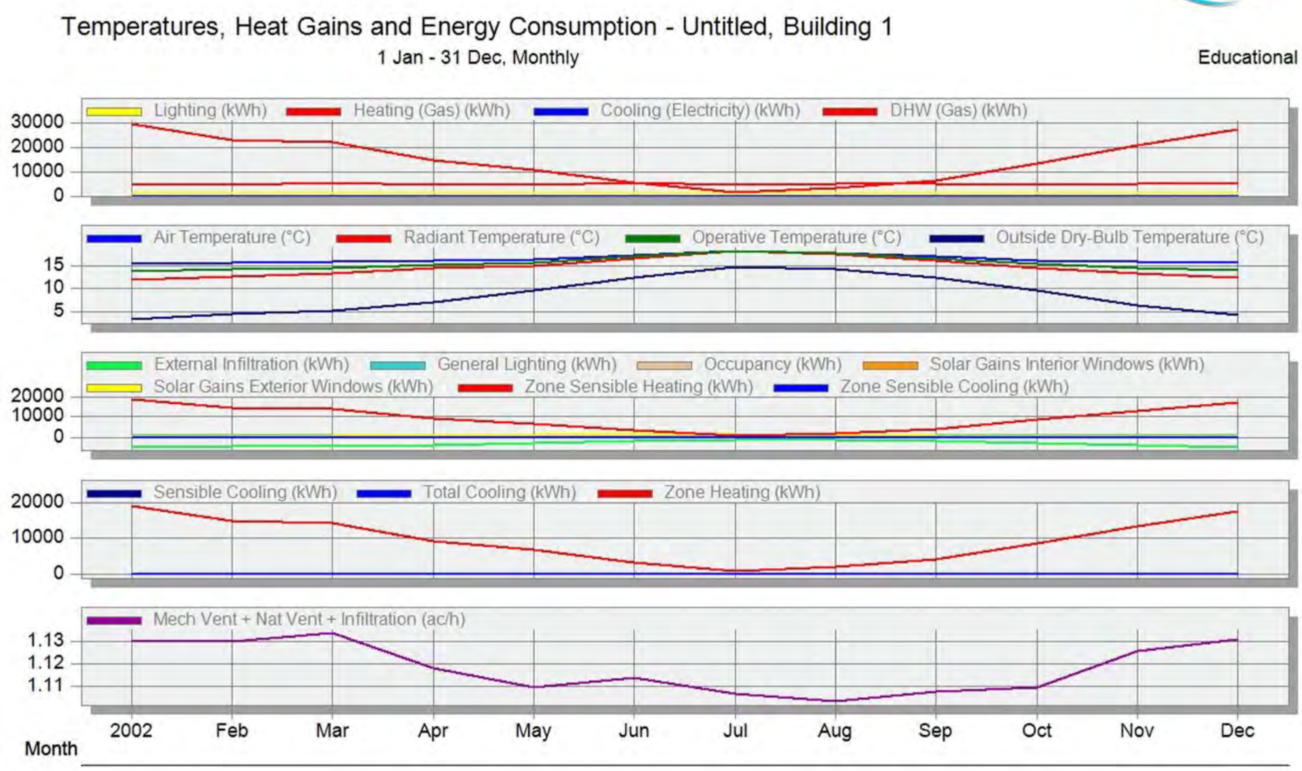
Figure A172. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.08
Operative Temperature (°C)	14.54
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.83
Walls (kW)	-15.03
Ceilings (int) (kW)	-3.90
Floors (int) (kW)	2.20
Ground Floors (kW)	1.29
Partitions (int) (kW)	0.00
Roofs (kW)	-16.38
Floors (ext) (kW)	-7.91
External Infiltration (kW)	-13.43
External Vent. (kW)	-3.56
Zone Sensible Heating (kW)	60.38

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 75.460 (kW)				
Ground Floor Total Design Heating Capacity = 20.190 (kW)				
Garden Store	15.50	1.06	**1.33**	143.5810
Store	16.77	0.38	**0.47**	85.2378
Hall Vestibule	16.93	1.62	**2.03**	61.0146
Drawing Room	15.88	3.11	**3.88**	87.6371
Kitchen	16.60	2.18	**2.73**	66.2564
Dining Room	15.64	3.88	**4.85**	96.1438
Laundry Room	15.53	1.80	**2.25**	117.6019
Pantry	16.58	0.58	**0.72**	92.2322
Service	15.49	1.54	**1.93**	145.6249
First Floor Total Design Heating Capacity = 23.890 (kW)				
Store	14.62	0.64	**0.80**	308.5255
Hall	15.20	3.23	**4.04**	117.0205
Bed Room	15.49	2.46	**3.07**	76.2775
Sitting Room	14.39	2.83	**3.54**	121.0729
Store	16.88	0.14	**0.18**	72.1501
Bed Room	16.29	1.18	**1.48**	61.1506
Bed Room	14.28	4.37	**5.46**	113.5531
Bath Room	15.10	1.07	**1.33**	115.7001
Shower Room	16.32	0.40	**0.50**	78.8129
Bed Room	14.40	2.41	**3.02**	120.7561
Landing	16.68	0.38	**0.47**	55.0122
Main Roof Total Design Heating Capacity = 29.600 (kW)				
Family Room	12.43	23.68	**29.60**	131.8768

Figure A173. The heating design simulation and data of the house.



Lighting (kWh)	1013.11	941.48	1081.33	989.23	1013.11	1057.45	1013.11	1047.22	1023.34	1013.11	1023.34	1047.22
Heating (Gas) (kWh)	29405.65	22722.85	22108.22	14434.22	10784.33	5232.26	1679.71	3308.62	6326.06	13459.67	20494.10	26974.54
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	4.04	0.00	0.00	0.00	0.00	0.00
DHW (Gas) (kWh)	4781.04	4530.79	5329.83	4697.62	4781.04	5246.41	4781.04	5055.43	4972.02	4781.04	4972.02	5055.43
Air Temperature (°C)	15.41	15.59	15.79	16.07	16.30	17.20	18.18	17.75	16.92	16.15	15.76	15.55
Radiant Temperature (°C)	11.97	12.61	13.21	14.37	14.98	16.60	18.16	17.35	16.04	14.38	13.17	12.34
Operative Temperature (°C)	13.69	14.10	14.50	15.22	15.64	16.90	18.17	17.55	16.48	15.27	14.47	13.94
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-4937.91	-4047.28	-4334.74	-3558.60	-2692.47	-1882.67	-1417.70	-1376.04	-1814.03	-2685.81	-3767.89	-4572.92
General Lighting (kWh)	1013.11	941.48	1081.33	989.23	1013.11	1057.45	1013.11	1047.22	1023.34	1013.11	1023.34	1047.22
Occupancy (kWh)	244.35	231.56	272.40	240.03	244.32	265.92	237.47	251.45	253.79	244.35	254.11	258.38
Solar Gains Interior Windows (kWh)	0.39	0.78	1.51	1.84	2.10	2.15	2.10	1.76	1.32	0.82	0.45	0.25
Solar Gains Exterior Windows (kWh)	269.46	500.63	892.45	1098.40	1181.90	1200.91	1199.14	992.19	758.20	483.07	314.29	179.23
Zone Sensible Heating (kWh)	18572.44	14291.65	13852.61	9002.47	6724.88	3222.46	1024.45	2040.68	3900.90	8424.34	12878.97	16988.50
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	-1.52	-1.61	-19.83	-68.57	-32.56	-3.59	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-7.83	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-10.10	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	19113.67	14769.85	14370.34	9382.25	7009.81	3400.97	1091.81	2150.60	4111.94	8748.78	13321.16	17533.45
Mech Vent + Nat Vent + Infiltration (ac/h)	1.13	1.13	1.13	1.12	1.11	1.11	1.11	1.10	1.11	1.11	1.13	1.13

Figure A174. The simulation detailed results of the house.

Case 59. A House Built in 1900

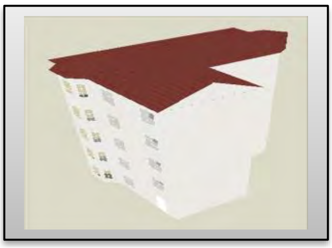
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone construction being pointed externally.	1.667	Increase 19.8 cm Insulation
	Flat -	-
	Pitched 2.108	Increase 32.9 cm Insulation
Floor throughout is of a suspended timber type.	1.357	Increase 31.3 cm Insulation
Internal Walls are a mixture of timber stud and plasterboard and plastered on the hard.	1.562	
Windows throughout are of a timber sash and casement single glazed style.		

* As a basis for a theory of possibility

Description

Purpose built first floor flat within a five storey block.

First Floor - Entrance Hallway, Living Room, Kitchen, 4 Bedrooms and Bathroom with WC.



Weather **Dry and Overcast**

Heating and hot water

A gas fired combination boiler serves both the central heating and hot water systems.

Gross internal floor area (m²) 88 m^2 **approx.**

Address

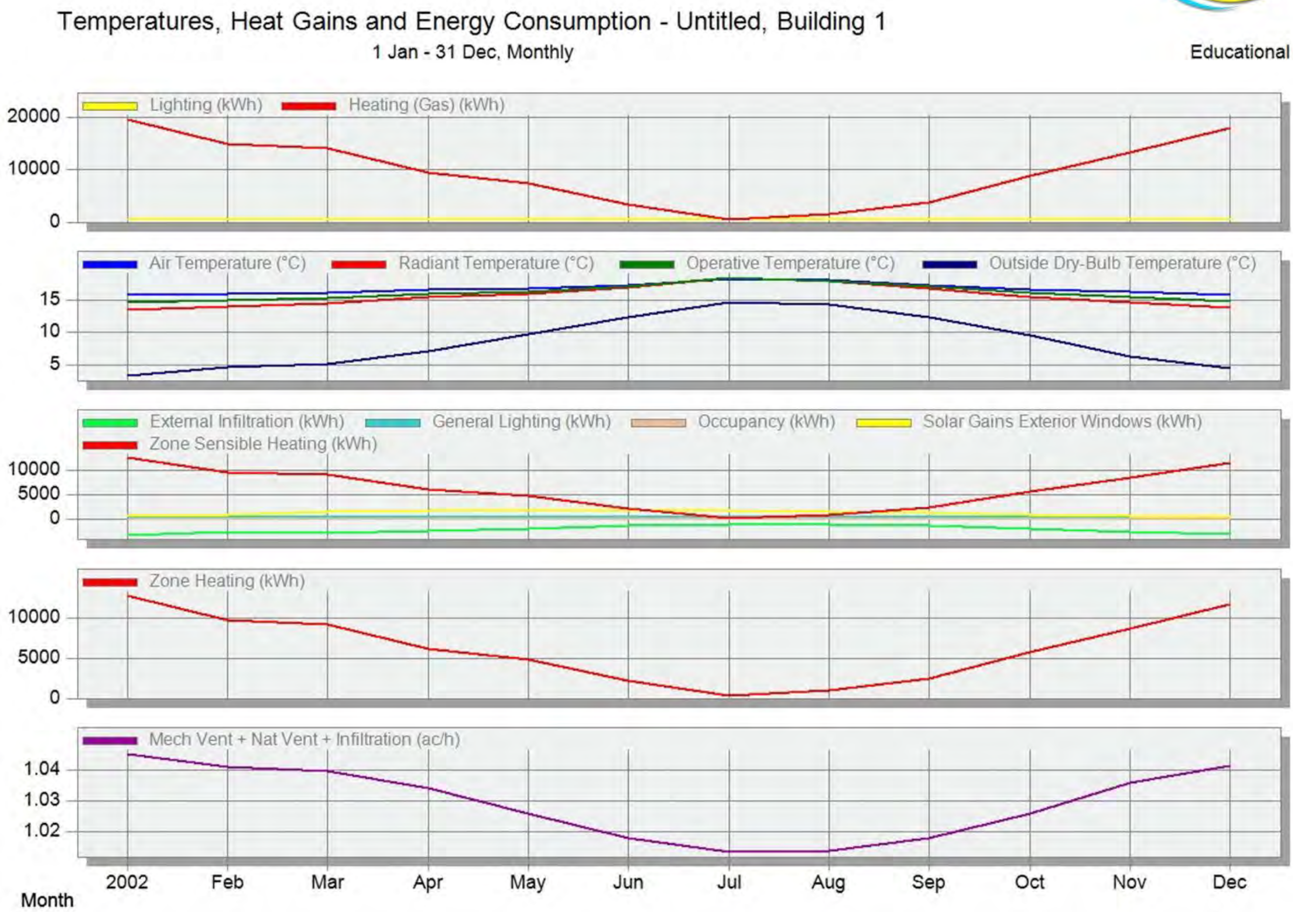
EDINBURGH EH10 4JD

Figure A175. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.31
Operative Temperature (°C)	15.65
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-4.38
Walls (kW)	-22.98
Ceilings (int) (kW)	-2.64
Floors (int) (kW)	0.63
Ground Floors (kW)	0.49
Partitions (int) (kW)	0.00
Roofs (kW)	-0.05
External Infiltration (kW)	-8.28
External Vent. (kW)	-24.85
Zone Sensible Heating (kW)	61.98

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 77.470 (kW)				
Block 1 Total Design Heating Capacity = 15.340 (kW)				
Service	15.42	2.62	**3.28**	282.8776
Lounge	15.06	2.29	**2.87**	259.5404
Bedroom2	16.17	1.16	**1.45**	202.0721
Bedroom3	16.07	1.22	**1.53**	215.9667
Dining Kitchen	16.54	1.96	**2.44**	169.9147
Hall	17.32	0.24	**0.30**	162.5691
Bedroom4	16.16	1.40	**1.75**	270.8767
Bedroom1	15.63	1.38	**1.72**	251.7549
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	0.26	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.34	0.00	**0.00**	0.0000
Block 2 Total Design Heating Capacity = 14.910 (kW)				
Service	15.28	2.58	**3.22**	277.8280
Lounge	14.81	2.29	**2.87**	259.4913
Bedroom2	16.03	1.12	**1.40**	194.7708
Bedroom3	15.95	1.18	**1.48**	208.5249
Dining Kitchen	16.42	1.85	**2.31**	160.4342
Hall	17.26	0.22	**0.28**	153.2839
Bedroom4	16.03	1.34	**1.67**	258.7057
Bedroom1	15.49	1.35	**1.68**	245.9912
Block 3 Total Design Heating Capacity = 14.980 (kW)				
Service	15.27	2.59	**3.24**	279.2432
Lounge	14.78	2.31	**2.88**	261.0813
Bedroom2	16.01	1.13	**1.41**	195.9700
Bedroom3	15.94	1.19	**1.48**	209.4449
Dining Kitchen	16.40	1.86	**2.32**	161.2488
Hall	17.25	0.22	**0.28**	154.0363

Figure A176. The heating design simulation and data of the house.



Lighting (kWh)	541.37	491.55	548.01	524.76	541.37	531.41	541.37	544.69	528.09	541.37	528.09	544.69
Heating (Gas) (kWh)	19524.84	14922.63	14124.26	9482.35	7387.71	3329.28	579.69	1612.87	3761.83	8896.71	13276.67	18024.20
Air Temperature (°C)	15.77	15.95	16.14	16.56	16.81	17.34	18.29	18.04	17.28	16.68	16.22	15.85
Radiant Temperature (°C)	13.53	14.04	14.53	15.46	15.89	16.95	18.41	17.92	16.77	15.52	14.59	13.75
Operative Temperature (°C)	14.65	14.99	15.33	16.01	16.35	17.14	18.35	17.98	17.03	16.10	15.41	14.80
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3136.55	-2578.22	-2760.49	-2314.92	-1785.10	-1202.80	-923.52	-931.37	-1205.65	-1782.10	-2433.90	-2896.25
General Lighting (kWh)	541.37	491.55	548.01	524.76	541.37	531.41	541.37	544.69	528.09	541.37	528.09	544.69
Occupancy (kWh)	169.91	156.42	177.50	165.34	169.89	172.48	164.93	169.60	169.01	169.91	169.21	173.72
Solar Gains Exterior Windows (kWh)	650.65	1026.18	1702.17	1901.77	1896.34	1762.54	1915.64	1691.65	1408.09	986.21	741.92	431.81
Zone Sensible Heating (kWh)	12655.73	9672.36	9155.16	6147.27	4790.24	2158.88	375.81	1045.90	2439.72	5769.15	8606.28	11682.99
Zone Heating (kWh)	12691.15	9699.71	9180.77	6163.53	4802.01	2164.03	376.80	1048.37	2445.19	5782.86	8629.84	11715.73
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A177. The simulation detailed results of the house.

Case 60. A House Built in 1900

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are approximately 600mm sandstone construction.	1.671	Increase 19.7 cm Insulation
	Flat -	-
	Pitched 2.088	Increase 32.9 cm Insulation
Floor are of suspended timber and solid concrete on the ground floor and suspended timber on first floor.	1.345	Increase 31.4 cm Insulation
Internal Walls are solid masonry finished with plaster on hard and timber framed partitions finished with plasterboard	1.544	
Windows The windows are u-PVC, double glazed in sash and casement style.		

* As a basis for a theory of possibility

Description

The property is a purpose built traditional two storey mid terrace dwelling with two storey extension to the rear.

The accommodation comprises of

Ground Floor: Entrance hall, living room/dining room family room and kitchen.

First Floor: Landing, four bedrooms and bathroom.

Weather raining and overcast

Heating and hot water

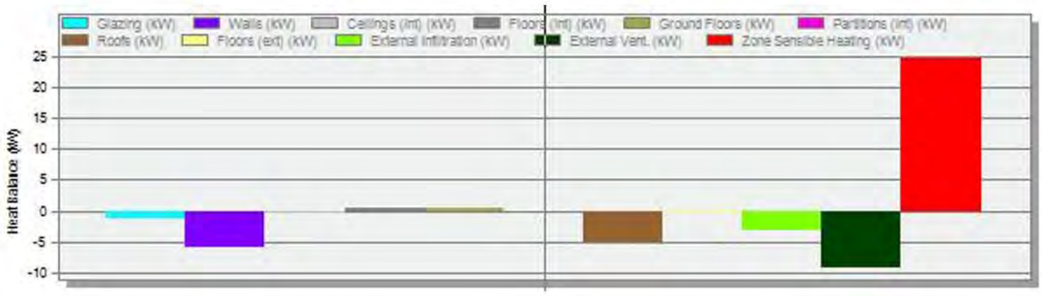
Central heating and hot water is provided by way of gas fired central heating system located within a storage cupboard on the first floor.

Gross internal floor area (m²) 128 m² **approx.**

Address

CUPAR KY15 4DB

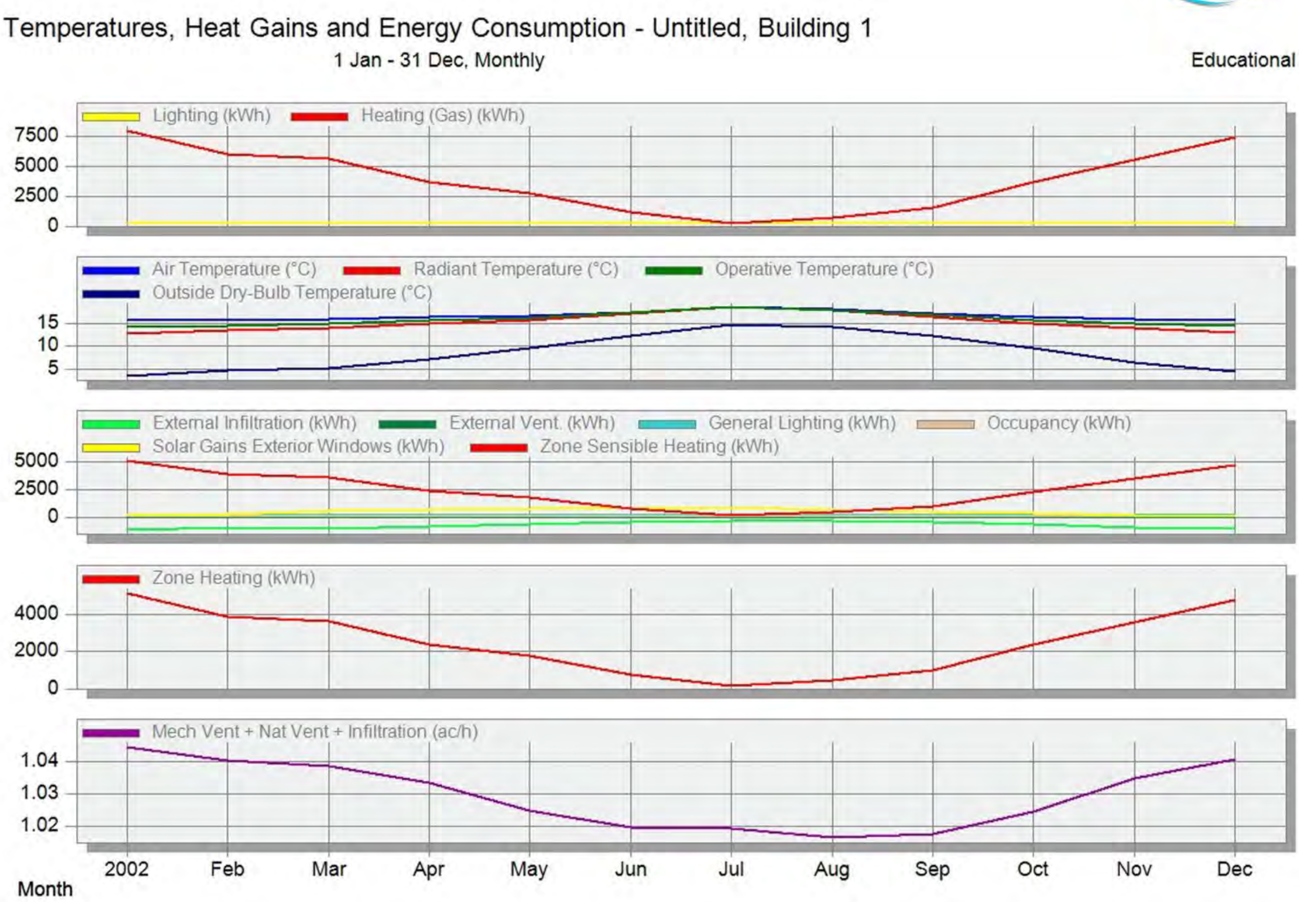
Figure A178. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.18
Operative Temperature (°C)	15.09
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.32
Walls (kW)	-5.99
Ceilings (int) (kW)	-0.46
Floors (int) (kW)	0.46
Ground Floors (kW)	0.52
Partitions (int) (kW)	0.00
Roofs (kW)	-5.10
Floors (ext) (kW)	-0.49
External Infiltration (kW)	-3.09
External Vent. (kW)	-9.26
Zone Sensible Heating (kW)	24.70

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 30.870 (kW)				
Ground Floor Total Design Heating Capacity = 15.910 (kW)				
Veslibule	15.58	0.36	**0.45**	517.4690
Lounge Dining Room	15.22	4.58	**5.73**	252.0786
Hall	17.08	0.95	**1.19**	184.9979
Kitchen	15.37	2.71	**3.39**	268.8299
Bed Room	15.67	4.12	**5.15**	224.5383
Occupied Roof Total Design Heating Capacity = 12.620 (kW)				
Service	14.03	0.44	**0.55**	206.5786
Airing Cupboard	15.24	0.51	**0.64**	211.6400
Bed Room	14.54	3.46	**4.33**	178.1832
Bed Room	14.13	1.07	**1.33**	192.1101
Landing	14.49	0.94	**1.17**	164.8167
Bed Room	14.57	2.52	**3.15**	191.6865
Corridor	15.38	1.16	**1.45**	191.1510
Window Roof Total Design Heating Capacity = 0.710 (kW)				
Zone 1	14.22	0.57	**0.71**	-4468.2901
Roof 1 Total Design Heating Capacity = 0.460 (kW)				
Zone 1	13.07	0.37	**0.46**	7382.6209
Window Roof Total Design Heating Capacity = 0.710 (kW)				
Zone 1	14.22	0.57	**0.71**	-4469.8783
Roof 2 Total Design Heating Capacity = 0.460 (kW)				
Zone 1	13.06	0.37	**0.46**	7382.2925

Figure A179. The heating design simulation and data of the house.



Lighting (kWh)	218.00	197.93	220.67	211.31	218.00	213.98	218.00	219.33	212.65	218.00	212.65	219.33
Heating (Gas) (kWh)	7974.10	6034.23	5635.31	3654.36	2708.42	1164.70	267.39	709.65	1517.93	3632.34	5494.02	7364.70
Air Temperature (°C)	15.63	15.75	15.95	16.38	16.71	17.51	18.65	18.11	17.17	16.42	15.96	15.68
Radiant Temperature (°C)	12.81	13.38	13.98	15.08	15.71	17.14	18.76	17.91	16.54	14.97	13.89	13.04
Operative Temperature (°C)	14.22	14.57	14.96	15.73	16.21	17.33	18.70	18.01	16.86	15.69	14.92	14.36
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1155.87	-944.48	-1009.44	-842.41	-650.29	-449.85	-352.01	-338.07	-433.54	-640.52	-884.33	-1064.19
External Vent. (kWh)	0.00	0.00	0.00	-0.30	-0.02	-1.09	-4.67	-2.10	-0.43	0.00	0.00	0.00
General Lighting (kWh)	218.00	197.93	220.67	211.31	218.00	213.98	218.00	219.33	212.65	218.00	212.65	219.33
Occupancy (kWh)	68.42	62.98	71.39	66.43	68.19	68.49	64.80	67.41	67.89	68.41	68.13	69.95
Solar Gains Exterior Windows (kWh)	199.96	333.24	600.68	723.72	831.65	813.53	862.83	721.97	543.69	351.84	232.58	132.43
Zone Sensible Heating (kWh)	5169.12	3910.89	3651.91	2367.56	1754.72	754.57	173.25	459.94	983.82	2354.10	3560.45	4773.77
Zone Heating (kWh)	5183.17	3922.25	3662.95	2375.33	1760.47	757.06	173.80	461.27	986.66	2361.02	3571.12	4787.06
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.03	1.04

Figure A180. The simulation detailed results of the house.

Case 61. A House Built in 1900

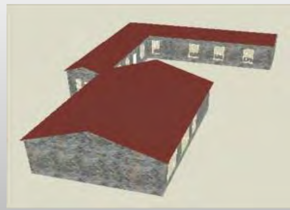
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stonework with a render finish to the rear elevation of the main property.	1.673	Increase 19.8 cm Insulation
	Flat -	-
	Pitched 2.179	Increase 33 cm Insulation
Floors are a mixture of suspended timber and solid concrete construction.	1.329	Increase 31 cm Insulation
Internal Walls have plaster finishes.	1.532	
Windows are of a u-PVC double glazed type.		

* As a basis for a theory of possibility

Description

The subject property comprises converted stables which now provides main living accommodation, annex living accommodation and stables.

The accommodation within the main building comprises:-Ground Floor - Entrance Hall, Living Room, Dining/Kitchen, Master Bedroom with en-suite Shower Room, 2 further Bedrooms, Utility Room and Bathroom with WC.



Weather **Dry but overcast**

Heating and hot water

Central heating and hot water is provided by way of gas fired central heating system located within a storage cupboard on the first floor.

Gross internal floor area (m²) 283 m^2 **approx.**

Address

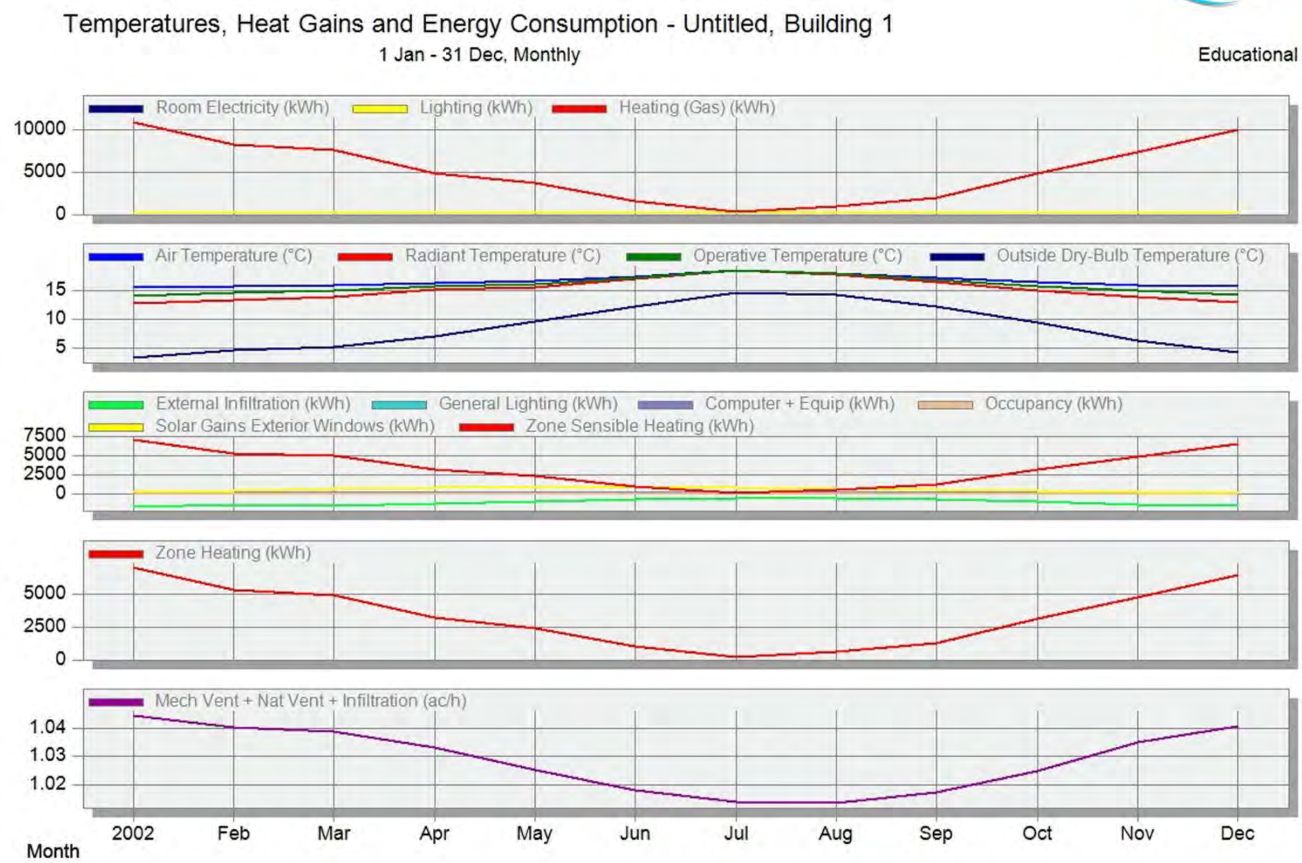
EDINBURGH EH10 7DZ

Figure A181. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.87
Operative Temperature (°C)	14.94
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.59
Walls (kW)	-11.06
Ceilings (int) (kW)	-4.30
Ground Floors (kW)	1.54
Partitions (int) (kW)	0.00
Roofs (kW)	-0.10
External Infiltration (kW)	-4.33
External Vent. (kW)	-12.99
Zone Sensible Heating (kW)	34.76

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 43.450 (kW)				
Ground Floor Total Design Heating Capacity = 43.450 (kW)				
Bed Room	15.05	0.93	**1.16**	419.3931
Bed Room	15.10	2.21	**2.77**	287.4142
Hall	15.16	1.59	**1.99**	370.5510
Service	14.92	1.00	**1.25**	461.0754
Lounge	14.54	2.12	**2.65**	351.0728
Utility Room	14.54	1.32	**1.65**	590.5607
Kitchen DiningRoom	14.79	1.25	**1.57**	382.0009
Hall	16.35	2.51	**3.14**	219.9718
Stables	14.03	6.56	**8.20**	321.4483
Lounge	14.93	4.64	**5.80**	258.1315
Bed Room	15.31	1.12	**1.39**	317.3141
Kitchen DiningRoom	14.95	4.98	**6.23**	256.0467
Service	15.88	0.51	**0.64**	326.2742
Service	15.88	0.54	**0.67**	319.2271
Bed Room	14.64	2.35	**2.94**	342.6947
Bed Room	15.31	1.12	**1.40**	317.6273
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	0.12	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.11	0.00	**0.00**	0.0000

Figure A182. The heating design simulation and data of the house.



Room Electricity (kWh)	159.66	144.21	159.66	154.51	159.66	154.51	159.66	159.66	154.51	159.66	154.51	159.66
Lighting (kWh)	233.01	211.57	235.87	225.86	233.01	228.72	233.01	234.44	227.29	233.01	227.29	234.44
Heating (Gas) (kWh)	10856.70	8162.01	7587.62	4879.42	3740.95	1602.20	309.95	906.99	1945.22	4859.50	7365.43	9979.61
Air Temperature (°C)	15.65	15.78	15.97	16.42	16.69	17.43	18.53	18.06	17.21	16.49	16.01	15.70
Radiant Temperature (°C)	12.76	13.37	14.00	15.15	15.66	17.04	18.63	17.84	16.60	15.03	13.92	13.00
Operative Temperature (°C)	14.20	14.58	14.99	15.79	16.17	17.23	18.58	17.95	16.91	15.76	14.96	14.35
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1621.11	-1324.17	-1416.99	-1187.24	-912.80	-634.02	-505.30	-482.49	-616.36	-901.76	-1240.79	-1491.03
General Lighting (kWh)	233.01	211.57	235.87	225.86	233.01	228.72	233.01	234.44	227.29	233.01	227.29	234.44
Computer + Equip (kWh)	159.66	144.21	159.66	154.51	159.66	154.51	159.66	159.66	154.51	159.66	154.51	159.66
Occupancy (kWh)	73.13	67.32	76.37	71.14	73.10	73.75	69.90	72.51	72.69	73.13	72.82	74.77
Solar Gains Exterior Windows (kWh)	261.98	432.72	753.71	891.28	915.85	872.27	930.07	802.14	630.91	421.95	300.68	174.03
Zone Sensible Heating (kWh)	7036.86	5289.19	4916.41	3161.23	2423.81	1038.07	200.73	587.73	1260.73	3149.18	4772.62	6467.87
Zone Heating (kWh)	7056.86	5305.30	4931.96	3171.62	2431.62	1041.43	201.47	589.54	1264.39	3158.67	4787.53	6486.74
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.02	1.03	1.04

Figure A183. The simulation detailed results of the house.

Case 62. A House Built in 1895

Material	U-Value W/m^{2}K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone 0.6m thick and pointed.	1.694	Increase 19.9 cm Insulation
	Flat -	-
	Pitched 2.180	Increase 33 cm Insulation
Floors are of suspended timber construction.	1.391	Increase 31.5 cm Insulation
Internal Walls are partly plastered on the hard and partly timber stud.	1.533	
Windows are of u-PVC framed double glazed variety.		

* As a basis for a theory of possibility

Description

Ground floor flat within a two storey detached building.

Ground floor: Vestibule, Hall, Living Room, Two Bedrooms, Kitchen, Bathroom.

Weather Dry.

Heating and hot water

There is a Potterton Promax Combi 28 HE A gas fired central heating boiler wall mounted in the kitchen. This supplies steel panel radiators a number of which are fitted with thermostatic valves. The boiler also provides the domestic hot water.

Gross internal floor area(m²) 70 m^2

Address

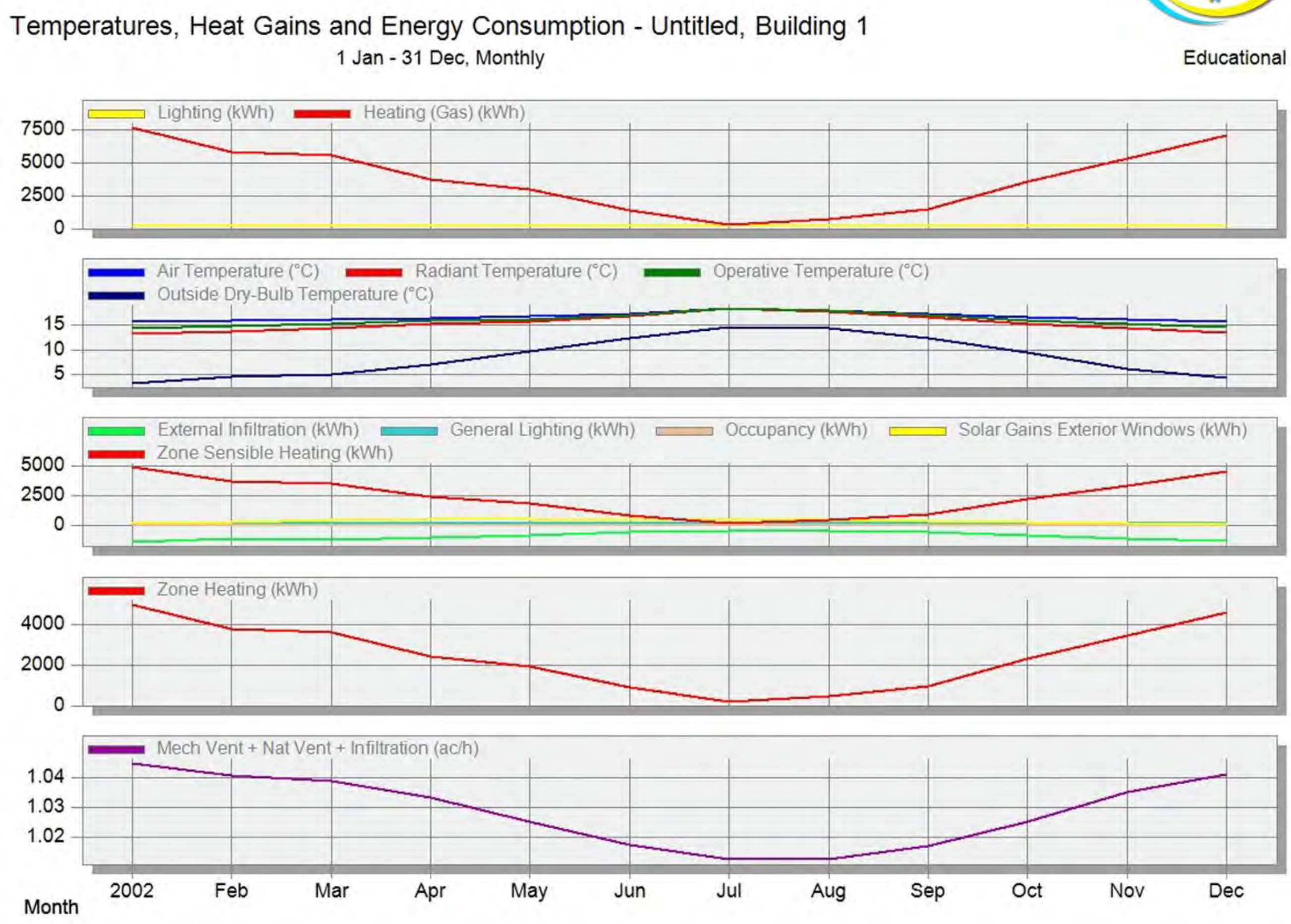
DUNFERMLINE KY12 9DS

Figure A184. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.74
Operative Temperature (°C)	15.37
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-0.93
Walls (kW)	-8.82
Ceilings (int) (kW)	-2.21
Floors (int) (kW)	0.31
Ground Floors (kW)	0.48
Partitions (int) (kW)	0.00
External Infiltration (kW)	-3.63
External Vent. (kW)	-10.90
Zone Sensible Heating (kW)	25.68

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 32.100 (kW)				
Ground Floor Total Design Heating Capacity = 15.350 (kW)				
Hall	16.65	1.69	**2.11**	228.3279
Bed Room	15.61	2.66	**3.33**	246.8392
Sitting Room	15.68	3.67	**4.59**	228.5951
Service	16.29	0.59	**0.74**	264.8042
Bed Room	15.45	1.82	**2.28**	282.4379
Kitchen	15.33	1.84	**2.30**	285.2137
First Floor Total Design Heating Capacity = 16.750 (kW)				
Longe	14.93	3.99	**4.99**	248.4487
Bed Room	14.94	4.00	**5.00**	248.7822
Service	15.66	1.46	**1.82**	248.6091
Bed Room	14.86	1.96	**2.45**	302.5480
Kitchen	14.76	1.99	**2.49**	309.1536
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.45	0.00	**0.00**	0.0000

Figure A185. The heating design simulation and data of the house.



Lighting (kWh)	204.37	185.56	206.88	198.10	204.37	200.61	204.37	205.62	199.35	204.37	199.35	205.62
Heating (Gas) (kWh)	7655.73	5836.89	5526.74	3747.54	2953.37	1358.24	276.50	723.68	1483.11	3544.89	5279.16	7070.69
Air Temperature (°C)	15.68	15.83	16.02	16.43	16.69	17.27	18.22	17.90	17.20	16.56	16.08	15.75
Radiant Temperature (°C)	13.19	13.73	14.26	15.24	15.67	16.85	18.35	17.73	16.66	15.27	14.26	13.41
Operative Temperature (°C)	14.43	14.78	15.14	15.83	16.18	17.06	18.29	17.82	16.93	15.91	15.17	14.58
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1364.70	-1117.90	-1195.57	-999.50	-767.77	-517.73	-392.27	-389.32	-517.08	-766.22	-1050.83	-1257.51
General Lighting (kWh)	204.37	185.56	206.88	198.10	204.37	200.61	204.37	205.62	199.35	204.37	199.35	205.62
Occupancy (kWh)	64.14	59.05	67.02	62.44	64.14	65.11	62.39	64.25	63.87	64.14	63.88	65.58
Solar Gains Exterior Windows (kWh)	195.49	305.69	499.55	552.69	545.68	506.13	543.97	489.65	413.54	294.23	223.19	129.97
Zone Sensible Heating (kWh)	4960.25	3781.25	3580.21	2427.86	1913.69	880.25	179.16	469.06	961.42	2297.30	3420.04	4580.99
Zone Heating (kWh)	4976.22	3793.98	3592.38	2435.90	1919.69	882.86	179.73	470.39	964.02	2304.18	3431.46	4595.95
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A186. The simulation detailed results of the house.

Case 63. A House Built in 1892

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone pointed externally and strapped and lined with plasterboard internally.	1.697	Increase 20 cm Insulation
	Flat -	-
	Pitched 2.159	Increase 32.9 cm Insulation
Floor is of a floating floor comprising flooring grade chipboard supported on timber batons over solid concrete.	1.389	Increase 31.5 cm Insulation
Internal Walls are timber stud lined with plasterboard.	1.581	
Windows are partly double glazed timber casement variety, partly double glazed u-PVC.		

* As a basis for a theory of possibility

Description

Detached two storey house.

Ground floor: entrance hall, office/bedroom, shower room, kitchen, dining room, toilet, bedroom with en suite bathroom and dressing room, morning room with utility room off, shower room, laundry room and kitchen/breakfast room.

First floor: Lounge, Master Bedroom with En Suite Dressing Room and Shower Room, Two Further Bedrooms with En Suite.

Weather Dry and Sunny

Heating and hot water

There is a Worcester Greenstar Utility oil fired central heating boiler floor standing in the garage. This supplies steel panel radiators throughout and also provides the domestic hot water. There are two Santon Premier Plus Solar unvented hot water systems.

Gross internal floor area (m²) 407 m^2 **approx.**

Address

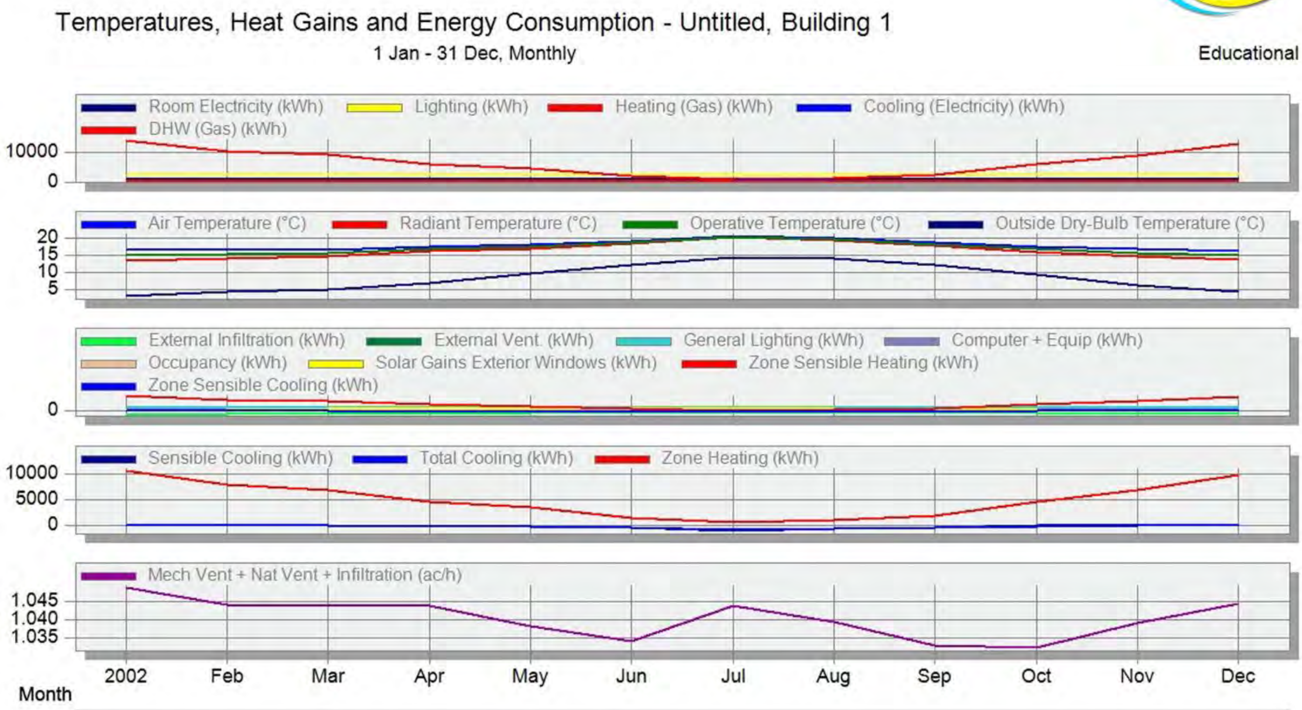
BALADO KINROSS KY13 0NL

Figure A187. The Software visualization of the house.

Air Temperature (°C)	20.77
Radiant Temperature (°C)	13.79
Operative Temperature (°C)	17.28
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-5.39
Walls (kW)	-18.59
Ceilings (int) (kW)	-2.34
Floors (int) (kW)	1.38
Ground Floors (kW)	0.38
Partitions (int) (kW)	-0.04
Roofs (kW)	-9.32
Floors (ext) (kW)	-0.97
External Infiltration (kW)	-6.58
External Vent. (kW)	-9.67
Zone Sensible Heating (kW)	51.07

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 63.840 (kW)				
Ground Floor Total Design Heating Capacity = 35.000 (kW)				
Garage	17.23	4.52	**5.65**	352.0230
Corridor	20.55	0.39	**0.49**	170.6433
Service	20.14	0.67	**0.84**	202.5570
Morning Room	18.11	2.71	**3.39**	301.2704
Corridor	19.51	0.27	**0.34**	574.9143
Bed room	18.64	2.63	**3.29**	245.5738
Storage	19.08	0.80	**1.00**	336.0566
Storage	20.16	0.20	**0.25**	409.2230
Veslibule	19.30	0.63	**0.79**	360.2623
Hall	19.36	1.76	**2.21**	217.3486
Annex Service	19.60	0.78	**0.98**	246.1164
Annex Kitchen	19.94	0.98	**1.23**	185.3818
Corridor	20.83	0.16	**0.20**	227.9517
Service	20.54	0.37	**0.46**	209.7835
Service	20.31	0.56	**0.70**	194.8393
Hall	18.03	1.39	**1.74**	648.5816
Dining room	20.08	1.02	**1.28**	175.0306
Corridor	19.60	0.24	**0.30**	587.7195
Service	19.95	1.22	**1.53**	174.7667
Hall	18.24	0.61	**0.76**	907.5926
Lounge	17.92	3.05	**3.81**	299.5522
Kitchen	17.28	3.01	**3.76**	369.9279
First Floor Total Design Heating Capacity = 14.150 (kW)				
Snug	16.27	0.47	**0.59**	143.0006
Bedroom	15.97	1.42	**1.78**	133.9863
Corridor	15.77	1.48	**1.85**	179.9314
Bedroom	16.22	0.46	**0.57**	146.3941
Service	16.04	0.95	**1.18**	161.6127

Figure A188. The heating design simulation and data of the house.



Room Electricity (kWh)	897.61	784.03	828.60	859.75	897.61	790.74	897.61	863.11	825.25	897.61	825.25	863.11
Lighting (kWh)	2530.04	2206.62	2327.03	2422.23	2530.04	2219.23	2530.04	2428.54	2320.73	2530.04	2320.73	2428.54
Heating (Gas) (kWh)	13789.94	10267.25	9141.75	6045.00	4612.79	2026.89	838.06	1330.86	2459.12	5883.45	8921.42	12761.72
Cooling (Electricity) (kWh)	0.00	0.00	10.56	85.91	142.33	307.76	639.38	412.26	202.88	24.04	0.00	0.00
DHW (Gas) (kWh)	98.07	85.28	89.54	93.80	98.07	85.28	98.07	93.80	89.54	98.07	89.54	93.80
Air Temperature (°C)	16.51	16.59	16.77	17.66	18.20	19.12	20.63	20.01	18.69	17.64	16.82	16.46
Radiant Temperature (°C)	13.57	14.10	14.75	16.19	17.00	18.55	20.42	19.53	17.85	16.04	14.71	13.71
Operative Temperature (°C)	15.04	15.35	15.76	16.92	17.60	18.84	20.53	19.77	18.27	16.84	15.76	15.09
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2383.50	-1960.77	-2099.07	-1856.44	-1528.68	-1144.32	-1038.94	-989.37	-1108.39	-1467.29	-1870.97	-2190.02
External Vent. (kWh)	0.00	0.00	-2.74	-10.91	-13.75	-13.07	-24.68	-17.01	-13.68	-4.63	0.00	0.00
General Lighting (kWh)	2530.04	2206.62	2327.03	2422.23	2530.04	2219.23	2530.04	2428.54	2320.73	2530.04	2320.73	2428.54
Computer + Equip (kWh)	897.61	784.03	828.60	859.75	897.61	790.74	897.61	863.11	825.25	897.61	825.25	863.11
Occupancy (kWh)	473.90	414.60	435.94	444.48	460.31	401.15	438.45	428.37	419.95	466.11	436.32	456.83
Solar Gains Exterior Windows (kWh)	450.01	809.03	1479.52	1895.26	2034.91	1996.26	2109.33	1751.36	1293.36	793.04	531.05	301.97
Zone Sensible Heating (kWh)	10452.20	7767.28	6904.27	4593.27	3528.22	1574.65	665.44	1046.95	1908.31	4471.35	6749.71	9664.92
Zone Sensible Cooling (kWh)	0.00	-0.00	-12.27	-106.53	-176.54	-386.38	-793.57	-501.85	-236.16	-24.49	0.00	0.00
Sensible Cooling (kWh)	0.00	-0.00	-12.27	-106.54	-176.54	-386.38	-793.57	-501.86	-236.16	-24.49	0.00	0.00
Total Cooling (kWh)	0.00	-0.00	-14.79	-120.27	-199.27	-430.86	-895.13	-577.16	-284.03	-33.65	0.00	0.00
Zone Heating (kWh)	10481.07	7790.42	6926.82	4611.36	3544.18	1582.95	670.13	1053.23	1918.15	4488.25	6770.87	9691.37
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.04	1.04	1.03	1.04	1.04	1.03	1.03	1.04	1.04

Figure A189. The simulation detailed results of the house.

Case 64. A House Built in 1891

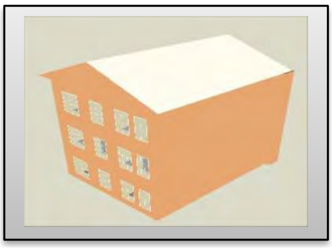
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of 600mm solid stone construction being pointed externally.	1.700	Increase 20 cm Insulation
	Flat -	-
	Pitched 2.183	Increase 32.9 cm Insulation
Floors are of suspended timber construction.	1.404	Increase 31.5 cm Insulation
Internal Walls are plastered on the hard and plasterboard lined.	1.575	
Windows are the original timber frame sash and casement style.		

* As a basis for a theory of possibility

Description

The subjects comprise a first floor flat situated in a four storey tenement.

First Floor: Hallway, living room, five bedrooms, kitchen and bathroom.



Weather Overcast with rain.

Heating and hot water

Gas fire central heating system with radiators. The central heating boiler is situated in the rear bedroom wall press.

Gross internal floor area(m²) 102 m^2

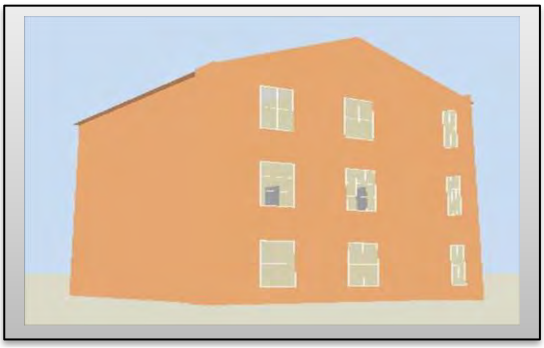


Figure A190. The Software visualization of the house.

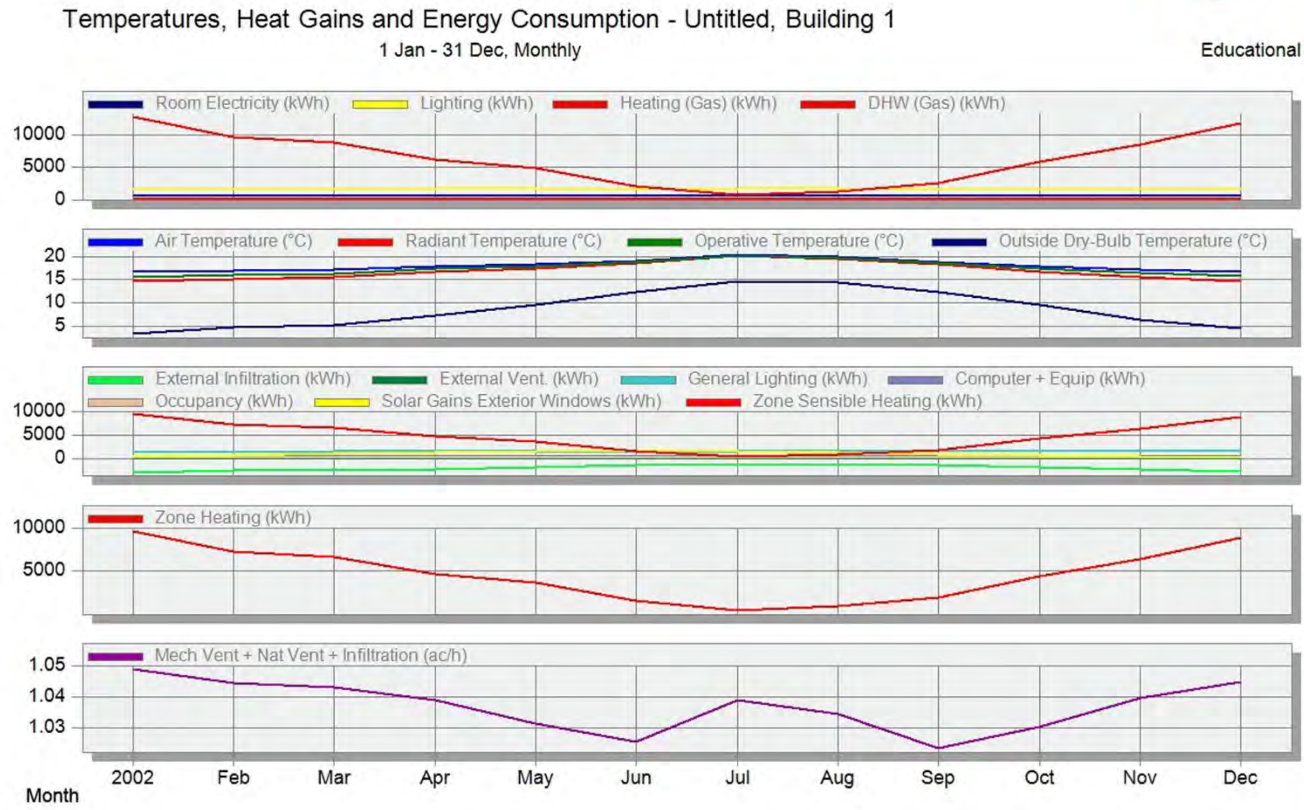
Address

EDINBURGH EH7 5HN

Air Temperature (°C)	20.67
Radiant Temperature (°C)	15.34
Operative Temperature (°C)	18.00
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.22
Walls (kW)	-20.36
Ceilings (int) (kW)	-3.48
Floors (int) (kW)	0.46
Ground Floors (kW)	0.06
Partitions (int) (kW)	0.00
Roofs (kW)	-0.08
External Infiltration (kW)	-7.71
External Vent. (kW)	-12.18
Zone Sensible Heating (kW)	46.43

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 58.010 (kW)				
First Floor Total Design Heating Capacity = 18.080 (kW)				
Hall	19.67	1.96	**2.45**	215.0139
Bed Room N	20.27	1.15	**1.43**	162.2647
Lounge	18.55	2.91	**3.63**	241.9473
Bed Room N	20.16	0.98	**1.22**	172.8820
Bed Room N	19.03	1.59	**1.99**	297.2855
Kitchen	19.77	0.94	**1.18**	202.6149
Bed Room S	19.11	2.35	**2.93**	221.4534
Bed Room S	19.70	0.98	**1.23**	205.2505
Bath Room	18.52	1.62	**2.02**	309.3266
Second Floor Total Design Heating Capacity = 19.270 (kW)				
Hall	16.35	2.01	**2.51**	219.6907
Bed Room N 1	16.74	1.35	**1.69**	191.4525
Lounge	15.18	3.10	**3.87**	257.7837
Bed Room N 2	16.57	1.15	**1.44**	203.5543
Bed Room N	15.55	1.62	**2.02**	301.3598
Kitchen	16.45	0.98	**1.22**	209.7600
Bed Room S 1	15.72	2.51	**3.14**	236.7301
Bed Room S	16.10	1.11	**1.38**	230.6319
Bath Room	15.17	1.60	**2.00**	305.0189
Third Floor Total Design Heating Capacity = 20.660 (kW)				
Hall	19.12	2.26	**2.82**	247.4730
Bed Room N 1	19.65	1.35	**1.69**	191.2201
Lounge	17.91	3.26	**4.07**	270.9795
Bed Room N 2	19.57	1.15	**1.43**	202.4039
Bed Room N	18.53	1.80	**2.25**	335.5878
Kitchen	19.21	1.09	**1.36**	234.0432
Bed Room S 1	18.49	2.67	**3.34**	251.8424
Bed Room S	19.12	1.14	**1.42**	237.2287

Figure A191. The heating design simulation and data of the house.



Room Electricity (kWh)	609.92	532.75	563.03	584.20	609.92	537.30	609.92	586.48	560.75	609.92	560.75	586.48
Lighting (kWh)	1734.22	1513.07	1596.47	1660.50	1734.22	1522.75	1734.22	1665.34	1591.63	1734.22	1591.63	1665.34
Heating (Gas) (kWh)	12772.61	9670.65	8845.99	6268.57	4890.41	2073.30	662.17	1227.05	2498.57	5866.74	8555.69	11892.52
DHW (Gas) (kWh)	66.64	57.94	60.84	63.74	66.64	57.94	66.64	63.74	60.84	66.64	60.84	63.74
Air Temperature (°C)	16.71	16.87	17.05	17.86	18.33	18.95	20.36	19.88	18.81	17.96	17.21	16.69
Radiant Temperature (°C)	14.54	15.04	15.59	16.73	17.37	18.51	20.18	19.56	18.23	16.76	15.65	14.63
Operative Temperature (°C)	15.62	15.95	16.32	17.29	17.85	18.73	20.27	19.72	18.52	17.36	16.43	15.66
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2819.63	-2327.60	-2494.47	-2194.32	-1803.31	-1322.64	-1187.87	-1146.96	-1310.33	-1750.04	-2231.46	-2594.56
External Vent. (kWh)	0.00	0.00	0.00	-0.72	-0.17	-2.39	-24.05	-11.95	-0.49	0.00	0.00	0.00
General Lighting (kWh)	1734.22	1513.07	1596.47	1660.50	1734.22	1522.75	1734.22	1665.34	1591.63	1734.22	1591.63	1665.34
Computer + Equip (kWh)	609.92	532.75	563.03	584.20	609.92	537.30	609.92	586.48	560.75	609.92	560.75	586.48
Occupancy (kWh)	326.74	286.23	303.73	313.05	326.61	286.91	312.18	304.97	300.61	326.69	301.74	315.25
Solar Gains Exterior Windows (kWh)	424.88	726.25	1256.73	1521.52	1573.98	1534.94	1577.12	1370.13	1070.24	714.99	491.42	285.87
Zone Sensible Heating (kWh)	9486.40	7182.08	6567.54	4694.99	3686.12	1578.84	522.87	949.47	1907.23	4393.28	6360.14	8830.51
Zone Heating (kWh)	9517.60	7206.25	6590.39	4712.10	3700.15	1585.80	526.33	954.28	1915.40	4408.74	6381.70	8858.87
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.04	1.03	1.03	1.04	1.03	1.02	1.03	1.04	1.04

Figure A192. The simulation detailed results of the house.

Case 65. A House Built in 1890

Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone construction. There is a canopy fixed to the rear wall.	1.706	Increase 20 cm Insulation
	Flat 2.183	Increase 31 cm Insulation
	Pitched 2.186	Increase 32.9 cm Insulation
Floors are mostly of suspended timber construction with solid flooring on the ground floor of the outshoot.	1.408	Increase 31 cm Insulation
Internal Walls are mostly of brick construction plastered on the hard	1.577	
Windows are of traditional single glazed double hung sash and casement design.		

* As a basis for a theory of possibility

Description

The subject form a two story detached, modern villa with annex flat and double garage all set within garden grounds.
Ground Floor: Entrance Vestibule and Reception Hall, Sitting room, Dining room, Studyroom, Kitchen/breakfast room, Box room, Utility room and Cloakroom with W.C and wash hand basin.

A stair leads up from the kitchen to the original maid's room.
First Floor: Landing, Four Bedroom, jack and Jill shower room and bathroom.

Weather Dry and Overcast.

Heating and hot water

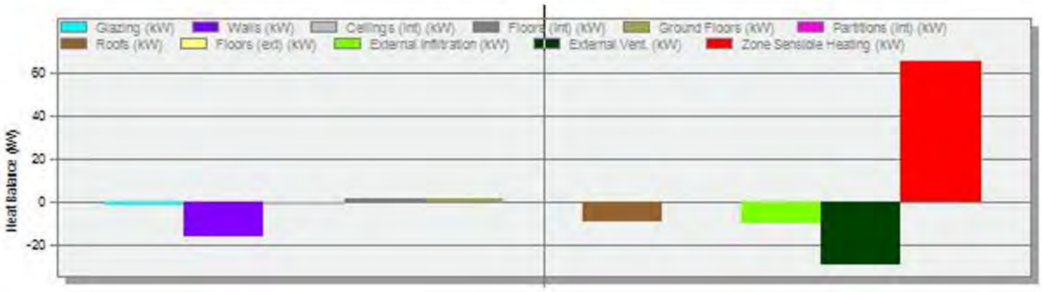
here is a gas fired central heating system with an older style floor mounted Ideal Concord boiler housed in the utility room serving a mixture of column style and flush panel radiators in all rooms (except in the shower room and cloakroom). There is a stainless steel flue mounted externally serving the central heating boiler.

Gross internal floor area (m²) 320 m^2 **approx.**

Address

EDINBURGH EH6 1DG

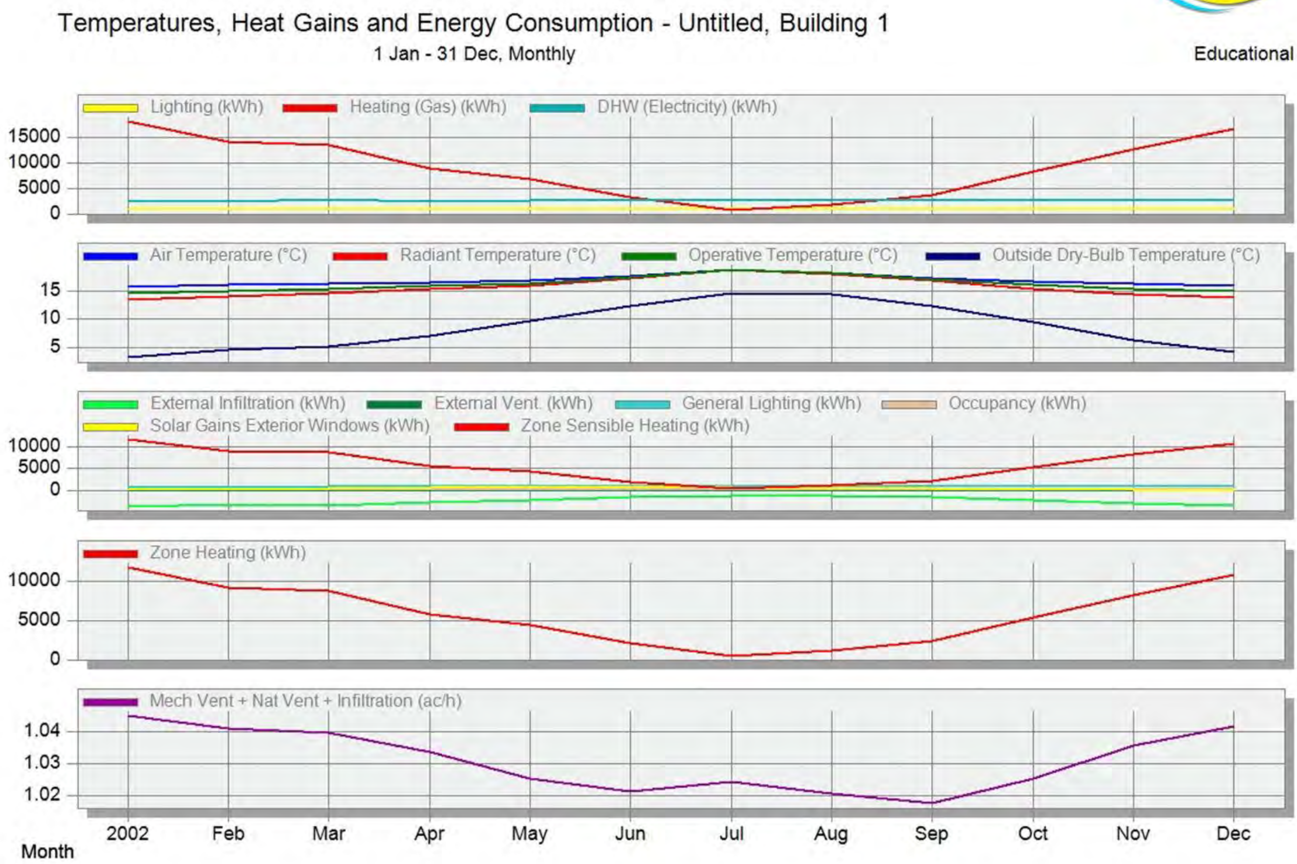
Figure A193. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.35
Operative Temperature (°C)	15.68
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.59
Walls (kW)	-16.05
Ceilings (int) (kW)	-1.87
Floors (int) (kW)	1.42
Ground Floors (kW)	1.08
Partitions (int) (kW)	0.01
Roofs (kW)	-9.01
Floors (ext) (kW)	-0.12
External Infiltration (kW)	-9.85
External Vent. (kW)	-29.55
Zone Sensible Heating (kW)	65.46

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 81.800 (kW)				
Ground Floor Total Design Heating Capacity = 28.870 (kW)				
Kitchen	16.41	2.91	**3.63**	172.5503
Hall Landing	17.04	2.94	**3.68**	154.4274
Studing Room	15.93	3.05	**3.81**	192.1031
Store	17.42	0.26	**0.32**	156.0965
Cloak Room	17.07	0.82	**1.03**	168.6014
Store	16.61	0.22	**0.27**	291.1695
Dining Room	15.95	3.60	**4.50**	187.5893
Drawing Room	16.27	4.27	**5.34**	172.1267
Vestibule	16.25	0.68	**0.84**	231.8163
Office	16.69	0.80	**1.00**	188.3855
Utility Room	15.10	2.55	**3.19**	272.3162
Service	15.31	1.01	**1.26**	299.9327
Garage Total Design Heating Capacity = 2.690 (kW)				
Zone 1	14.01	2.15	**2.69**	240.3813
First Floor Total Design Heating Capacity = 28.970 (kW)				
Bed Room	15.88	3.58	**4.47**	184.6423
Master BedRoom	15.96	5.69	**7.12**	174.7119
Bed Room	16.78	3.87	**4.84**	150.6078
Service	17.29	0.92	**1.15**	143.8045
Service	16.57	1.07	**1.33**	180.0021
Lnading Hall	16.63	1.98	**2.47**	164.2861
Bed Room	15.78	2.26	**2.82**	202.8471
Bed Room	14.28	3.82	**4.77**	275.9162
Attic Total Design Heating Capacity = 5.130 (kW)				
Zone 1	16.46	4.10	**5.13**	34.3642

Figure A194. The heating design simulation and data of the house.



Lighting (kWh)	923.31	853.31	973.31	899.97	923.31	949.98	923.31	948.31	924.98	923.31	924.98	948.31
Heating (Gas) (kWh)	18096.27	13980.92	13434.85	8794.26	6669.75	3155.40	762.03	1801.67	3546.02	8308.45	12605.47	16585.69
DHW (Electricity) (kWh)	2534.53	2401.87	2825.45	2490.31	2534.53	2781.23	2534.53	2679.99	2635.77	2534.53	2635.77	2679.99
Air Temperature (°C)	15.73	15.94	16.14	16.45	16.70	17.59	18.68	18.15	17.23	16.55	16.13	15.88
Radiant Temperature (°C)	13.48	13.98	14.46	15.36	15.83	17.19	18.70	17.90	16.69	15.35	14.42	13.77
Operative Temperature (°C)	14.61	14.96	15.30	15.91	16.27	17.39	18.69	18.02	16.96	15.95	15.28	14.82
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3696.34	-3051.04	-3271.11	-2707.79	-2073.90	-1447.27	-1108.54	-1079.51	-1409.97	-2082.19	-2861.94	-3437.78
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-5.10	-21.27	-12.49	0.00	0.00	0.00	0.00
General Lighting (kWh)	923.31	853.31	973.31	899.97	923.31	949.98	923.31	948.31	924.98	923.31	924.98	948.31
Occupancy (kWh)	238.75	224.38	261.23	233.54	237.76	249.75	223.68	238.81	243.69	238.75	245.24	250.03
Solar Gains Exterior Windows (kWh)	157.51	286.28	523.69	658.17	707.04	706.02	735.47	605.44	453.27	283.39	183.35	104.65
Zone Sensible Heating (kWh)	11714.14	9051.03	8698.26	5693.35	4316.67	2041.06	492.33	1165.53	2295.33	5380.20	8160.96	10737.55
Zone Heating (kWh)	11762.57	9087.60	8732.65	5716.27	4335.33	2051.01	495.32	1171.09	2304.91	5400.49	8193.55	10780.70
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.02	1.03	1.04	1.04

Figure A195. The simulation detailed results of the house.

Case 66. A House Built in 1890

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are a mixture of traditional of stone and brick construction rendered with roughcast and painted externally.	1.709	Increase 20 cm Insulation
	Flat 2.186	Increase 32.4 cm Insulation
	Pitched 2.126	Increase 32.8 cm Insulation
Floors are mostly of suspended timber construction with some solid sections at ground level.	1.413	Increase 31.5 cm Insulation
Internal Walls are mostly of solid construction and plastered on the hard.	1.581	
Windows are of traditional timber casement design with a mixture of single and double glazed panels.		

* As a basis for a theory of possibility

Description

The subject comprise a semidetached Victorian family house.
Ground Floor: Entrance porch/Sun room, Reception hall, Drawing room, Sitting room, Kitchen/breakfast, Cloakroom with W.C and wash hand basin and rear porch.

First Floor: Landing, principle bedroom with en suite bathroom, two Bedroom with en suite bathroom, two further bedroom and shower room.

Weather Dry

Heating and hot water

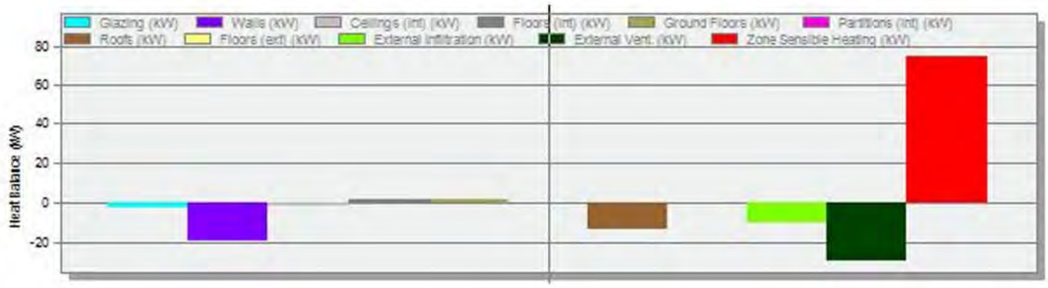
There is a gas fired central heating system on the ground floor with a Worcester Greenstar boiler serving a mixture of column and flush panel radiators and with electric room heaters serving the upper floor bedrooms. There is underfloor heating in the sum room. Hot water is supplied by the central heating boiler and it is assumed that there is a backup immersion heater to the hot water cylinder.

Gross internal floor area (m²) 339.5 m^2

Address

EAST LOTHIAN EH31 2DH

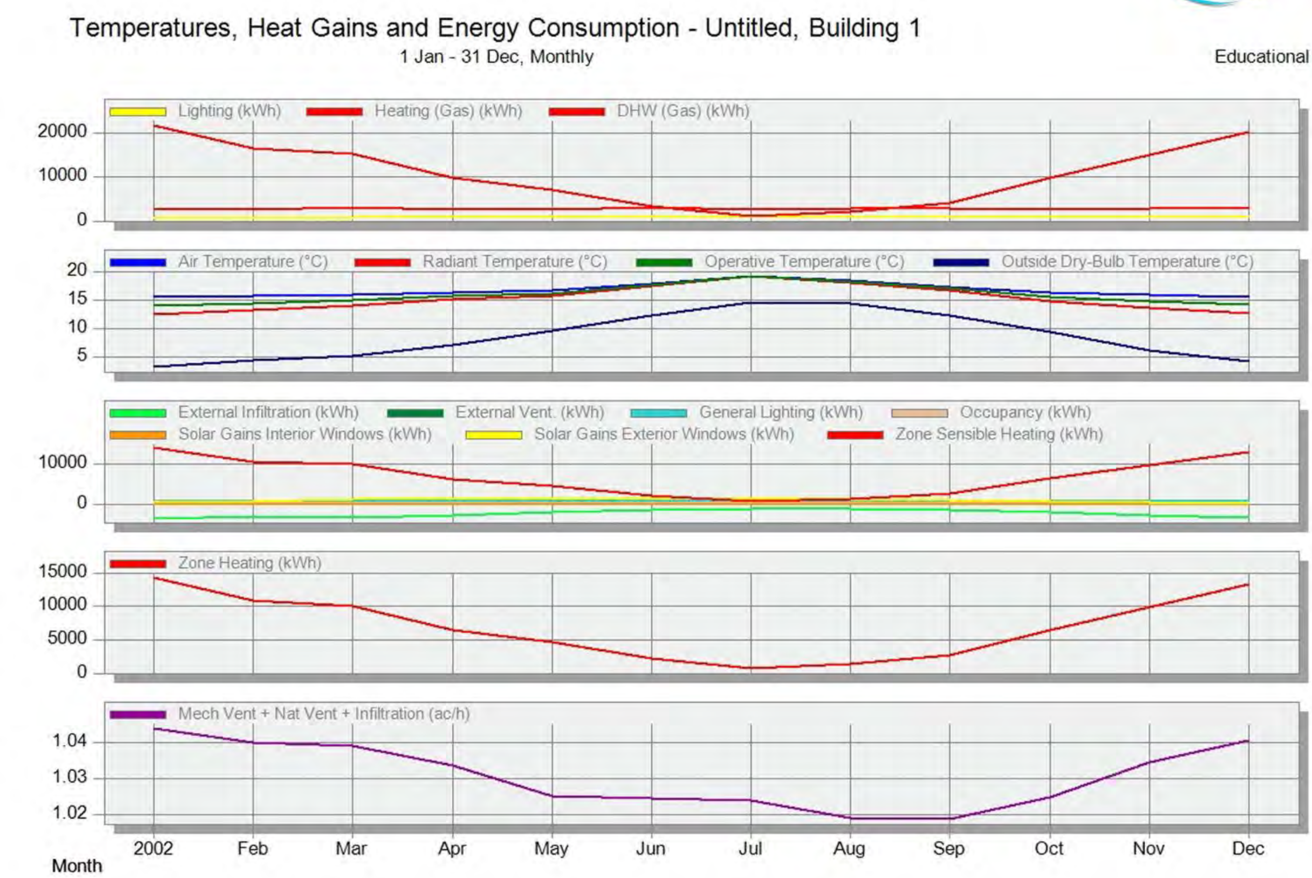
Figure A196. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.79
Operative Temperature (°C)	14.90
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.66
Walls (kW)	-19.79
Ceilings (int) (kW)	-1.52
Floors (int) (kW)	1.42
Ground Floors (kW)	1.72
Partitions (int) (kW)	-0.01
Roofs (kW)	-13.33
Floors (ext) (kW)	-0.36
External Infiltration (kW)	-9.97
External Vent. (kW)	-29.90
Zone Sensible Heating (kW)	74.20

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 92.730 (kW)				
Ground Floor Total Design Heating Capacity = 35.580 (kW)				
Sitting Room	15.08	6.14	**7.68**	205.0285
Sitting Room	15.88	4.88	**6.10**	181.2276
Vestibule	16.11	4.48	**5.60**	177.0744
Store	15.07	1.02	**1.27**	330.5197
Service	16.50	0.70	**0.88**	204.6188
Family Room	15.97	3.80	**4.75**	182.8165
Kitchen DiningRoom	15.60	6.35	**7.94**	187.5282
LivingRoom Vestibule	14.72	1.09	**1.36**	321.6594
Garage Total Design Heating Capacity = 9.190 (kW)				
Zone 2	13.99	3.67	**4.59**	282.6049
Zone 1	13.97	3.68	**4.60**	283.6579
First Floor Total Design Heating Capacity = 31.540 (kW)				
Master BedRoom	15.16	5.76	**7.20**	182.4910
Service	15.49	2.23	**2.78**	195.4020
Shower Room	15.73	4.56	**5.70**	166.4873
Double BedRoom	16.21	1.84	**2.30**	162.0905
Double BedRoom	15.96	3.22	**4.02**	161.5318
Hall	15.57	1.68	**2.09**	200.6249
Double BedRoom	15.24	3.82	**4.78**	184.1040
BathRoom	14.42	2.13	**2.67**	250.2633
Main Roof Total Design Heating Capacity = 16.420 (kW)				
Zone 1	13.10	13.14	**16.42**	136.8337

Figure A197. The heating design simulation and data of the house.



Lighting (kWh)	774.81	715.85	816.21	755.16	774.81	796.56	774.81	795.51	775.86	774.81	775.86	795.51
Heating (Gas) (kWh)	21886.79	16517.42	15431.06	9755.61	7188.71	3365.49	1007.00	2182.03	4186.11	9882.57	15168.36	20250.13
DHW (Gas) (kWh)	2733.39	2590.32	3047.14	2685.70	2733.39	2999.45	2733.39	2890.26	2842.57	2733.39	2842.57	2890.26
Air Temperature (°C)	15.45	15.64	15.92	16.35	16.62	17.79	19.03	18.27	17.23	16.30	15.80	15.56
Radiant Temperature (°C)	12.48	13.15	13.90	15.14	15.71	17.49	19.18	18.07	16.65	14.81	13.60	12.75
Operative Temperature (°C)	13.97	14.39	14.91	15.74	16.17	17.64	19.10	18.17	16.94	15.55	14.70	14.15
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3666.67	-3014.63	-3252.94	-2711.28	-2078.22	-1535.21	-1252.32	-1149.32	-1438.68	-2044.80	-2812.02	-3391.99
External Vent. (kWh)	0.00	0.00	0.00	-0.71	0.00	-12.49	-20.72	-10.72	-1.71	0.00	0.00	0.00
General Lighting (kWh)	774.81	715.85	816.21	755.16	774.81	796.56	774.81	795.51	775.86	774.81	775.86	795.51
Occupancy (kWh)	201.09	188.90	219.40	195.76	199.49	206.75	185.38	198.44	204.37	201.05	206.41	210.48
Solar Gains Interior Windows (kWh)	0.32	0.54	1.02	1.20	1.26	1.20	1.25	1.11	0.86	0.56	0.36	0.22
Solar Gains Exterior Windows (kWh)	405.35	668.10	1200.30	1363.66	1429.85	1368.29	1456.54	1256.13	1011.37	672.27	461.42	266.83
Zone Sensible Heating (kWh)	14168.09	10689.89	9986.31	6311.09	4648.60	2175.52	650.85	1411.42	2709.29	6395.48	9815.22	13108.08
Zone Heating (kWh)	14226.41	10736.32	10030.19	6341.15	4672.66	2187.57	654.55	1418.32	2720.97	6423.67	9859.44	13162.58
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.03	1.04

Figure A198. The simulation detailed results of the house.

Appendix A

Case 67. A House Built in 1890

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are stone features of a decorative nature.	1.721	Increase 20.2 cm Insulation
	Flat 2.167	Increase 32.4 cm Insulation
	Pitched 2.185	Increase 32.7 cm Insulation
Floors are predominantly of suspended construction, formed by timber joists supporting tongue and groove timber flooring.	1.494	Increase 31.7 cm Insulation
Internal Walls are predominantly lined in lath and plaster.	1.584	
Windows are original timber sash and case units.		

* As a basis for a theory of possibility

Description

Two storey large detached villa.

Ground Floor: Entrance Vestibule with Toilet off, Entrance Hall, Sitting room, Dining room, Family Room, Kitchen, Study, Rear Hall, Various Passages, Rear Vestibule, Bedroom with separate Bathroom adjacent, Rear Hall, Utility Room and Larder.

First Floor: Half Landing with Bedroom off, Upper Landing, Five Bedrooms and Bathroom, Rear Landing, Lower Hall, Two Bedrooms, Box room and Bathroom.

Weather Dry and Sunny

Heating and hot water

A "Keston C90" gas fired central heating boiler serves a full system of water filled radiators, fitted with thermostatic radiator valves throughout. The boiler also provides the domestic hot water supply, which is centered on a large spray insulated copper hot water cylinder in the bathroom. This is fitted both with an immersion heater and a thermostat.

Gross internal floor area (m²) 470 m² **approx.**

Address

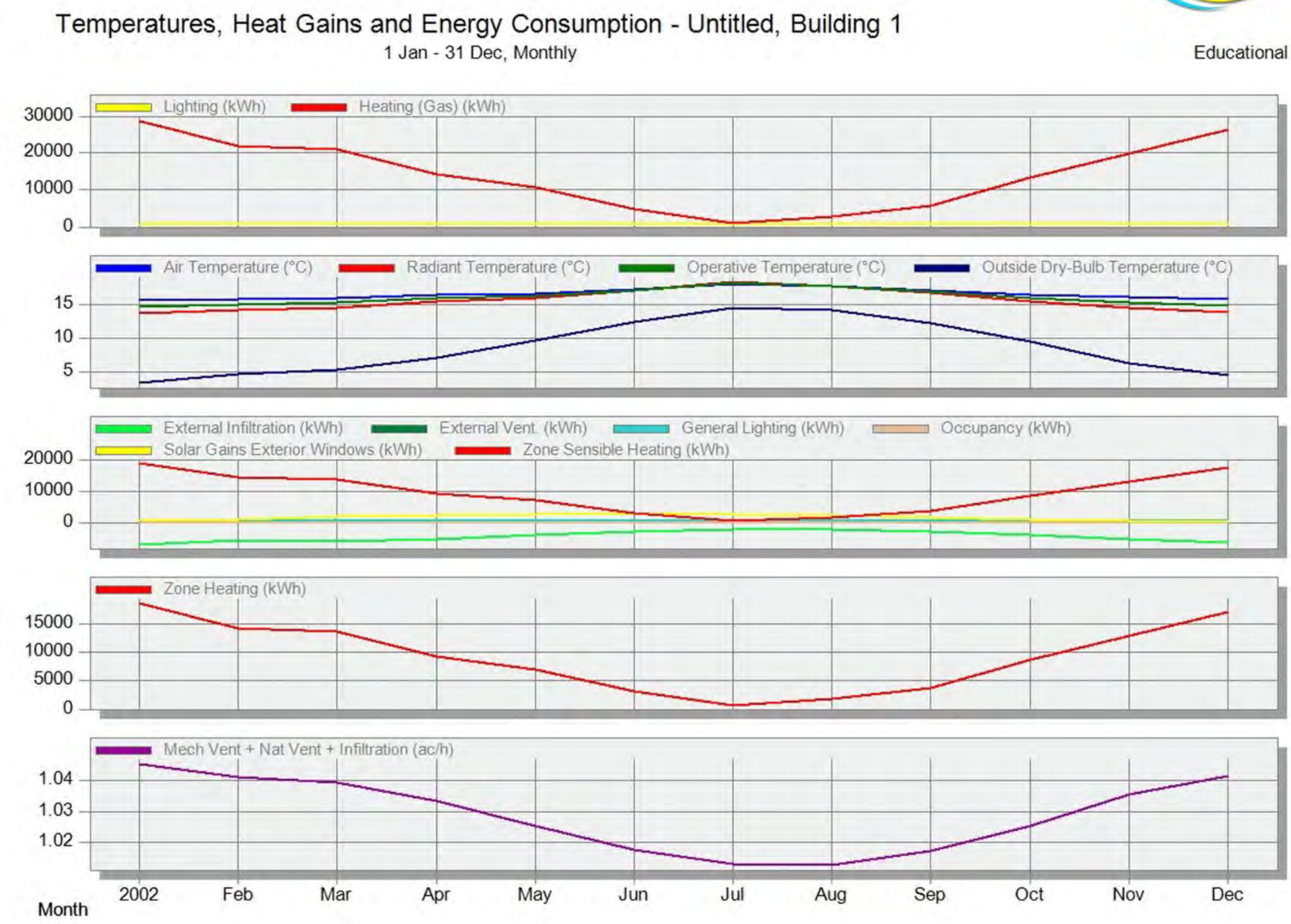
KIRKCALDY KY2 5QY

Figure A199. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.44
Operative Temperature (°C)	15.72
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-6.50
Walls (kW)	-24.10
Ceilings (int) (kW)	-6.14
Floors (int) (kW)	1.00
Ground Floors (kW)	1.52
Partitions (int) (kW)	-0.00
Roofs (kW)	-3.44
Floors (ext) (kW)	-0.05
External Infiltration (kW)	-17.14
External Vent. (kW)	-51.42
Zone Sensible Heating (kW)	106.11

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 132.640 (kW)				
Ground Floor Total Design Heating Capacity = 62.320 (kW)				
Study Room	15.45	3.86	**4.83**	334.6465
Lounge	15.69	11.52	**14.40**	252.3146
Entrance Hall	17.33	7.52	**9.40**	203.5317
Kitchen	15.48	5.69	**7.11**	286.1163
Corridor	17.56	0.57	**0.72**	218.9218
Family Room	14.97	3.38	**4.22**	342.0817
Veslibule	16.01	2.72	**3.41**	274.3277
Service	16.24	1.37	**1.71**	293.1609
Cloak Room	14.63	1.79	**2.23**	493.9165
Dining Room	16.56	1.86	**2.32**	255.7924
Hall	17.10	3.51	**4.38**	224.6764
Utility	16.14	0.91	**1.14**	326.6631
Store	15.00	0.89	**1.12**	619.8640
Veslibule	16.48	0.58	**0.73**	338.3646
Storage	16.60	0.55	**0.69**	320.3550
Music Room	15.28	3.13	**3.91**	342.1558
First Floor Total Design Heating Capacity = 67.230 (kW)				
Study Room	14.75	4.31	**5.39**	373.6504
BedRoom	14.78	12.40	**15.50**	271.5577
Hall	16.23	8.42	**10.53**	227.9722
BedRoom	14.97	5.27	**6.59**	293.8064
Corridor	16.98	0.70	**0.88**	268.5929
BedRoom	14.53	3.52	**4.40**	356.5782
Service	15.28	3.02	**3.78**	304.4248
Service	15.65	1.53	**1.91**	327.6870
BedRoom	14.28	1.89	**2.36**	522.8186
Service	15.89	2.05	**2.57**	282.7475
Corridor	16.35	3.97	**4.97**	254.4691

Figure A200. The heating design simulation and data of the house.



Lighting (kWh)	754.51	685.07	763.74	731.36	754.51	740.59	754.51	759.13	735.97	754.51	735.99	759.12
Heating (Gas) (kWh)	28527.33	21879.63	20834.23	14241.62	10831.70	4945.05	1155.48	2795.32	5860.67	13388.69	19909.78	26328.98
Air Temperature (°C)	15.77	15.92	16.07	16.45	16.73	17.32	18.20	17.88	17.18	16.59	16.15	15.85
Radiant Temperature (°C)	13.68	14.15	14.62	15.51	15.98	17.11	18.45	17.84	16.78	15.52	14.61	13.88
Operative Temperature (°C)	14.72	15.04	15.35	15.98	16.36	17.21	18.33	17.86	16.98	16.05	15.38	14.86
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-6478.15	-5305.71	-5659.36	-4714.27	-3637.01	-2459.68	-1835.86	-1825.20	-2429.48	-3623.36	-4982.48	-5976.00
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.13	-1.08	0.00	0.00	0.00	0.00	0.00
General Lighting (kWh)	754.51	685.07	763.74	731.36	754.51	740.59	754.51	759.13	735.97	754.51	735.99	759.12
Occupancy (kWh)	237.71	218.80	248.26	231.37	237.69	240.86	231.11	238.04	236.56	237.71	236.70	242.97
Solar Gains Exterior Windows (kWh)	688.52	1202.85	2156.26	2587.82	2796.26	2749.06	2831.59	2396.02	1850.52	1195.32	793.82	457.28
Zone Sensible Heating (kWh)	18473.41	14167.16	13488.87	9219.92	7013.45	3202.21	748.15	1810.68	3796.67	8671.34	12891.65	17049.70
Zone Heating (kWh)	18542.76	14221.76	13542.25	9257.05	7040.60	3214.28	751.06	1816.96	3809.43	8702.65	12941.35	17113.84
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A201. The simulation detailed results of the house.

Case 68. A House Built in 1889

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone construction with a pointed external finish.	1.710	Increase 20 cm Insulation
	Flat 2.094	Increase 32.3 cm Insulation
	Pitched 2.184	Increase 33 cm Insulation
Floors are of suspended timber construction.	1.437	Increase 31.6 cm Insulation
Internal Walls are partly lined with lath and plaster, and partly plastered on the hard.	1.622	
Windows are of traditional timber sash and case design with single glazed panels fitted in the main.		

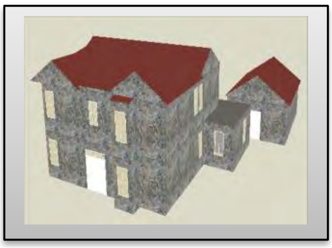
* As a basis for a theory of possibility

Description

The subjects comprise a two storey DETACHED VILLA.

On ground floor: Entrance vestibule, hallway, lounge, dining room, study, kitchen, sitting room, utility room and bathroom.

On first floor: Upper hall, four main bedrooms (one with en-suite shower room) and one further shower room.



Weather Dry and sunny.

Heating and hot water

There is an oil fired boiler within the utility room which serves a range of panel radiators within the property and also provides domestic hot water. The oil storage tank is located to the rear of the utility wing and is of modern PVC design.

Gross internal floor area(m²) 244 m^2

Address

ABERFOYLE STIRLING FK8 3SZ

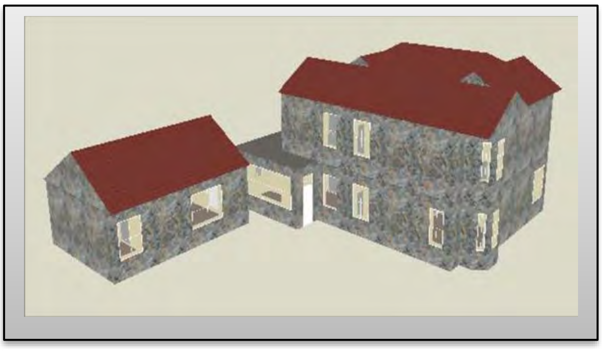
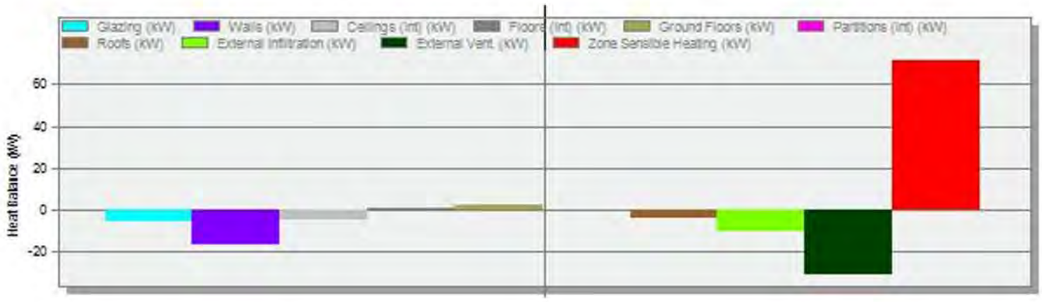


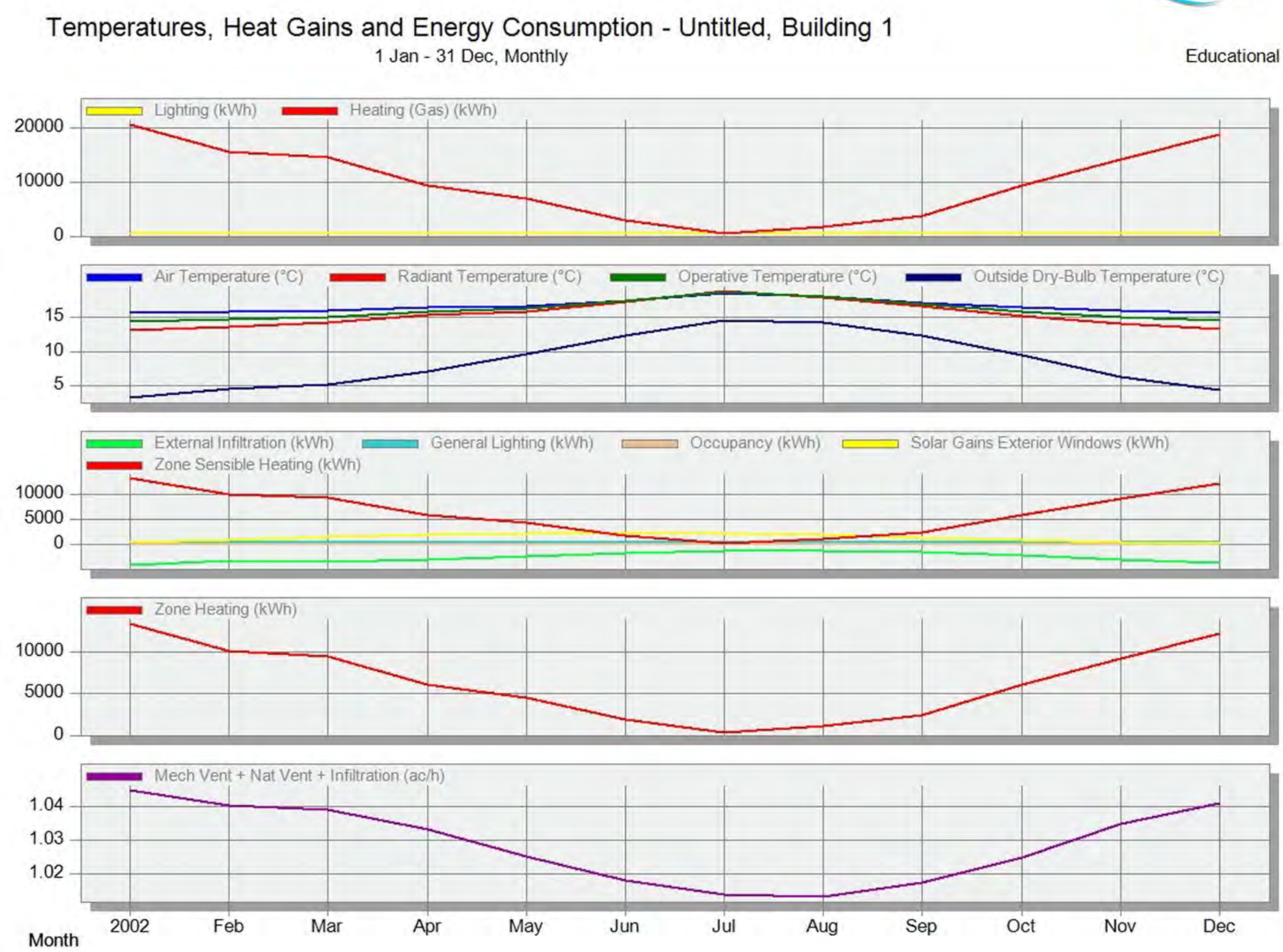
Figure A202. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.45
Operative Temperature (°C)	15.23
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-5.74
Walls (kW)	-17.19
Ceilings (int) (kW)	-5.10
Floors (int) (kW)	0.80
Ground Floors (kW)	1.81
Partitions (int) (kW)	0.00
Roofs (kW)	-4.20
External Infiltration (kW)	-10.51
External Vent. (kW)	-31.54
Zone Sensible Heating (kW)	71.61

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 89.530 (kW)				
First Floor Total Design Heating Capacity = 38.680 (kW)				
Dining Room	15.42	4.92	**6.15**	228.7602
Veslibule	15.76	1.34	**1.67**	266.6248
Family Room	15.48	4.51	**5.64**	234.3076
Corridor	16.79	4.44	**5.55**	181.4808
Lounge	15.42	5.09	**6.36**	231.6036
Service	16.21	1.75	**2.18**	219.2616
Kitchen	16.48	3.29	**4.11**	191.9755
Study Room	14.33	1.80	**2.25**	382.3671
Sunroom	13.36	3.81	**4.77**	428.4487
Second Floor Total Design Heating Capacity = 36.110 (kW)				
Bed Room3	14.84	5.12	**6.40**	238.0579
Storage	15.03	1.49	**1.87**	298.2738
Bed Room1	14.32	5.29	**6.61**	275.1855
Corridor	15.66	5.14	**6.43**	210.4108
Bed Room2	14.32	5.92	**7.40**	269.3800
Service	15.39	1.97	**2.47**	247.7152
Bed Room4	14.81	3.94	**4.93**	256.4792
Cottage Total Design Heating Capacity = 14.740 (kW)				
Bed Room	14.71	2.41	**3.02**	313.7562
Bathroom	14.86	0.89	**1.11**	438.2972
Service	16.01	0.51	**0.63**	321.8168
Kitchen Lounge	14.58	7.38	**9.23**	260.3733
Storage	15.40	0.60	**0.75**	435.5845

Figure A203. The heating design simulation and data of the house.



Lighting (kWh)	585.62	531.73	592.80	567.66	585.62	574.84	585.62	589.21	571.25	585.62	571.25	589.21
Heating (Gas) (kWh)	20479.67	15508.13	14495.85	9358.09	6939.39	2908.27	573.92	1682.00	3790.06	9270.92	14107.78	18865.16
Air Temperature (°C)	15.66	15.80	15.96	16.38	16.69	17.42	18.49	18.02	17.15	16.47	16.01	15.73
Radiant Temperature (°C)	13.05	13.60	14.18	15.29	15.85	17.24	18.78	17.96	16.65	15.16	14.10	13.28
Operative Temperature (°C)	14.36	14.70	15.07	15.84	16.27	17.33	18.63	17.99	16.90	15.81	15.05	14.50
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3941.83	-3221.64	-3438.86	-2873.35	-2217.81	-1541.24	-1215.40	-1159.33	-1479.21	-2186.41	-3015.04	-3630.51
General Lighting (kWh)	585.62	531.73	592.80	567.66	585.62	574.84	585.62	589.21	571.25	585.62	571.25	589.21
Occupancy (kWh)	183.80	169.20	192.02	178.87	183.77	185.41	175.83	182.64	182.93	183.80	183.05	187.92
Solar Gains Exterior Windows (kWh)	478.91	894.10	1658.00	2144.25	2285.07	2279.75	2356.98	1947.60	1431.18	879.62	560.58	319.88
Zone Sensible Heating (kWh)	13266.20	10043.51	9386.38	6058.06	4492.72	1882.99	371.54	1089.37	2454.94	6003.82	9135.62	12219.63
Zone Heating (kWh)	13311.79	10080.28	9422.30	6082.76	4510.61	1890.37	373.04	1093.30	2463.54	6026.10	9170.05	12262.35
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.02	1.03	1.04

Figure A204. The simulation detailed results of the house.

Case 69. A House Built in 1885

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stonework, lined with lath and plaster internally.	1.723	Increase 20.3 cm Insulation
	Flat 2.197	Increase 32 cm Insulation
	Pitched 2.282	Increase 33 cm Insulation
Floors are of suspended timber construction.	1.517	Increase 31.7 cm Insulation
Internal Walls are brickwork plastered on the hard.	1.666	
Windows are original timber sash and case windows which are single glazed and there are modern UPVC framed and double glazed window.		

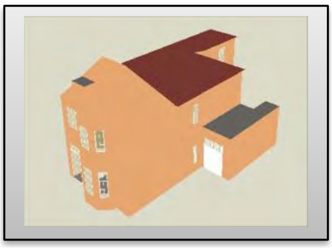
* As a basis for a theory of possibility

Description

Converted flat located at ground floor level in a two storey and attics flatted semi-detached villa containing two flats.

Ground Floor: Common Entrance Vestibule, Hallway, Lounge, Dining Room, Kitchen, Bathroom, Bedroom.

First Floor: Two Bedrooms.



Weather Dry.

Heating and hot water

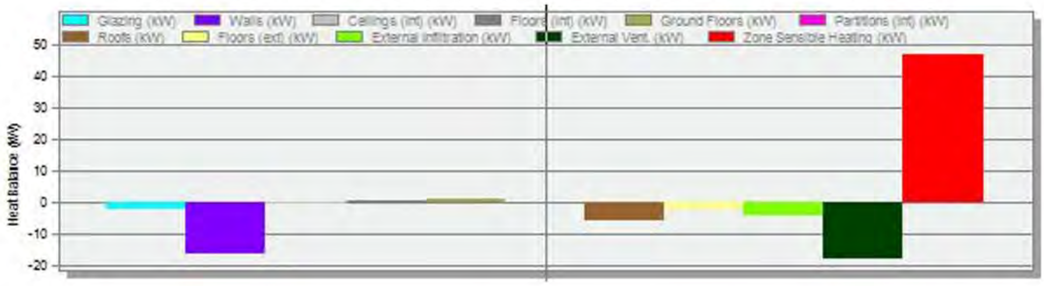
Background heating is provided by electric storage radiators and gas fires fitted at the fireplaces. Domestic hot water is provided by electric immersion heater within a modern insulated hot water tank located in a cupboard off the kitchen.

Gross internal floor area(m²) 140 m^2

Address

EDINBURGH EH6 1AW

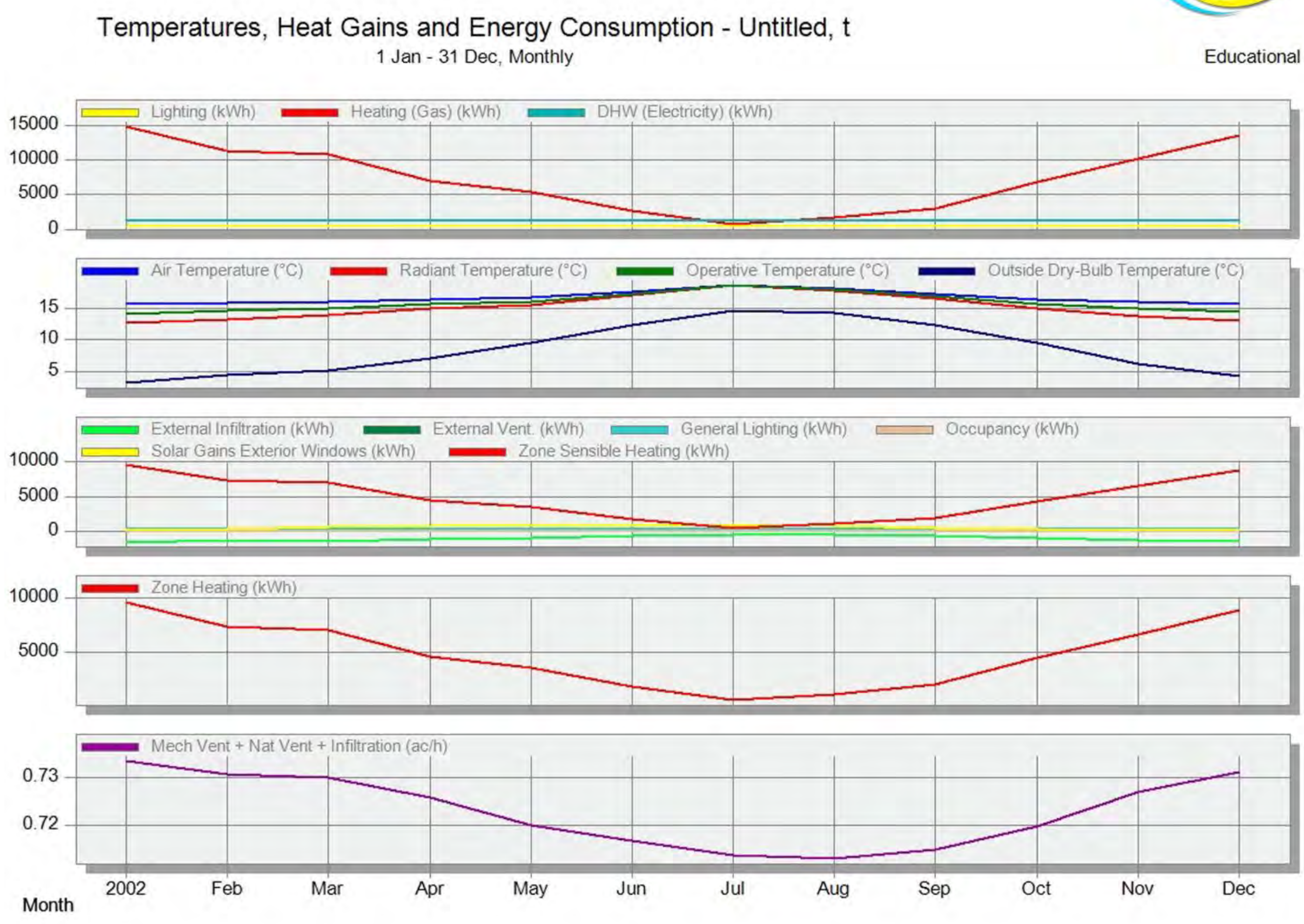
Figure A205. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.16
Operative Temperature (°C)	15.08
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.13
Walls (kW)	-16.30
Ceilings (int) (kW)	-0.56
Floors (int) (kW)	0.56
Ground Floors (kW)	0.95
Partitions (int) (kW)	0.00
Roofs (kW)	-5.72
Floors (ext) (kW)	-1.82
External Infiltration (kW)	-4.21
External Vent. (kW)	-17.98
Zone Sensible Heating (kW)	47.16

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
t Total Design Heating Capacity = 58.950 (kW)				
Ground Floor Total Design Heating Capacity = 27.350 (kW)				
Service	17.24	0.28	**0.35**	184.3759
Bed Room	16.35	3.32	**4.15**	187.5335
Dining Room	16.15	2.41	**3.02**	204.2057
Sitting Room	15.57	4.44	**5.55**	217.7800
Service	16.46	0.82	**1.02**	221.9000
Hall Vestibule	16.08	2.72	**3.40**	243.7402
Kitchen	14.89	2.69	**3.37**	313.2344
Service	16.34	0.24	**0.30**	350.4815
Garage	14.17	2.89	**3.61**	359.6661
Store	15.28	0.64	**0.81**	488.0957
Landing	15.80	0.21	**0.26**	704.2832
Store	14.98	0.40	**0.51**	805.7407
Store	13.43	0.80	**1.00**	1546.6265
First Floor Total Design Heating Capacity = 20.500 (kW)				
Bed Room	16.00	3.09	**3.87**	189.6803
HallWay	16.46	0.64	**0.80**	192.3048
Service	15.71	2.66	**3.33**	201.5967
Roof	14.78	5.06	**6.32**	221.5955
Bed Room	14.42	2.85	**3.56**	286.6598
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.53	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 6.530 (kW)				
Zone 1	13.37	5.22	**6.53**	168.3689
Roof 1 Total Design Heating Capacity = 4.370 (kW)				
Zone 1	12.87	3.50	**4.37**	220.2846

Figure A206. The heating design simulation and data of the house.



Lighting (kWh)	398.69	369.15	422.05	388.84	398.69	412.21	398.69	410.37	400.52	398.69	400.52	410.37
Heating (Gas) (kWh)	14808.12	11332.17	10797.10	6950.64	5431.48	2692.77	793.32	1650.52	3040.29	6779.82	10243.45	13602.58
DHW (Electricity) (kWh)	1210.61	1147.25	1349.57	1189.49	1210.61	1328.45	1210.61	1280.09	1258.97	1210.61	1258.97	1280.09
Air Temperature (°C)	15.53	15.74	15.98	16.37	16.61	17.52	18.57	18.02	17.17	16.37	15.93	15.67
Radiant Temperature (°C)	12.65	13.25	13.84	14.94	15.43	16.92	18.47	17.63	16.41	14.85	13.76	12.97
Operative Temperature (°C)	14.09	14.50	14.91	15.65	16.02	17.22	18.52	17.83	16.79	15.61	14.85	14.32
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1563.94	-1290.86	-1387.42	-1152.09	-878.26	-612.68	-467.00	-452.91	-600.52	-880.42	-1210.60	-1452.41
External Vent. (kWh)	0.00	0.00	-0.10	-0.39	-0.41	-3.51	-3.95	-2.46	-0.41	0.00	0.00	0.00
General Lighting (kWh)	398.69	369.15	422.05	388.84	398.69	412.21	398.69	410.37	400.52	398.69	400.52	410.37
Occupancy (kWh)	100.75	94.94	110.69	98.09	99.82	105.38	94.32	100.94	102.93	100.71	103.90	105.84
Solar Gains Exterior Windows (kWh)	179.98	343.87	627.70	820.43	883.43	882.50	927.86	752.65	549.27	331.91	214.76	119.35
Zone Sensible Heating (kWh)	9591.12	7339.70	6993.43	4501.98	3517.76	1744.02	513.82	1069.29	1970.07	4392.75	6634.70	8810.66
Zone Heating (kWh)	9625.28	7365.91	7018.12	4517.92	3530.46	1750.30	515.66	1072.84	1976.19	4406.89	6658.24	8841.68
Mech Vent + Nat Vent + Infiltration (ac/h)	0.73	0.73	0.73	0.73	0.72	0.72	0.71	0.71	0.71	0.72	0.73	0.73

Figure A207. The simulation detailed results of the house.

Case 70. A House Built in 1880

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone construction pointed externally.	1.734	Increase 20.8 cm Insulation
	Flat -	-
	Pitched 2.336	Increase 33 cm Insulation
Floors are of a suspended timber design overlaid with chipboard.	1.544	Increase 31.8 cm Insulation
Internal Walls are a mixture of lathe and plaster and plasterboard.	1.669	
Windows are of a timber frame single glazed sash and case design.		

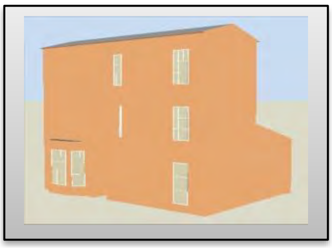
* As a basis for a theory of possibility

Description

The subjects comprise a self-contained second and attic floor flat within a three storey and attic building. There are five residential dwellings to the immediate block.

Second floor; Entrance hall, living room, 2 bedrooms, kitchen, bathroom and cloakroom with WC.

Attic floor; 2 bedrooms.



Weather Overcast.

Heating and hot water

Heating and hot water is provided via a wall mounted gas fired boiler located to the kitchen. Radiators have been fitted off this.

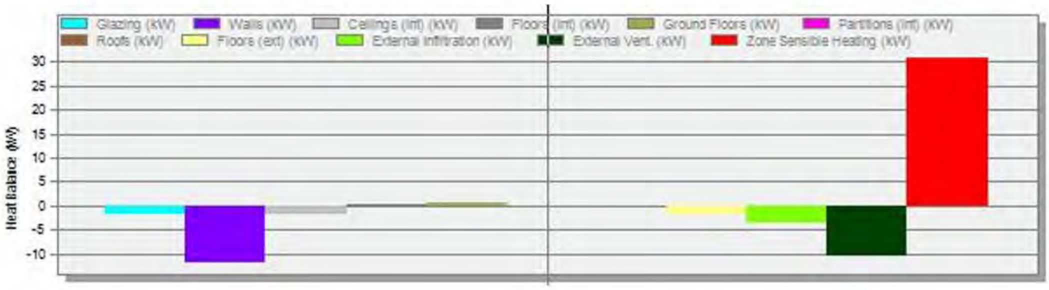
Hot water is also available via an immersion heater which is connected to an insulated hot water cylinder.

Gross internal floor area(m²) 106 m^2

Address

DUNFERMLINE KY12 0PH

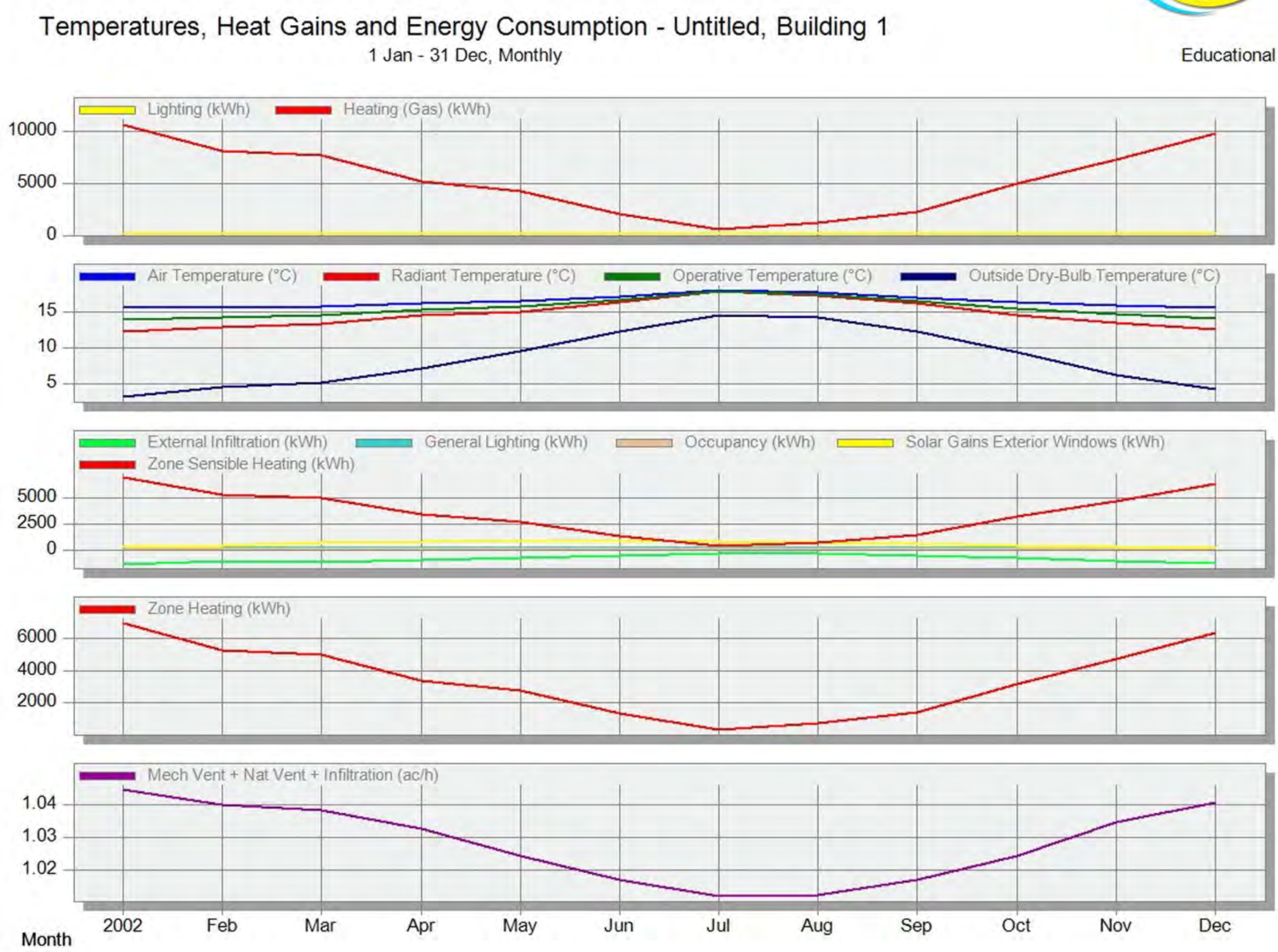
Figure A208. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.39
Operative Temperature (°C)	14.70
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.92
Walls (kW)	-12.00
Ceilings (int) (kW)	-1.85
Floors (int) (kW)	0.26
Ground Floors (kW)	0.59
Partitions (int) (kW)	-0.21
Roofs (kW)	-0.04
Floors (ext) (kW)	-1.79
External Infiltration (kW)	-3.52
External Vent. (kW)	-10.56
Zone Sensible Heating (kW)	30.97

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 38.710 (kW)				
Ground Floor Total Design Heating Capacity = 18.910 (kW)				
Bed Room	14.48	2.69	**3.36**	389.0098
hall	15.97	3.85	**4.81**	266.6042
Kitchen	15.05	1.52	**1.90**	389.5576
Bed Room	14.76	3.48	**4.34**	443.2783
Bath Room	15.60	0.65	**0.82**	434.3168
Lounge	14.59	2.62	**3.27**	456.3242
Service	15.95	0.33	**0.41**	498.7816
First Floor Total Design Heating Capacity = 10.660 (kW)				
Hall	14.33	3.48	**4.35**	364.1656
Bed Room S	14.18	1.64	**2.05**	421.1625
Bed Room S	13.81	3.41	**4.26**	397.8132
Block 1 Total Design Heating Capacity = 9.140 (kW)				
Hall	14.56	2.92	**3.65**	336.9741
Bed Room S 1	14.47	1.48	**1.85**	378.8529
Bed Room S	14.06	2.91	**3.64**	362.1054
Block 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	1.00	0.00	**0.00**	0.0000
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.56	0.00	**0.00**	0.0000

Figure A209. The heating design simulation and data of the house.



Lighting (kWh)	170.37	154.69	172.46	165.14	170.37	167.23	170.37	171.41	166.18	170.37	166.18	171.41
Heating (Gas) (kWh)	10661.30	8117.07	7702.24	5212.74	4227.41	2072.25	555.34	1175.72	2209.56	4926.63	7284.86	9815.66
Air Temperature (°C)	15.60	15.69	15.84	16.21	16.47	17.10	18.00	17.71	17.05	16.34	15.90	15.64
Radiant Temperature (°C)	12.30	12.89	13.44	14.52	15.02	16.36	17.90	17.29	16.19	14.63	13.49	12.57
Operative Temperature (°C)	13.95	14.29	14.64	15.36	15.74	16.73	17.95	17.50	16.62	15.48	14.69	14.10
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1312.36	-1068.93	-1138.52	-944.66	-721.05	-484.74	-356.54	-356.95	-485.73	-719.27	-998.40	-1206.44
General Lighting (kWh)	170.37	154.69	172.46	165.14	170.37	167.23	170.37	171.41	166.18	170.37	166.18	171.41
Occupancy (kWh)	53.47	49.22	55.86	52.04	53.47	54.32	52.46	53.84	53.22	53.47	53.25	54.67
Solar Gains Exterior Windows (kWh)	274.05	440.67	740.29	841.33	852.56	805.11	857.23	755.85	619.60	429.21	313.41	182.48
Zone Sensible Heating (kWh)	6913.15	5262.37	4992.86	3378.26	2739.90	1343.39	359.99	762.27	1432.61	3193.54	4722.34	6364.40
Zone Heating (kWh)	6929.84	5276.09	5006.46	3388.28	2747.82	1346.96	360.97	764.22	1436.21	3202.31	4735.16	6380.18
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.02	1.02	1.01	1.01	1.02	1.02	1.03	1.04

Figure A210. The simulation detailed results of the house.

Case 71. A House Built in 1879

Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone construction.	1.759	Increase 20.9 cm Insulation
	Flat 2.207	Increase 32.4 cm Insulation
	Pitched 2.336	Increase 33 cm Insulation
Floors are of a suspended timber construction.	1.546	Increase 31.8 cm Insulation
Internal Walls are plastered masonry and plasterboard lined.	1.688	
Windows are replacement u-PVC double glazed.		

* As a basis for a theory of possibility

Description

The property is a two storey and attic semidetached villa.

Ground floor: Entrance vestibule and hall way, Lounge, open plan Dining room/Sitting room, Kitchen with Maids room/Study over and Bathroom.

First floor: 4 Bedrooms and Bathroom .

Attic level: 2 further Bedrooms, Study and Bathroom.

Weather Overcast.

Heating and hot water

Space heating is provided by a gas fired radiatorcentral heating installation.

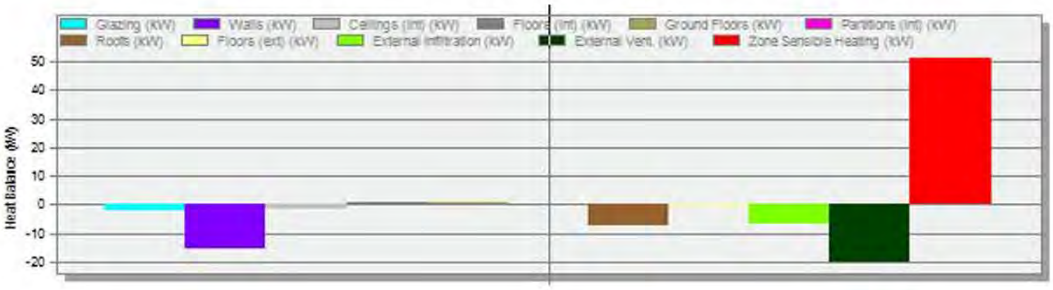
The boiler is located within rear Bedroom at attic level. Hot water is also stored within an insulated tank within same room.

Gross internal floor area(m²) 270 m^2

Address

EDINBURGH EH1 1NF

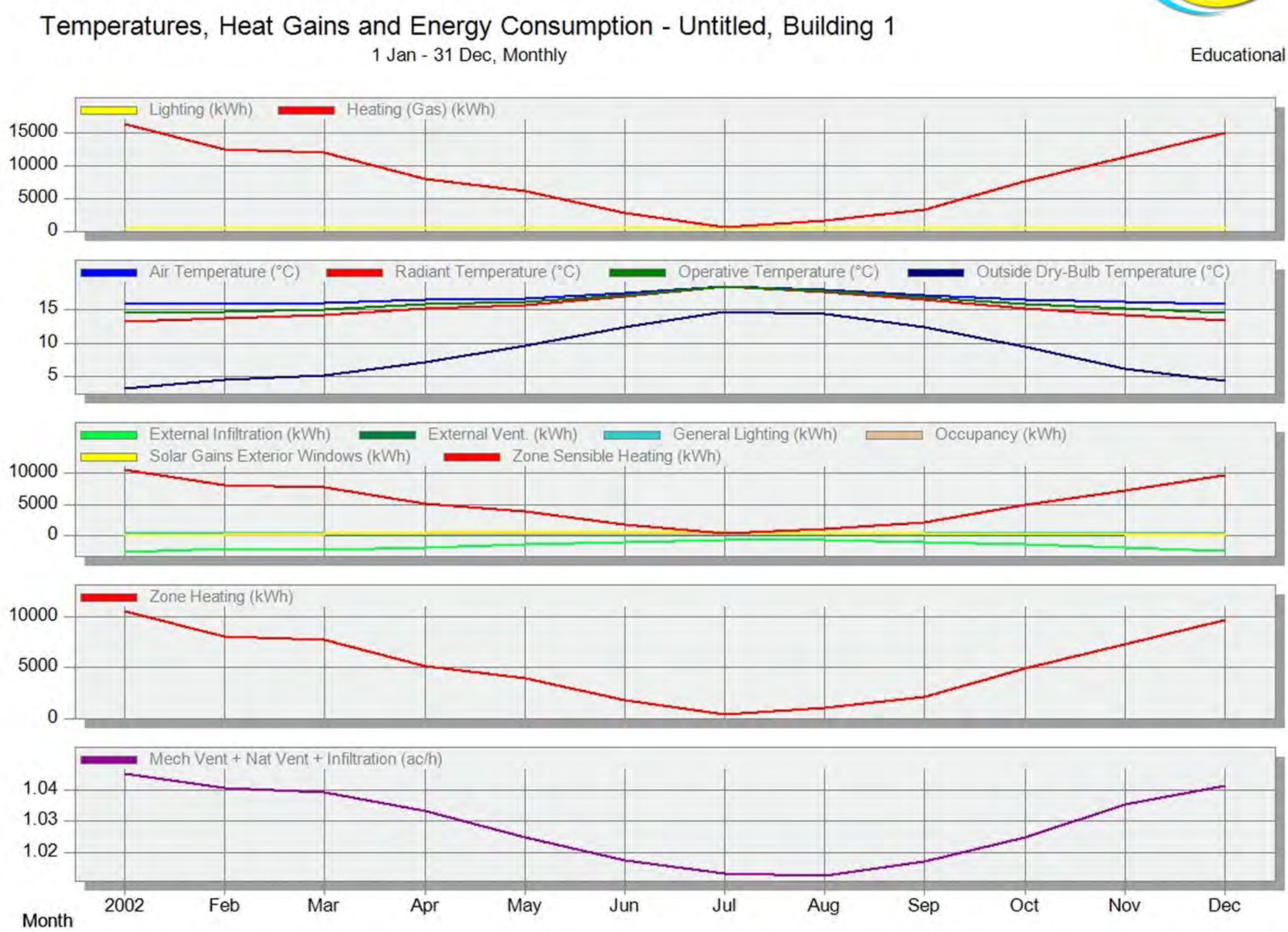
Figure A211. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.65
Operative Temperature (°C)	15.32
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.86
Walls (kW)	-15.47
Ceilings (int) (kW)	-1.23
Floors (int) (kW)	0.76
Ground Floors (kW)	1.06
Partitions (int) (kW)	0.00
Roofs (kW)	-7.43
Floors (ext) (kW)	-0.34
External Infiltration (kW)	-6.72
External Vent. (kW)	-20.17
Zone Sensible Heating (kW)	51.35

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 64.220 (kW)				
Ground Floor Total Design Heating Capacity = 27.240 (kW)				
Family Room	16.00	5.02	**6.27**	188.5788
Garage	13.70	3.59	**4.49**	355.8355
Vestibule	14.63	0.78	**0.98**	1511.6155
Setting Room	15.65	5.03	**6.29**	202.6185
Hall	15.93	1.98	**2.48**	217.6334
Inner Hall	17.35	1.17	**1.46**	155.2292
BathRoom	16.41	0.74	**0.92**	215.2663
side Vestibule	16.33	0.35	**0.44**	272.4674
Store	16.37	0.29	**0.36**	279.4307
Kitchen	14.33	2.84	**3.55**	324.1252
First Floor Total Design Heating Capacity = 23.410 (kW)				
Bed Room	15.83	2.38	**2.97**	193.7445
Study Room	13.40	3.28	**4.10**	374.1347
Bed Room	15.49	2.65	**3.32**	210.2729
Service	16.30	0.33	**0.42**	258.3183
Hall	17.08	1.14	**1.43**	151.9954
Stire	16.15	0.30	**0.37**	289.3973
Service	16.16	0.74	**0.92**	215.5749
Bed Room	15.15	2.78	**3.47**	279.1500
Drawing Room	15.13	5.13	**6.41**	206.5614
SecondFloor Roof Total Design Heating Capacity = 11.870 (kW)				
Box Room	14.23	1.79	**2.24**	147.4915
Bed Room	14.79	1.75	**2.19**	130.0405
Landing	14.36	0.41	**0.52**	135.7209
Bed Room	15.40	2.30	**2.87**	171.3259
Hall	15.18	1.42	**1.78**	140.5641
Bed Room	14.99	1.36	**1.70**	120.0533
Service	14.54	0.46	**0.57**	127.2312

Figure A212. The heating design simulation and data of the house.



Lighting (kWh)	492.85	447.49	498.89	477.73	492.85	483.77	492.85	495.87	480.75	492.85	480.75	495.87
Heating (Gas) (kWh)	16257.46	12509.07	11891.56	7916.90	6127.58	2734.24	656.26	1650.73	3333.57	7596.19	11288.19	14972.02
Air Temperature (°C)	15.69	15.82	15.97	16.35	16.63	17.32	18.31	17.89	17.10	16.47	16.05	15.76
Radiant Temperature (°C)	13.10	13.58	14.07	15.06	15.57	16.88	18.34	17.62	16.44	15.09	14.11	13.34
Operative Temperature (°C)	14.40	14.70	15.02	15.71	16.10	17.10	18.32	17.76	16.77	15.78	15.08	14.55
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2531.07	-2070.31	-2207.02	-1837.67	-1411.40	-961.20	-725.20	-711.75	-942.22	-1407.04	-1942.90	-2334.40
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.38	-0.08	0.00	0.00	0.00	0.00
General Lighting (kWh)	492.85	447.49	498.89	477.73	492.85	483.77	492.85	495.87	480.75	492.85	480.75	495.87
Occupancy (kWh)	154.68	142.40	161.61	150.56	154.67	156.22	149.00	154.14	153.93	154.68	154.05	158.15
Solar Gains Exterior Windows (kWh)	130.68	230.68	411.63	501.54	536.19	528.87	550.70	460.50	354.06	225.17	152.47	85.95
Zone Sensible Heating (kWh)	10538.23	8107.50	7706.62	5129.83	3970.58	1771.80	425.22	1070.00	2160.98	4923.51	7315.90	9704.60
Zone Heating (kWh)	10567.35	8130.89	7729.51	5145.98	3982.93	1777.26	426.57	1072.98	2166.82	4937.52	7337.32	9731.82
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.02	1.04	1.04

Figure A213. The simulation detailed results of the house.

Case 72. A House Built in 1876

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional 700 mm thick solid stone construction.	1.763	Increase 20.8 cm Insulation
	Flat 2.209	Increase 32.46 cm Insulation
	Pitched 2.394	Increase 33 cm Insulation
Floors are of a suspended timber construction.	1.552	Increase 31.8 cm Insulation
Internal Walls are brick construction and plaster on the hard.	1.716	
Windows are mostly of timber single glazed double hung sash and casement design.		

* As a basis for a theory of possibility

Description

The subjects comprise a substantial Victorian detached villa.

Ground floor: Entrance vestibule and hall way, Lounge, open plan Dining room/Sitting room, Kitchen with Maids room/Study over and Bathroom.

First floor: Drawing room, five Bedrooms and Bath room.

Attic level: 2 further Bedrooms, Study and Bathroom.

Weather Dry.

Heating and hot water

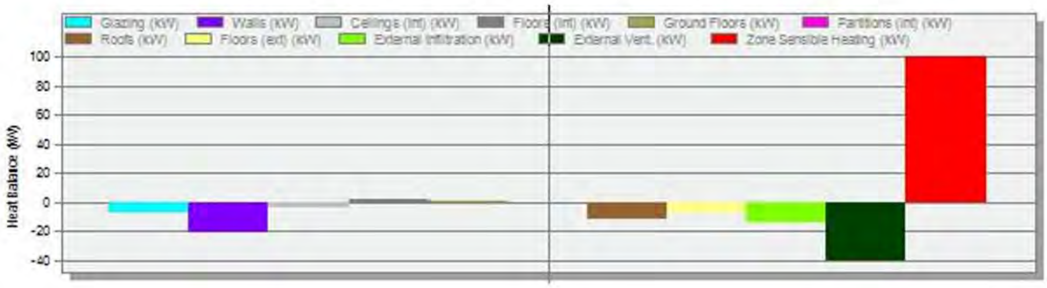
There is a gas fired central heating system with a floor mounted Ideal Concord boiler housed in the cupboard adjoining the utility room serving a mixture of pressed steel and column style radiators in all rooms.

Gross internal floor area(m²) 269 m²

Address

BO'NESS WEST LOTHIAN EH51 9EN

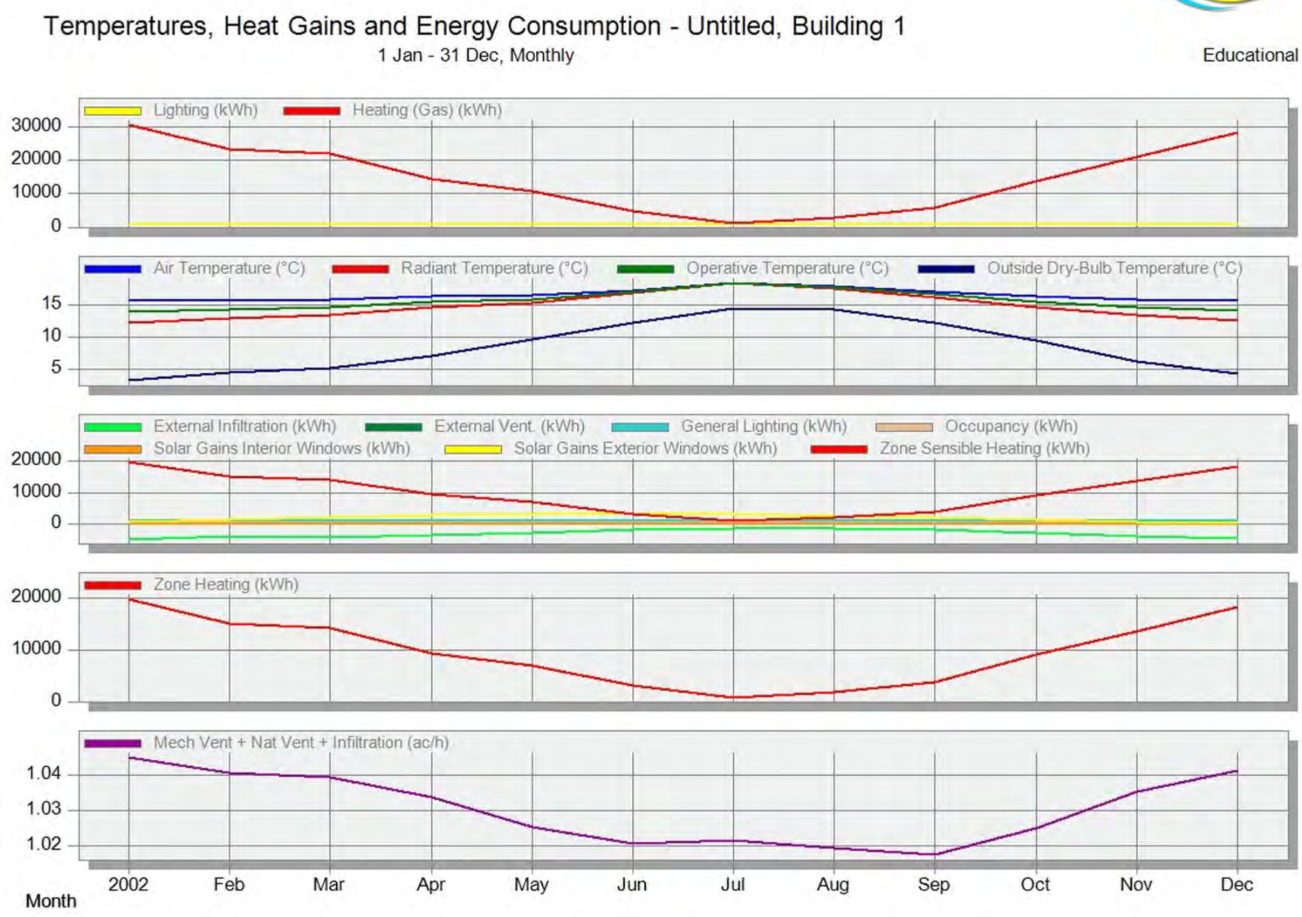
Figure A214. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.25
Operative Temperature (°C)	14.63
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-7.50
Walls (kW)	-20.64
Ceilings (int) (kW)	-3.71
Floors (int) (kW)	1.66
Ground Floors (kW)	1.52
Partitions (int) (kW)	-0.02
Roofs (kW)	-11.39
Floors (ext) (kW)	-6.63
External Infiltration (kW)	-13.44
External Vent. (kW)	-40.32
Zone Sensible Heating (kW)	100.27

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 125.330 (kW)				
First Floor Total Design Heating Capacity = 36.000 (kW)				
Service	15.92	1.48	**1.85**	207.0033
Bed Room	15.21	3.83	**4.78**	222.7963
Hall	16.06	2.19	**2.74**	194.4035
Bed Room	15.41	2.95	**3.69**	213.7235
Landing	16.25	1.32	**1.65**	245.4233
Bed Room	15.42	3.31	**4.13**	211.9566
Drawing Room	15.05	7.89	**9.87**	203.8769
Bed Room	15.31	4.23	**5.29**	206.6294
Service	15.40	1.60	**2.00**	240.4560
Window Total Design Heating Capacity = 0.560 (kW)				
Zone 1	13.50	0.45	**0.56**	3981.3712
Tower Total Design Heating Capacity = 0.550 (kW)				
Zone 1	13.56	0.44	**0.55**	3922.0683
Ground Floor Total Design Heating Capacity = 45.470 (kW)				
Dining Room	15.70	6.81	**8.51**	213.8142
Hall	16.35	4.52	**5.65**	232.6265
Sitting Room	15.46	3.17	**3.96**	250.6643
Kitchen	15.36	10.87	**13.59**	231.3305
Service	16.94	1.53	**1.92**	193.4133
BootRoom	14.63	1.08	**1.35**	449.8003
Pantry	16.17	0.73	**0.91**	284.5949
Service	16.47	1.12	**1.40**	220.3244
HallwWay	17.27	0.42	**0.53**	187.0958
Office	16.58	2.23	**2.78**	196.3448
Coal Shed	16.17	1.04	**1.30**	247.0767
Paint Store	15.36	1.41	**1.77**	375.1587
Service	14.50	0.31	**0.39**	2791.2718
Store	16.51	0.61	**0.76**	253.3176

Figure A215. The heating design simulation and data of the house.



Lighting (kWh)	916.26	831.95	927.51	888.16	916.26	899.40	916.26	921.89	893.78	916.26	893.78	921.89
Heating (Gas) (kWh)	30546.30	23255.34	21894.74	14420.64	10853.94	4848.82	1268.86	2892.51	5937.88	13866.44	21017.94	28127.15
Air Temperature (°C)	15.66	15.78	15.95	16.36	16.60	17.37	18.48	17.98	17.07	16.38	15.96	15.71
Radiant Temperature (°C)	12.31	12.93	13.56	14.78	15.36	16.86	18.51	17.68	16.30	14.68	13.49	12.58
Operative Temperature (°C)	13.98	14.35	14.76	15.57	15.98	17.12	18.49	17.83	16.69	15.53	14.73	14.14
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-5051.06	-4132.20	-4412.97	-3683.77	-2830.84	-1952.90	-1530.85	-1471.43	-1888.06	-2800.79	-3868.85	-4652.75
External Vent. (kWh)	0.00	0.00	-0.19	-0.50	-0.21	-5.94	-20.19	-13.63	-0.35	0.00	0.00	0.00
General Lighting (kWh)	916.26	831.95	927.51	888.16	916.26	899.40	916.26	921.89	893.78	916.26	893.78	921.89
Occupancy (kWh)	287.57	264.73	300.35	279.34	286.95	286.66	272.39	282.92	285.12	287.57	286.40	294.02
Solar Gains Interior Windows (kWh)	0.09	0.21	0.44	0.58	0.69	0.72	0.69	0.57	0.40	0.23	0.11	0.06
Solar Gains Exterior Windows (kWh)	645.93	1189.31	2161.71	2720.09	2946.27	2951.89	3033.82	2510.39	1878.82	1176.65	758.08	430.04
Zone Sensible Heating (kWh)	19786.42	15061.44	14179.38	9337.35	7026.40	3137.01	819.84	1871.37	3844.24	8980.13	13611.78	18218.57
Zone Heating (kWh)	19855.10	15115.97	14231.58	9373.42	7055.06	3151.73	824.76	1880.13	3859.62	9013.18	13661.66	18282.65
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.02	1.03	1.04	1.04

Figure A216. The simulation detailed results of the house.

Case 73. A House Built in 1875

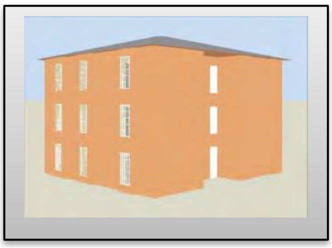
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are built of traditional solid stonework pointed externally	1.775	Increase 21 cm Insulation
	Flat -	-
	Pitched 2.398	Increase 33.17 cm Insulation
Floors are of a suspended timber construction.	1.555	Increase 31.8 cm Insulation
Internal Walls have plaster finishes.	1.733	
Windows are of a timber double glazed type.		

* As a basis for a theory of possibility

Description

The property comprises a purpose built first floor flat.

First Floor: Entrance hall, living room, five bedrooms, kitchen/dining room, shower room and WC apartment.



Weather Dry and sunny.

Heating and hot water

The property benefits from a gas fired central heating system with the gas boiler located in the kitchen. This boiler provides hot water.

The property benefits from a gas fire in the living room.

Gross internal floor area(m²) 165 m^2

Address

EDINBURGH EH7 4AA

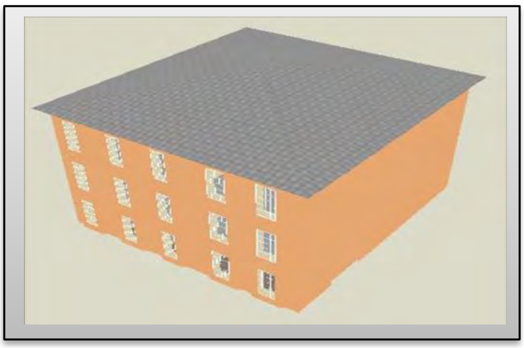
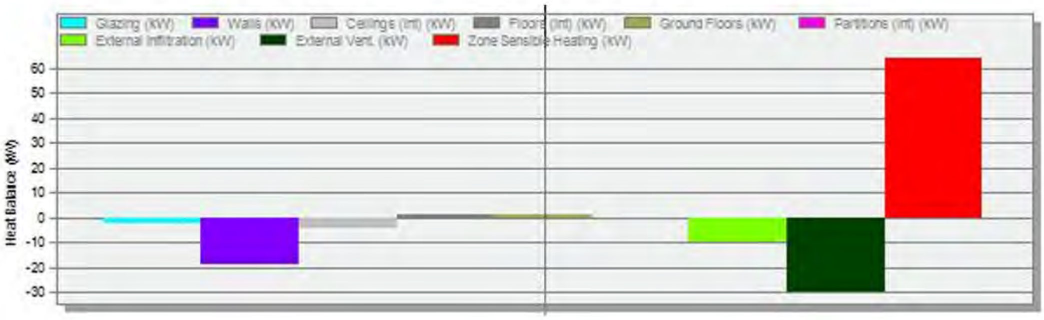


Figure A217. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.68
Operative Temperature (°C)	15.84
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.12
Walls (kW)	-18.97
Ceilings (int) (kW)	-4.69
Floors (int) (kW)	0.79
Ground Floors (kW)	0.91
Partitions (int) (kW)	0.00
External Infiltration (kW)	-9.93
External Vent. (kW)	-29.80
Zone Sensible Heating (kW)	63.64

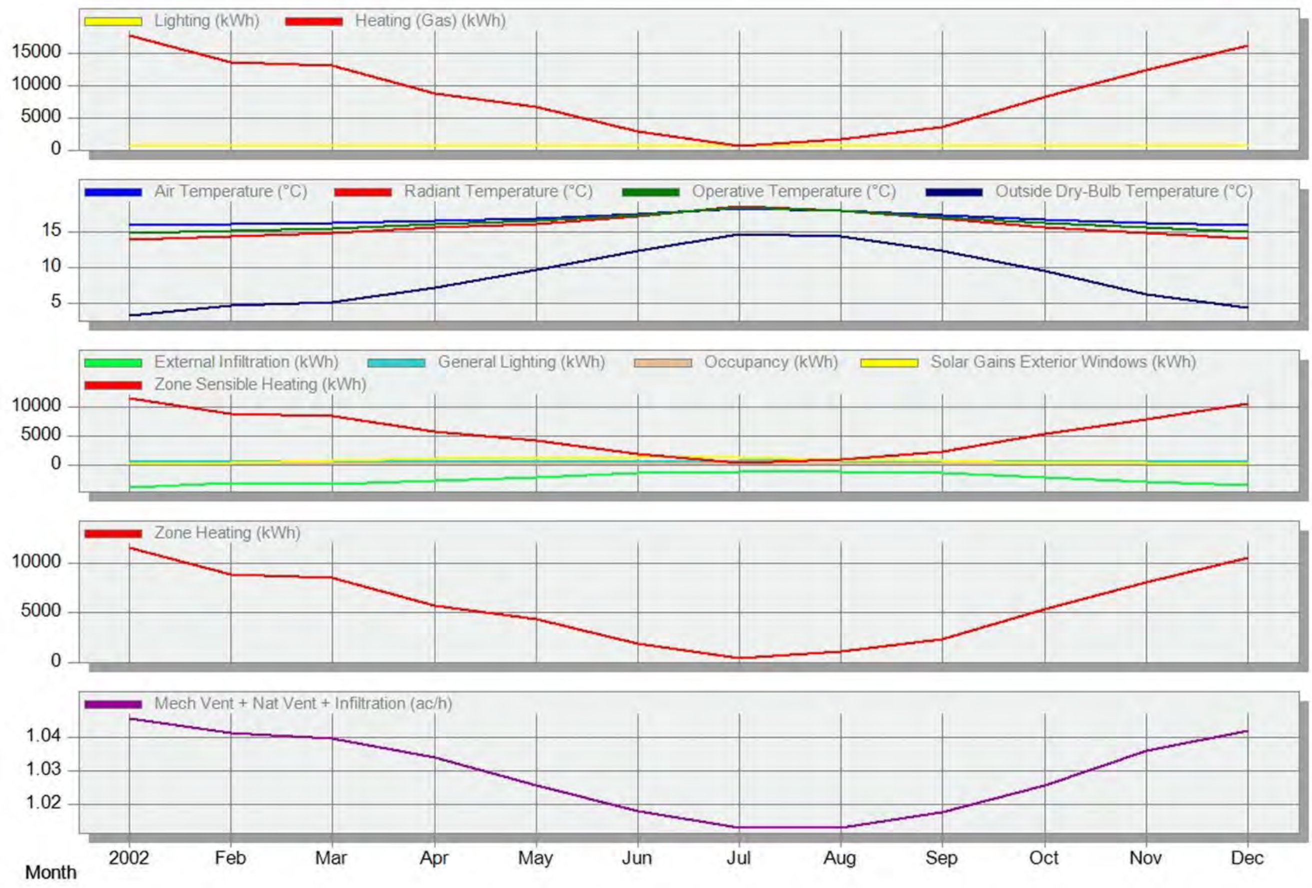
Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 79.530 (kW)				
Ground Floor Total Design Heating Capacity = 25.780 (kW)				
Bed Room 1	16.48	2.12	**2.65**	171.7552
Kitchen	15.87	3.83	**4.79**	188.3474
Hall	17.17	1.72	**2.15**	163.4010
Living Room	15.93	4.62	**5.77**	182.9509
Cupboard	17.50	0.20	**0.25**	151.4331
Bed Room 2	16.81	1.29	**1.61**	171.7125
Bed Room 3	15.11	1.88	**2.35**	283.6254
Bed Room 4	16.73	1.61	**2.01**	167.5603
Service 1	15.79	0.37	**0.46**	412.7141
Service	17.64	0.50	**0.62**	138.6767
Bed Room	15.34	2.50	**3.12**	230.9443
First Floor Total Design Heating Capacity = 25.030 (kW)				
Bed Room 1	16.26	2.05	**2.56**	165.5855
Kitchen	15.60	3.74	**4.67**	183.4931
Hall	17.03	1.61	**2.01**	152.7064
Living Room	15.65	4.48	**5.60**	177.5295
Cupboard	17.39	0.19	**0.24**	144.4806
Bed Room 2	16.64	1.24	**1.54**	165.0396
Bed Room 3	14.89	1.88	**2.35**	282.6589
Bed Room 4	16.55	1.54	**1.93**	160.6947
Service 1	15.66	0.38	**0.47**	417.4439
Service	17.51	0.47	**0.58**	129.8317
Bed Room	15.09	2.46	**3.08**	228.0817
Second Floor Total Design Heating Capacity = 28.720 (kW)				
Bed Room 1	15.60	2.36	**2.96**	191.3589
Kitchen	14.96	4.24	**5.29**	208.0010
Hall	16.41	1.93	**2.41**	182.8400
Living Room	14.99	5.09	**6.36**	201.6618

Figure A218. The heating design simulation and data of the house.

Temperatures, Heat Gains and Energy Consumption - Untitled, Building 1

1 Jan - 31 Dec, Monthly

Educational



Lighting (kWh)	665.42	604.19	673.59	645.01	665.42	653.18	665.42	669.51	649.09	665.42	649.09	669.51
Heating (Gas) (kWh)	17716.15	13656.74	13089.02	8769.46	6645.83	2873.03	547.26	1564.85	3550.66	8313.45	12330.77	16302.17
Air Temperature (°C)	15.85	16.02	16.18	16.57	16.83	17.40	18.30	17.98	17.24	16.68	16.26	15.94
Radiant Temperature (°C)	13.83	14.29	14.72	15.63	16.07	17.16	18.48	17.89	16.79	15.62	14.76	14.04
Operative Temperature (°C)	14.84	15.16	15.45	16.10	16.45	17.28	18.39	17.94	17.01	16.15	15.51	14.99
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3783.50	-3107.08	-3316.37	-2773.03	-2140.79	-1452.25	-1095.46	-1088.20	-1426.11	-2132.66	-2924.65	-3497.17
General Lighting (kWh)	665.42	604.19	673.59	645.01	665.42	653.18	665.42	669.51	649.09	665.42	649.09	669.51
Occupancy (kWh)	208.85	192.26	218.20	203.29	208.85	211.67	202.22	208.69	207.94	208.85	208.00	213.53
Solar Gains Exterior Windows (kWh)	235.40	452.70	812.53	1114.92	1237.40	1264.93	1286.90	1038.92	733.47	428.31	284.09	161.79
Zone Sensible Heating (kWh)	11477.03	8846.86	8478.94	5681.39	4306.37	1861.90	354.56	1014.20	2301.63	5387.67	7988.36	10561.00
Zone Heating (kWh)	11515.50	8876.88	8507.86	5700.15	4319.79	1867.47	355.72	1017.15	2307.93	5403.74	8015.00	10596.41
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A219. The simulation detailed results of the house.

Case 74. A House Built in 1867

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Wall are of traditional stone construction and the two storey projection to rear is of brick construction.	1.790	Increase 21 cm Insulation
	Flat 2.210	Increase 32 cm Insulation
	Pitched 2.402	Increase 33 cm Insulation
Floor is partly of solid construction but mostly of suspended timber construction overlaid with tongue and groove floorboards.	1.561	Increase 31.8 cm Insulation
Internal Wall are mainly of plaster faced solid construction, plastered on wooden lath or lined with plasterboard.	1.737	
Windows are of timber framed single glazed.		

* As a basis for a theory of possibility

Description

The subjects form the north east most half of two semidetached villas.

On ground floor: Entrance vestibule, hallway, lounge, drawing room, study, kitchen/breakfast room and shower apartment.

On first floor (entered by a timber staircase in the hallway): Split level landing, five bedrooms and two bathrooms.

Weather

Dry and Bright.

Heating and hot water

Central heating takes the form of a gas fired wall mounted boiler located at a high level within the shower apartment at ground level and vented by means of a balanced flue to the outside serving panel radiators through micro-bore piping around the house. The temperature throughout the house is controlled by a room thermostat within the hallway and individual thermostats fitted to a number of the radiators.

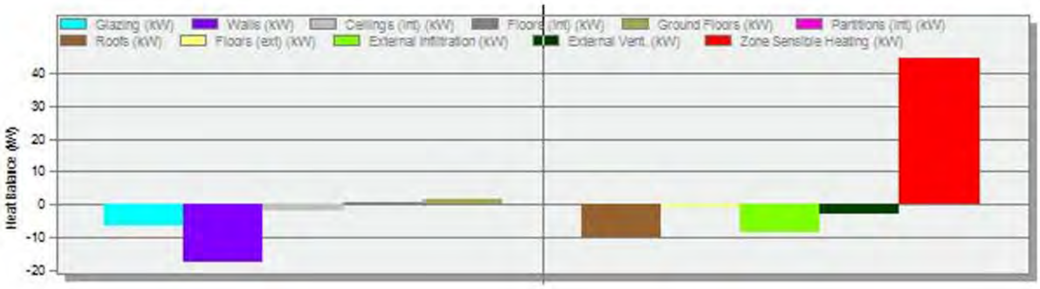
Gross internal floor area (m²)

250 m^2 **approx.**

Address

DALKEITH EH3 2DF

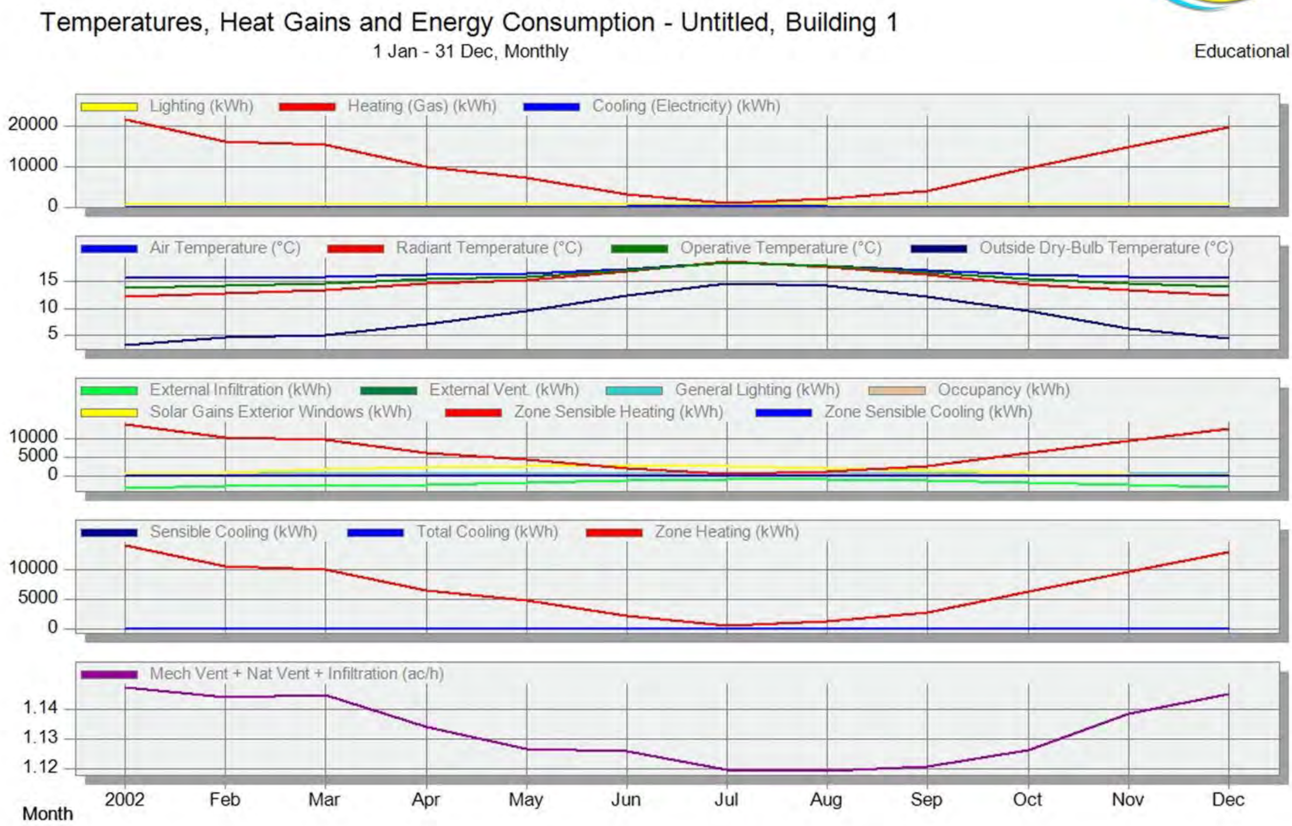
Figure A220. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.16
Operative Temperature (°C)	14.58
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-6.49
Walls (kW)	-17.46
Ceilings (int) (kW)	-1.85
Floors (int) (kW)	0.94
Ground Floors (kW)	1.93
Partitions (int) (kW)	0.00
Roofs (kW)	-9.75
Floors (ext) (kW)	-0.60
External Infiltration (kW)	-8.46
External Vent. (kW)	-2.83
Zone Sensible Heating (kW)	44.44

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 55.570 (kW)				
Ground Floor Total Design Heating Capacity = 18.110 (kW)				
Entrance Hall	16.40	1.43	**1.79**	102.3259
Service	16.10	1.26	**1.58**	107.5584
Drawing Room	15.47	2.52	**3.15**	127.8507
Living Room	15.56	2.61	**3.26**	116.3056
Library	15.20	2.01	**2.52**	152.6511
Kitchen	14.31	4.64	**5.81**	169.6673
Master BedRoom Total Design Heating Capacity = 6.070 (kW)				
Zone 1	13.55	4.85	**6.07**	181.5448
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.30	0.00	**0.00**	0.0000
Main Roof Total Design Heating Capacity = 12.140 (kW)				
Hall	15.74	1.54	**1.92**	135.4428
Bed Room	14.20	1.92	**2.40**	125.1156
Service	14.17	1.52	**1.90**	125.2196
Bed Room	14.49	2.02	**2.53**	115.4296
Bed Room	15.45	0.95	**1.18**	88.7594
Bed Room	14.60	1.76	**2.21**	113.8419
Window Total Design Heating Capacity = 0.730 (kW)				
Zone 1	13.41	0.58	**0.73**	1.#INF
Window Total Design Heating Capacity = 0.630 (kW)				
Zone 1	13.37	0.51	**0.63**	1.#INF
Window Total Design Heating Capacity = 0.720 (kW)				
Zone 1	13.39	0.58	**0.72**	1.#INF
Ground Floor Annex Total Design Heating Capacity = 10.300 (kW)				
Sun Room	14.24	4.54	**5.67**	164.9988
Lounge	13.01	3.71	**4.63**	269.3585
First Floor Annex Total Design Heating Capacity = 3.490 (kW)				
BedRoom	14.34	2.79	**3.49**	135.1125

Figure A221. The heating design simulation and data of the house.



Lighting (kWh)	615.52	558.88	623.07	596.64	615.52	604.19	615.52	619.30	600.42	615.52	600.42	619.30
Heating (Gas) (kWh)	21643.88	16377.21	15348.65	9858.78	7276.17	3255.04	855.23	2040.22	4105.50	9782.24	14936.76	19984.82
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.07	0.66	0.02	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.59	15.69	15.83	16.22	16.52	17.43	18.58	17.97	17.02	16.25	15.85	15.64
Radiant Temperature (°C)	12.23	12.85	13.49	14.73	15.38	17.02	18.70	17.71	16.30	14.55	13.37	12.49
Operative Temperature (°C)	13.91	14.27	14.66	15.47	15.95	17.22	18.64	17.84	16.66	15.40	14.61	14.06
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3155.62	-2570.80	-2740.36	-2277.26	-1745.79	-1232.90	-979.65	-913.79	-1168.13	-1714.69	-2393.92	-2901.64
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-1.28	-4.28	-2.52	0.00	0.00	0.00	0.00
General Lighting (kWh)	615.52	558.88	623.07	596.64	615.52	604.19	615.52	619.30	600.42	615.52	600.42	619.30
Occupancy (kWh)	193.18	177.84	201.77	187.78	192.88	192.70	182.78	190.51	191.84	193.18	192.39	197.51
Solar Gains Exterior Windows (kWh)	529.38	978.54	1800.66	2353.43	2549.83	2541.74	2593.72	2141.22	1549.21	955.89	620.73	356.70
Zone Sensible Heating (kWh)	13670.83	10308.27	9625.59	6136.92	4522.60	2006.32	519.87	1254.81	2531.20	6131.02	9390.23	12607.59
Zone Sensible Cooling (kWh)	0.00	0.00	-1.29	-2.94	-2.92	-24.97	-63.03	-27.49	-3.17	-0.01	-0.11	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.17	-1.27	-0.06	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.17	-1.65	-0.06	0.00	0.00	0.00	0.00
Zone Heating (kWh)	14068.52	10645.19	9976.62	6408.21	4729.51	2115.77	555.90	1326.14	2668.57	6358.45	9708.89	12990.14
Mech Vent + Nat Vent + Infiltration (ac/h)	1.15	1.14	1.14	1.13	1.13	1.13	1.12	1.12	1.12	1.13	1.14	1.15

Figure A222. The simulation detailed results of the house.

Case 75. A House Built in 1865

Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone construction, having being extended vertically in cavity brick, all externally rendered.	1.803	Increase 21 cm Insulation
	Flat -	-
	Pitched 2.441	Increase 33.12 cm Insulation
Floors are of solid concrete construction.	1.571	Increase 31.8 cm Insulation
Internal Walls are a mixture of plaster on the hard, lath and plaster and plasterboard types.	1.765	
Windows comprise a mixture of replacement double glazed hardwood and u-PVC units.		

* As a basis for a theory of possibility

Description

The property is a mid-terraced farm cottage.

The accommodation within comprises:

Ground floor: Entrance, Porch, Hall, WC compartment with wash hand basin, Bedroom 5 / Study, Kitchen / Dining Room, Sitting Room, Conservatory.

First floor: Landing, Four Bedrooms, Bathroom and WC.

Weather Overcast.

Heating and hot water

The property has a full oil fired central heating system, which is served by a Potterton Flowsure Plus boiler, located within the under stairs cupboard. This provides hot water on demand to the property.

Gross internal floor area(m²) 135 m^2

Address

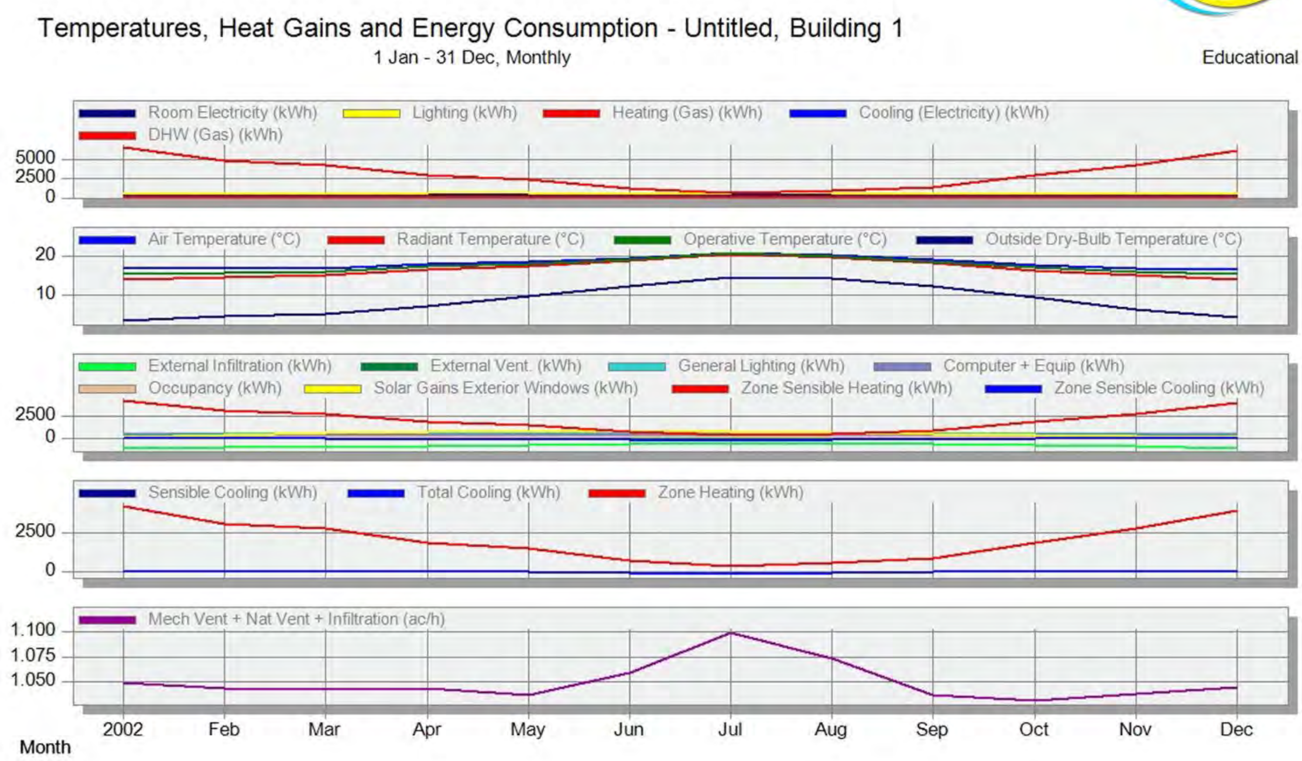
DUNS TD11 3LZ

Figure A223. The Software visualization of the house.

Air Temperature (°C)	22.00
Radiant Temperature (°C)	15.28
Operative Temperature (°C)	18.64
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.74
Walls (kW)	-9.78
Ceilings (int) (kW)	-1.84
Floors (int) (kW)	0.25
Ground Floors (kW)	0.19
Partitions (int) (kW)	-0.22
Roofs (kW)	-0.76
External Infiltration (kW)	-3.14
External Vent. (kW)	-9.41
Zone Sensible Heating (kW)	26.38

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 32.980 (kW)				
Ground Floor Total Design Heating Capacity = 20.140 (kW)				
Study Room	18.58	2.22	**2.77**	317.1416
Corridor	19.79	1.90	**2.38**	295.6542
Kitchen	19.76	2.21	**2.76**	239.2890
Sitting Room	18.63	4.14	**5.17**	274.7070
Service	18.20	0.62	**0.78**	607.0075
Conservatory	17.19	3.68	**4.60**	378.6724
Porch	17.25	1.34	**1.68**	556.5959
First Floor Total Design Heating Capacity = 10.580 (kW)				
Bed Room	19.45	1.66	**2.08**	179.8216
Bed Room	18.11	3.25	**4.07**	219.6491
Corridor	19.44	1.48	**1.85**	230.7661
Bed Room	18.15	2.07	**2.58**	250.4200
Roof Porch Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.65	0.00	**0.00**	0.0000
Glass Roof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-3.34	0.00	**0.00**	0.0000

Figure A224. The heating design simulation and data of the house.



Room Electricity (kWh)	423.40	369.83	390.85	405.55	423.40	372.99	423.40	407.13	389.27	423.40	389.27	407.13
Lighting (kWh)	618.12	537.50	564.37	591.25	618.12	537.50	618.12	591.25	564.37	618.12	564.37	591.25
Heating (Gas) (kWh)	6594.70	4829.76	4313.21	2939.71	2369.54	1165.27	607.34	882.55	1341.40	2890.98	4315.00	6104.72
Cooling (Electricity) (kWh)	0.00	0.04	0.60	3.19	3.35	14.29	36.26	17.89	3.99	0.47	0.00	0.00
DHW (Gas) (kWh)	56.93	49.51	51.98	54.46	56.93	49.51	56.93	54.46	51.98	56.93	51.98	54.46
Air Temperature (°C)	16.79	16.85	16.92	17.95	18.57	19.46	20.97	20.31	19.04	17.85	16.95	16.68
Radiant Temperature (°C)	14.06	14.59	15.16	16.71	17.47	18.91	20.63	19.75	18.25	16.41	15.02	14.10
Operative Temperature (°C)	15.42	15.72	16.04	17.33	18.02	19.19	20.80	20.03	18.64	17.13	15.99	15.39
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1097.13	-898.28	-954.15	-855.46	-714.90	-549.52	-505.49	-474.65	-521.91	-665.90	-841.57	-1002.41
External Vent. (kWh)	0.00	-0.05	-0.20	-4.19	-4.20	-12.87	-30.20	-14.18	-6.42	-0.81	0.00	0.00
General Lighting (kWh)	618.12	537.50	564.37	591.25	618.12	537.50	618.12	591.25	564.37	618.12	564.37	591.25
Computer + Equip (kWh)	423.40	369.83	390.85	405.55	423.40	372.99	423.40	407.13	389.27	423.40	389.27	407.13
Occupancy (kWh)	198.18	172.29	180.69	188.83	197.17	167.71	187.10	182.07	177.95	197.84	180.92	189.56
Solar Gains Exterior Windows (kWh)	220.13	375.42	645.93	758.05	780.31	752.19	786.53	680.48	544.33	361.71	255.16	145.91
Zone Sensible Heating (kWh)	4270.67	3126.54	2790.66	1899.72	1530.07	752.19	391.52	569.49	865.72	1868.87	2792.26	3953.69
Zone Sensible Cooling (kWh)	0.00	-0.18	-2.69	-14.38	-15.06	-60.17	-136.86	-65.12	-17.07	-1.93	0.00	0.00
Sensible Cooling (kWh)	0.00	-0.18	-2.69	-14.38	-15.05	-60.15	-136.83	-65.11	-17.06	-1.93	0.00	0.00
Total Cooling (kWh)	0.00	-0.18	-2.69	-14.38	-15.06	-64.31	-163.16	-80.50	-17.94	-2.14	0.00	0.00
Zone Heating (kWh)	4286.55	3139.34	2803.59	1910.81	1540.20	757.43	394.77	573.66	871.91	1879.14	2804.75	3968.07
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.04	1.04	1.06	1.10	1.07	1.04	1.03	1.04	1.04

Figure A225. The simulation detailed results of the house.

Case 76. A House Built in 1864

Material	U-Value W/m^{2}K	How to reach Zero Carbon home (theoretically*)
Main Walls are of stone construction pointed externally.	1.876	Increase 21.13 cm Insulation
	Flat 2.359	Increase 32.47 cm Insulation
	Pitched 2.480	Increase 33 cm Insulation
Floors are of timber construction with solid flooring to the front vestibule.	1.597	Increase 31.87 cm Insulation
Internal Walls have plaster finishes.	1.783	
Windows are of timber sash and case single glazed type.		

* As a basis for a theory of possibility

Description

The property comprises a three story semi-detached house

Ground Floor - Entrance Hall, Living Room, Sitting Room, Dining Room, Kitchen, Utility Room and Shower Room with WC.
First Floor - Landing, Drawing Room, 2 Bedrooms and Bathroom with WC.
Second Floor - Landing, Bedroom with En-suite, 2 Bedrooms and Box Room.

Weather Dry and sunny.

Heating and hot water

The property benefits from a gas fired central heating system serving steel panel and cast iron radiators. The hot water is presumed to be provided via the hot water cylinder located within the boiler cupboard.

Gross internal floor area (m²) 260 m^2 **approx.**

Address

EDINBURGH, EH9 1NZ

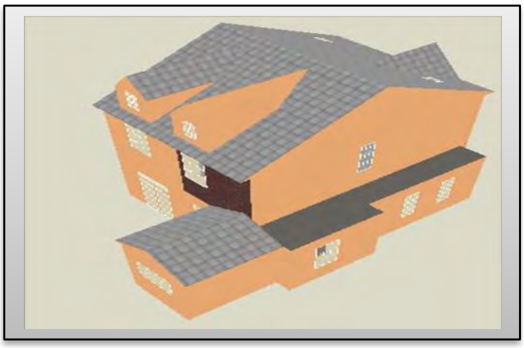
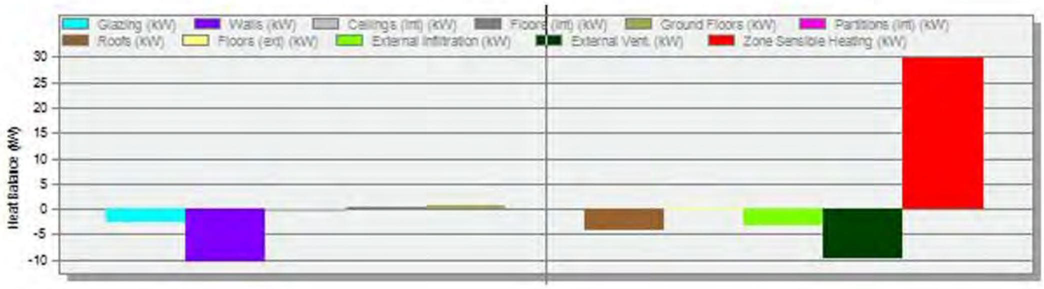


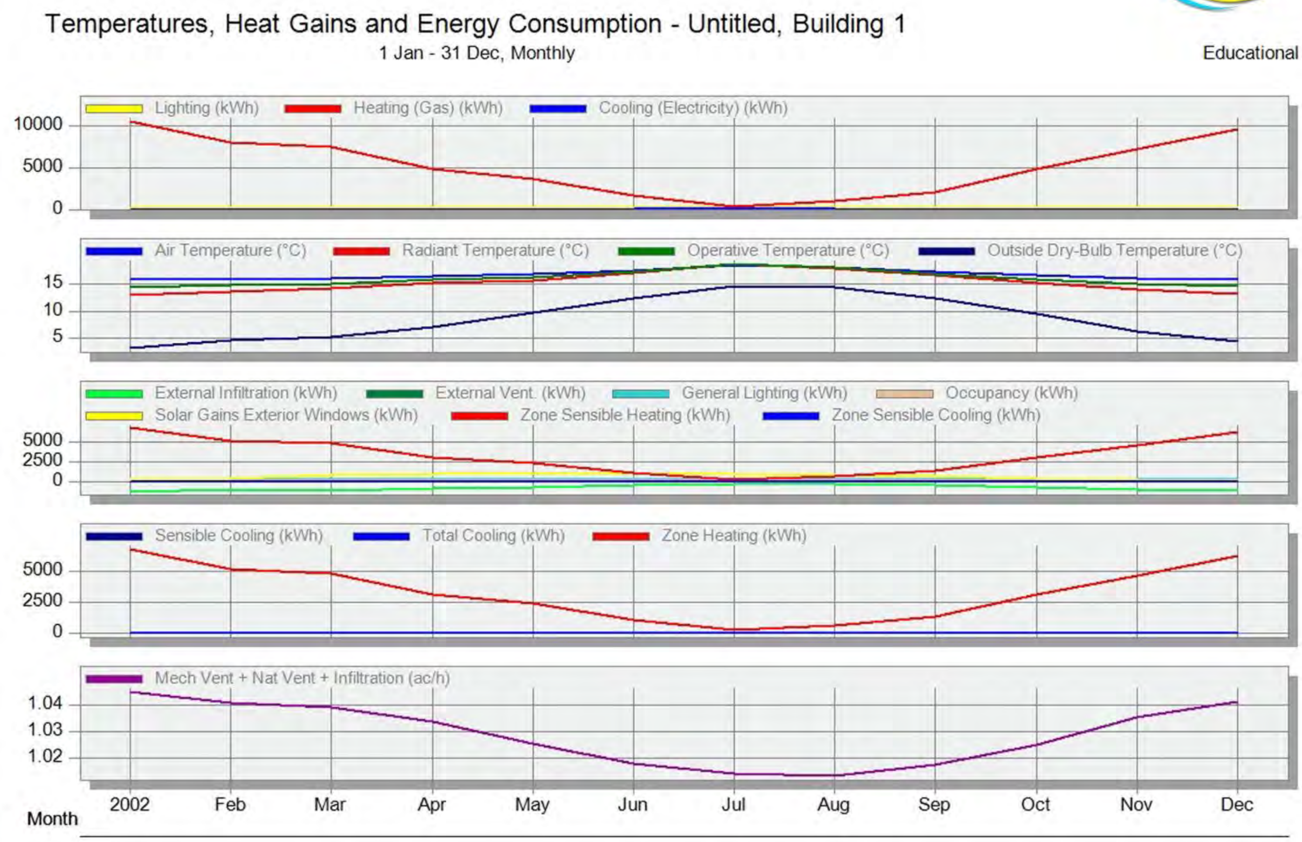
Figure A226. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.37
Operative Temperature (°C)	15.19
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.50
Walls (kW)	-10.52
Ceilings (int) (kW)	-0.51
Floors (int) (kW)	0.33
Ground Floors (kW)	0.60
Partitions (int) (kW)	-0.02
Roofs (kW)	-4.04
Floors (ext) (kW)	-0.20
External Infiltration (kW)	-3.28
External Vent. (kW)	-9.84
Zone Sensible Heating (kW)	29.91

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 37.390 (kW)				
Ground Floor Total Design Heating Capacity = 16.540 (kW)				
Utility Room	14.15	2.50	**3.12**	575.7245
Sitting Room	15.89	2.77	**3.46**	242.6273
Hall veslibule	15.61	2.36	**2.95**	271.9110
Bath room	17.07	0.46	**0.57**	193.4971
Dining room	16.32	1.36	**1.71**	217.6542
Family Room	14.97	1.93	**2.41**	315.9881
Kitchen	13.53	1.86	**2.32**	571.3910
First Floor Total Design Heating Capacity = 11.900 (kW)				
Drawing Room	15.14	3.85	**4.81**	301.7412
BedRoom	15.81	1.42	**1.78**	231.3512
Bed Room	14.89	1.83	**2.29**	300.4462
Hall	14.91	1.96	**2.45**	320.0160
Service	16.82	0.46	**0.57**	193.6735
Roof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.26	0.00	**0.00**	0.0000
Occupied Roof Total Design Heating Capacity = 7.200 (kW)				
Service	14.97	0.23	**0.29**	254.9411
Box Room	13.90	0.40	**0.51**	186.5326
BedRoom	14.35	1.85	**2.31**	161.5661
Top Hall	14.80	1.24	**1.54**	215.2074
BedRoom	14.72	0.80	**1.00**	136.4216
BedRoom	15.41	1.24	**1.55**	160.2724

Figure A227. The heating design simulation and data of the house.



Lighting (kWh)	223.60	203.02	226.34	216.74	223.60	219.49	223.60	224.97	218.11	223.60	218.11	224.97
Heating (Gas) (kWh)	10440.16	7927.38	7421.39	4797.35	3697.48	1597.38	331.48	937.23	2011.62	4792.15	7174.49	9640.87
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.01	0.13	0.04	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.66	15.82	16.00	16.42	16.69	17.36	18.43	17.99	17.16	16.49	16.04	15.73
Radiant Temperature (°C)	12.93	13.49	14.04	15.11	15.63	16.94	18.51	17.77	16.51	15.05	14.01	13.16
Operative Temperature (°C)	14.30	14.65	15.02	15.76	16.16	17.15	18.47	17.88	16.83	15.77	15.03	14.44
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1232.32	-1010.52	-1081.65	-906.38	-697.59	-477.81	-374.00	-362.24	-467.58	-690.65	-948.92	-1135.48
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.01	-0.23	-0.06	0.00	0.00	0.00	0.00
General Lighting (kWh)	223.60	203.02	226.34	216.74	223.60	219.49	223.60	224.97	218.11	223.60	218.11	224.97
Occupancy (kWh)	70.18	64.60	73.32	68.29	70.17	70.97	67.49	69.85	69.82	70.18	69.89	71.75
Solar Gains Exterior Windows (kWh)	245.37	430.78	757.21	938.12	990.61	974.08	1007.43	852.40	650.48	421.69	286.24	164.30
Zone Sensible Heating (kWh)	6770.84	5140.74	4812.46	3110.74	2397.69	1035.87	214.97	607.92	1304.88	3108.08	4652.45	6252.26
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.06	-0.55	-0.14	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.07	-0.55	-0.14	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.07	-0.60	-0.16	0.00	0.00	0.00	0.00
Zone Heating (kWh)	6786.11	5152.79	4823.91	3118.28	2403.36	1038.30	215.46	609.20	1307.56	3114.90	4663.42	6266.57
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A228. The simulation detailed results of the house.

Case 77. A House Built in 1864

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone construction and being timber clad externally.	1.841	Increase 21.3 cm Insulation
	Flat 2.212	Increase 32.5 cm Insulation
	Pitched 2.453	Increase 33 cm Insulation
Floors are of timber construction.	1.606	Increase 31.8 cm Insulation
Internal Walls are brick construction plastered on the hard.	1.786	
Windows are of timber framed single glazed.		

* As a basis for a theory of possibility

Description

The property comprises a three story detached house set within ground.

Ground Floor: Entrance Hall, Living Room, Sitting Room, Dining Room, Kitchen, Utility Room and Shower Room with WC.
First Floor: Landing, Four Bedrooms and Bathroom with WC.
Second Floor - Landing, Three Bedroom, Bathroom.

Weather Dry.

Heating and hot water

The property benefits from a gas fired central heating system with a relatively modern boiler.

The hot water storage tank is located within a cupboard.

Gross internal floor area (m²) 354 m^2 **approx.**

Address

MIDLOTHIAN, EH22 3DF

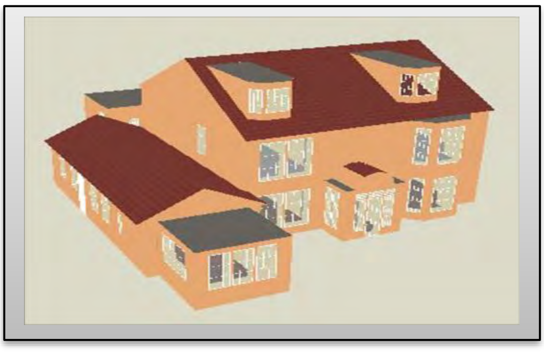
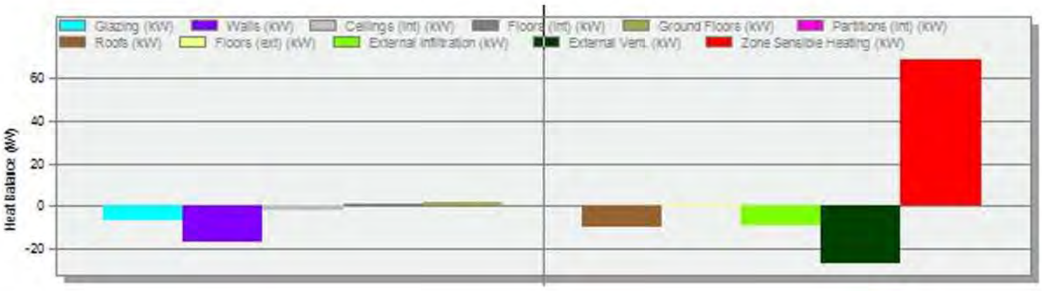


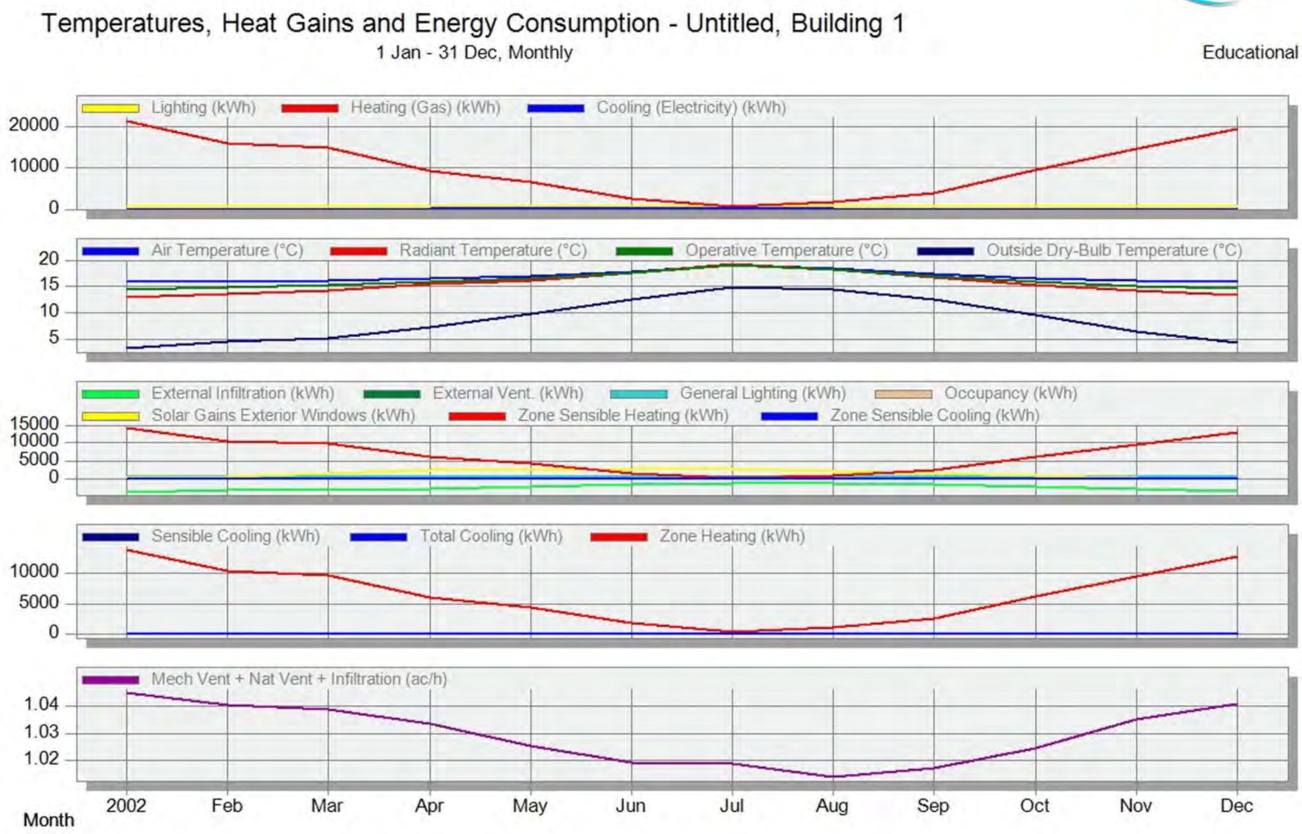
Figure A229. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.30
Operative Temperature (°C)	15.15
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-6.54
Walls (kW)	-16.79
Ceilings (int) (kW)	-2.25
Floors (int) (kW)	0.97
Ground Floors (kW)	1.91
Partitions (int) (kW)	0.00
Roofs (kW)	-9.80
Floors (ext) (kW)	-0.33
External Infiltration (kW)	-9.03
External Vent. (kW)	-27.10
Zone Sensible Heating (kW)	68.81

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 86.010 (kW)				
Ground Floor Total Design Heating Capacity = 34.680 (kW)				
Service	16.59	0.78	**0.98**	209.6077
Drawing Room	15.53	4.90	**6.13**	209.2128
Sitting Room	15.40	2.44	**3.05**	238.4359
Kitchen	16.32	2.36	**2.95**	188.0611
Dining Room	16.11	2.76	**3.45**	193.7028
Laundry	15.53	2.18	**2.72**	229.8530
Garden Room	13.69	4.95	**6.19**	323.4338
Utility Room	15.74	1.89	**2.37**	224.2993
Lardar	14.47	0.66	**0.82**	742.8564
Pantry	15.52	1.49	**1.86**	248.1743
Hall	16.85	3.33	**4.16**	167.6208
Vestibule Total Design Heating Capacity = 1.460 (kW)				
Zone 1	13.07	1.17	**1.46**	790.0758
Entrance Roof Total Design Heating Capacity = 0.550 (kW)				
Zone 1	13.57	0.44	**0.55**	924.9608
Garage Total Design Heating Capacity = 8.470 (kW)				
Zone 1	13.23	6.77	**8.47**	347.3015
First Floor Total Design Heating Capacity = 21.450 (kW)				
Service	16.31	0.79	**0.99**	213.0391
Master BedRoom	15.15	4.88	**6.10**	208.4783
Bed Room	15.10	2.44	**3.05**	238.4721
Bed Room	15.21	2.58	**3.23**	231.0715
Bed Room	14.91	3.05	**3.81**	240.0204
Hall	16.23	3.42	**4.27**	177.8908
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.75	0.00	**0.00**	0.0000
Main Roof Scond Floor Total Design Heating Capacity = 16.150 (kW)				
Bed Room	14.20	2.93	**3.66**	178.4766

Figure A230. The heating design simulation and data of the house.



Lighting (kWh)	623.91	566.49	631.56	604.77	623.91	612.43	623.91	627.74	608.60	623.91	608.60	627.74
Heating (Gas) (kWh)	21357.49	16133.25	14902.32	9329.18	6717.06	2700.40	541.21	1650.52	3800.12	9540.50	14677.20	19677.99
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.03	0.38	2.54	0.13	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.67	15.81	15.99	16.40	16.73	17.58	18.79	18.16	17.15	16.45	16.01	15.74
Radiant Temperature (°C)	12.93	13.50	14.10	15.25	15.88	17.39	19.02	18.07	16.61	15.06	13.98	13.16
Operative Temperature (°C)	14.30	14.65	15.04	15.83	16.30	17.49	18.91	18.12	16.88	15.76	14.99	14.45
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3393.93	-2777.78	-2967.97	-2481.22	-1920.55	-1362.62	-1113.95	-1030.53	-1276.05	-1880.94	-2597.92	-3127.17
External Vent. (kWh)	0.00	0.00	0.00	-0.31	-0.05	-1.02	-6.28	-0.83	0.00	0.00	0.00	0.00
General Lighting (kWh)	623.91	566.49	631.56	604.77	623.91	612.43	623.91	627.74	608.60	623.91	608.60	627.74
Occupancy (kWh)	195.82	180.26	204.57	190.51	195.65	195.80	184.05	192.73	194.74	195.82	195.02	200.20
Solar Gains Exterior Windows (kWh)	389.30	856.35	1715.57	2366.99	2666.19	2760.93	2792.03	2218.23	1539.50	866.56	474.14	258.23
Zone Sensible Heating (kWh)	13842.77	10455.05	9656.22	6043.39	4350.83	1748.75	350.37	1069.21	2462.18	6182.12	9510.61	12753.54
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	-0.01	-0.14	-1.72	-10.21	-0.49	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	-0.01	-0.14	-1.72	-10.21	-0.49	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	-0.01	-0.14	-1.72	-11.45	-0.58	0.00	0.00	0.00	0.00
Zone Heating (kWh)	13882.37	10486.62	9686.51	6063.97	4366.09	1755.26	351.79	1072.84	2470.08	6201.32	9540.18	12790.69
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.01	1.02	1.02	1.04	1.04

Figure A231. The simulation detailed results of the house.

Case 78. A House Built in 1861

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid masonry, natural stone finishes.	1.806	Increase 21 cm Insulation
	Flat -	-
	Pitched 2.547	Increase 33 cm Insulation
Floors are of a suspended timber construction.	1.575	Increase 31.8 cm Insulation
Internal Walls are plaster on solid and plasterboard on timber stud.	1.775	
Windows comprise a mixture of replacement double glazed hardwood and PVC units.		

* As a basis for a theory of possibility

Description

A double upper flat.

Ground Floor: Shared Entrance Vestibule. Threshold Door and Private Stair.

First Floor: Landing/Hall, Livingroom, Sitting/Dining room, Bedroom, Kitchen/Breakfast room , Shower room and Storage.

Weather Clear and dry.

Heating and hot water

A gas fired combination condensing boiler connected to a wet wall mounted radiator heating system. Hot water is from the boiler.

Gross internal floor area(m²) 130 m^2

Address

EDINBURGH EH5 1NN

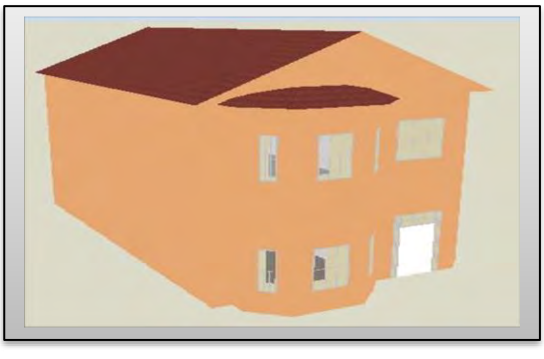
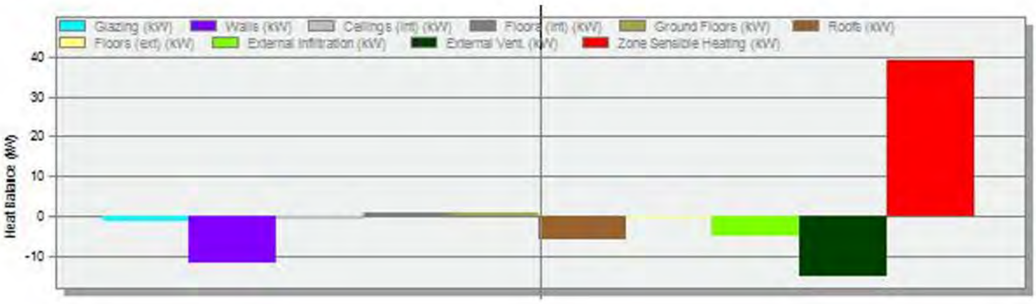


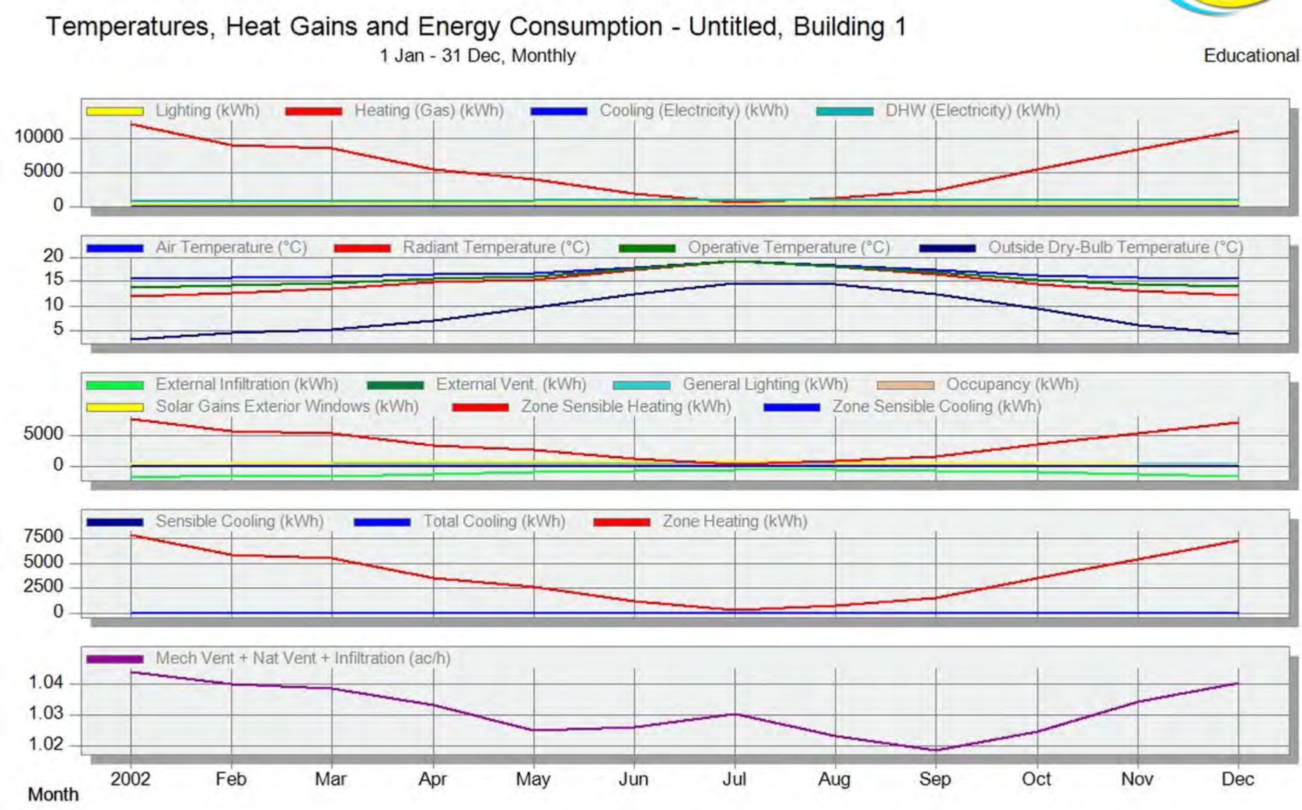
Figure A232. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	10.98
Operative Temperature (°C)	14.49
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.27
Walls (kW)	-11.91
Ceilings (int) (kW)	-0.70
Floors (int) (kW)	0.70
Ground Floors (kW)	0.62
Roofs (kW)	-6.02
Floors (ext) (kW)	-0.28
External Infiltration (kW)	-5.09
External Vent. (kW)	-15.26
Zone Sensible Heating (kW)	39.18

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 48.980 (kW)				
Ground Floor Total Design Heating Capacity = 19.000 (kW)				
Kitchen	15.25	3.15	**3.94**	251.9331
Sitting Room	15.25	3.15	**3.94**	251.7306
Lounge	15.26	4.39	**5.48**	239.1264
Landing	16.30	1.73	**2.16**	219.7784
Bed Room	15.16	2.18	**2.72**	277.8208
Service	16.03	0.61	**0.76**	284.4127
First Floor Total Design Heating Capacity = 19.420 (kW)				
Bed Room	15.03	3.21	**4.01**	256.2600
Bed Room	15.04	3.20	**4.00**	256.0998
Wardrobe	14.96	4.53	**5.66**	246.7114
Landing	16.09	1.78	**2.22**	225.7575
Bed Room	14.96	2.20	**2.75**	280.4863
Service	15.86	0.62	**0.78**	293.6481
Main Roof Total Design Heating Capacity = 10.560 (kW)				
Zone 1	12.75	8.45	**10.56**	152.0260
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.88	0.00	**0.00**	0.0000

Figure A233. The heating design simulation and data of the house.



Lighting (kWh)	340.41	313.93	357.10	331.59	340.41	348.27	340.41	348.76	339.93	340.41	339.93	348.76
Heating (Gas) (kWh)	12012.71	9031.27	8464.17	5358.65	4026.18	1879.47	565.65	1227.31	2328.08	5450.43	8333.63	11129.42
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
DHW (Electricity) (kWh)	819.79	776.88	913.89	805.49	819.79	899.59	819.79	866.84	852.54	819.79	852.54	866.84
Air Temperature (°C)	15.44	15.59	15.85	16.27	16.52	17.70	18.94	18.17	17.15	16.20	15.74	15.53
Radiant Temperature (°C)	11.92	12.63	13.41	14.75	15.35	17.25	19.00	17.85	16.38	14.43	13.12	12.21
Operative Temperature (°C)	13.68	14.11	14.63	15.51	15.94	17.47	18.97	18.01	16.77	15.32	14.43	13.87
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1869.15	-1532.49	-1652.90	-1378.32	-1052.44	-780.22	-638.41	-580.80	-728.22	-1032.07	-1427.40	-1726.62
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-6.74	-17.14	-9.04	-0.67	0.00	0.00	0.00
General Lighting (kWh)	340.41	313.93	357.10	331.59	340.41	348.27	340.41	348.76	339.93	340.41	339.93	348.76
Occupancy (kWh)	90.33	84.64	98.04	87.92	89.71	92.33	83.63	89.20	91.46	90.33	92.37	94.28
Solar Gains Exterior Windows (kWh)	258.85	408.86	674.08	756.86	758.38	712.76	759.99	674.58	560.86	394.34	296.00	172.56
Zone Sensible Heating (kWh)	7777.99	5846.02	5478.35	3466.68	2603.49	1214.73	365.39	793.71	1506.58	3526.93	5393.51	7205.72
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.21	0.00	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.21	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.29	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	7808.26	5870.32	5501.71	3483.12	2617.01	1221.66	367.67	797.75	1513.25	3542.78	5416.86	7234.12
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.02	1.03	1.03	1.02	1.02	1.02	1.03	1.04

Figure A234. The simulation detailed results of the house.

Case 79. A House Built in 1860

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are pointed stone. Cavity walls at the front extension stone finished.	1.880	Increase 21.2 cm Insulation
	Flat -	-
	Pitched 2.626	Increase 33 cm Insulation
Floors are concrete at the front projection and kitchen.	1.623	Increase 32 cm Insulation
Internal Walls are lath and plaster, plasterboard and plastered hard.	1.789	
Windows are u-PVC double glazed windows.		

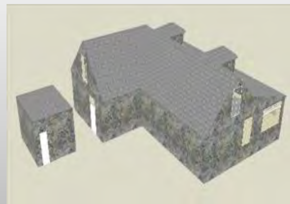
* As a basis for a theory of possibility

Description

Detached farm house.

On ground floor: sunroom to the front into original hall, lounge, dining room, bedroom with en-suite and kitchen.

On first floor: three further bedrooms and bathroom.



Weather Dry and sunny.

Heating and hot water

There is electric underfloor heating in the en-suite and bathroom.

The oil fired Rayburn Heatranger stove provides part of the heating and hot water for the property. The hot water cylinder is located behind the cupboard in the back bedroom. Oil tank adjacent to horse mill.

Gross internal floor area(m²) 180 m^2

Address

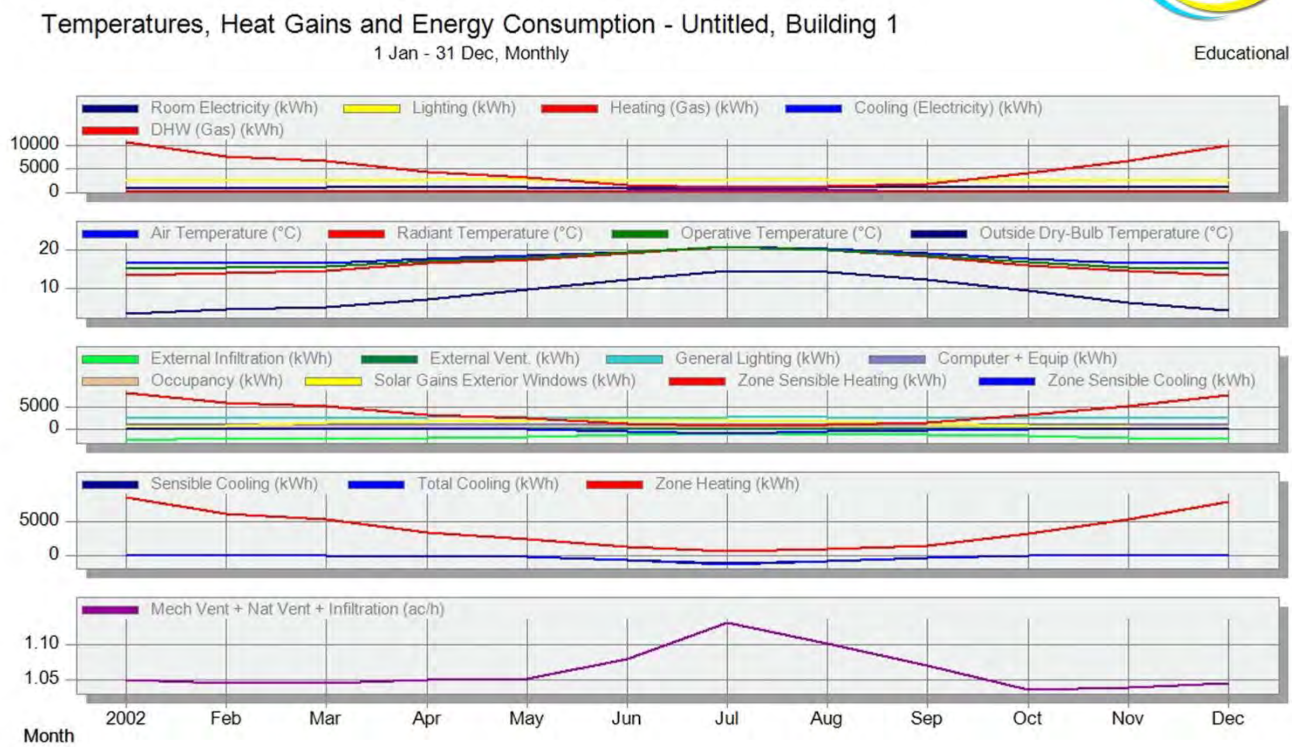
FALKIRK FK2 8RT

Figure A235. The Software visualization of the house.

Air Temperature (°C)	21.99
Radiant Temperature (°C)	13.75
Operative Temperature (°C)	17.87
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-5.32
Walls (kW)	-13.10
Ceilings (int) (kW)	-2.91
Floors (int) (kW)	1.44
Ground Floors (kW)	0.62
Partitions (int) (kW)	-0.81
Roofs (kW)	-10.80
Floors (ext) (kW)	-0.49
External Infiltration (kW)	-7.93
External Vent. (kW)	-7.94
Zone Sensible Heating (kW)	47.19

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 58.980 (kW)				
Ground Floor Total Design Heating Capacity = 32.370 (kW)				
Dining Room	19.27	3.06	**3.83**	174.8649
Sun Room	17.28	9.82	**12.27**	254.5565
Hall	20.71	0.60	**0.75**	150.3934
Lounge	18.61	5.57	**6.96**	183.5463
Master BedRoom	20.12	1.15	**1.44**	165.8733
Service	20.65	1.25	**1.56**	129.4130
Kitchen	17.72	4.45	**5.56**	248.4908
Main Roof Total Design Heating Capacity = 19.150 (kW)				
Bed Room	16.73	5.15	**6.43**	165.3563
Bed Room	17.46	2.91	**3.63**	160.7152
Service	19.10	1.52	**1.90**	148.3181
Hall	18.27	1.89	**2.36**	193.3549
Bed Room	16.31	3.86	**4.83**	202.8284
Roof SunRoom Total Design Heating Capacity = 0.000 (kW)				
Zone 1	0.01	0.00	**0.00**	0.0000
Utility Room Total Design Heating Capacity = 4.680 (kW)				
Zone 1	16.46	3.74	**4.68**	362.0700
Window Roof Total Design Heating Capacity = 0.960 (kW)				
Zone 1	16.24	0.77	**0.96**	1532.8228
Roof Window Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-2.02	0.00	**0.00**	0.0000
Window Roof Total Design Heating Capacity = 1.250 (kW)				
Zone 1	14.87	1.00	**1.25**	3683.1967
Roof Window Total Design Heating Capacity = 0.570 (kW)				
Zone 1	12.52	0.46	**0.57**	960.7907
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.74	0.00	**0.00**	0.0000

Figure A236. The heating design simulation and data of the house.



Room Electricity (kWh)	1060.00	925.87	978.50	1015.29	1060.00	933.79	1060.00	1019.25	974.54	1060.00	974.54	1019.25
Lighting (kWh)	2786.42	2423.01	2544.22	2665.29	2786.42	2423.09	2786.42	2665.32	2544.19	2786.42	2544.19	2665.32
Heating (Gas) (kWh)	10766.66	7729.45	6776.01	4297.74	3150.31	1599.69	942.90	1284.59	1846.79	4049.96	6707.95	9895.84
Cooling (Electricity) (kWh)	0.00	0.00	7.67	66.98	117.98	425.35	929.57	556.98	229.47	21.90	0.56	0.00
DHW (Gas) (kWh)	115.81	100.70	105.74	110.77	115.81	100.70	115.81	110.77	105.74	115.81	105.74	110.77
Air Temperature (°C)	16.63	16.62	16.71	17.79	18.52	19.55	20.99	20.35	19.04	17.69	16.69	16.53
Radiant Temperature (°C)	13.42	14.00	14.70	16.47	17.45	19.13	20.91	19.89	18.23	16.10	14.46	13.50
Operative Temperature (°C)	15.02	15.31	15.70	17.13	17.99	19.34	20.95	20.12	18.64	16.90	15.57	15.01
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2749.10	-2236.62	-2376.99	-2135.42	-1804.56	-1405.70	-1282.45	-1211.15	-1325.75	-1660.82	-2085.21	-2509.92
External Vent. (kWh)	0.00	0.00	-4.33	-25.81	-40.05	-71.24	-133.13	-87.47	-64.75	-8.00	-0.21	0.00
General Lighting (kWh)	2786.42	2423.01	2544.22	2665.29	2786.42	2423.09	2786.42	2665.32	2544.19	2786.42	2544.19	2665.32
Computer + Equip (kWh)	1060.00	925.87	978.50	1015.29	1060.00	933.79	1060.00	1019.25	974.54	1060.00	974.54	1019.25
Occupancy (kWh)	496.44	431.37	448.99	461.45	476.83	404.70	452.43	437.86	423.98	486.00	452.27	474.82
Solar Gains Exterior Windows (kWh)	397.35	767.66	1467.22	1785.06	2046.78	2085.44	2078.16	1725.22	1304.60	804.75	464.67	258.54
Zone Sensible Heating (kWh)	8535.28	6120.36	5358.15	3387.53	2476.81	1256.54	740.24	1008.57	1448.95	3191.18	5305.54	7844.11
Zone Sensible Cooling (kWh)	0.00	0.00	-10.86	-92.59	-163.08	-569.86	-1156.18	-689.07	-291.66	-26.60	-0.75	0.00
Sensible Cooling (kWh)	0.00	0.00	-10.73	-92.23	-162.68	-567.94	-1153.15	-687.50	-291.41	-26.59	-0.75	0.00
Total Cooling (kWh)	0.00	0.00	-10.74	-93.77	-165.17	-595.77	-1302.06	-780.02	-321.25	-30.66	-0.78	0.00
Zone Heating (kWh)	8577.28	6156.03	5395.02	3421.72	2508.77	1274.35	751.89	1023.33	1469.62	3223.25	5341.12	7883.23
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.05	1.05	1.05	1.05	1.08	1.13	1.10	1.07	1.04	1.04	1.05

Figure A237. The simulation detailed results of the house.

Case 80. A House Built in 1855

Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone.	1.884	Increase 21 cm Insulation
	Flat -	-
	Pitched 2.647	Increase 33 cm Insulation
Floors are suspended timber with fitted coverings throughout.	1.634	Increase 32 cm Insulation
Internal Walls are plastered masonry and plasterboard lined.	1.785	
Windows are replacement timber frame sash and casement style double glazing.		

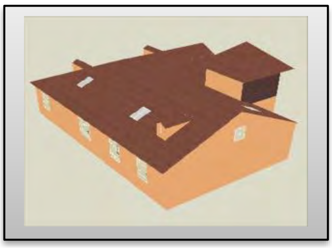
* As a basis for a theory of possibility

Description

The property comprises an end terraced dwelling house. There is a flat located below the property at street level under separate ownership.

Ground Floor: Entrance Vestibule and Hallway, Livingroom, Diningroom ,Games Room, Bedroom, Kitchen and Shower Room. Lower Ground Level: Study.

First Floor: Master Bedroom with En Suite Shower Room, 3 further Bedrooms and Bathroom.



Weather Dry and sunny.

Heating and hot water

Space heating is provided by a gas fired radiator central heating installation. The boiler is located within the Kitchen.

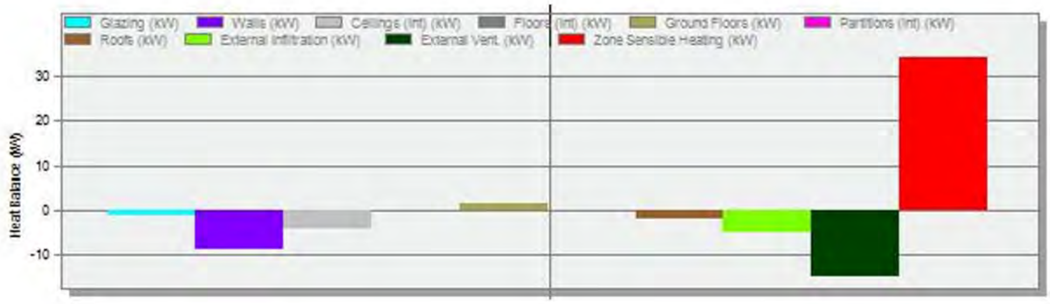
Hot water is assumed to be stored within an insulated tank. This was unseen.

Gross internal floor area(m²) 290 m^2

Address

LAUDER TD6 2US

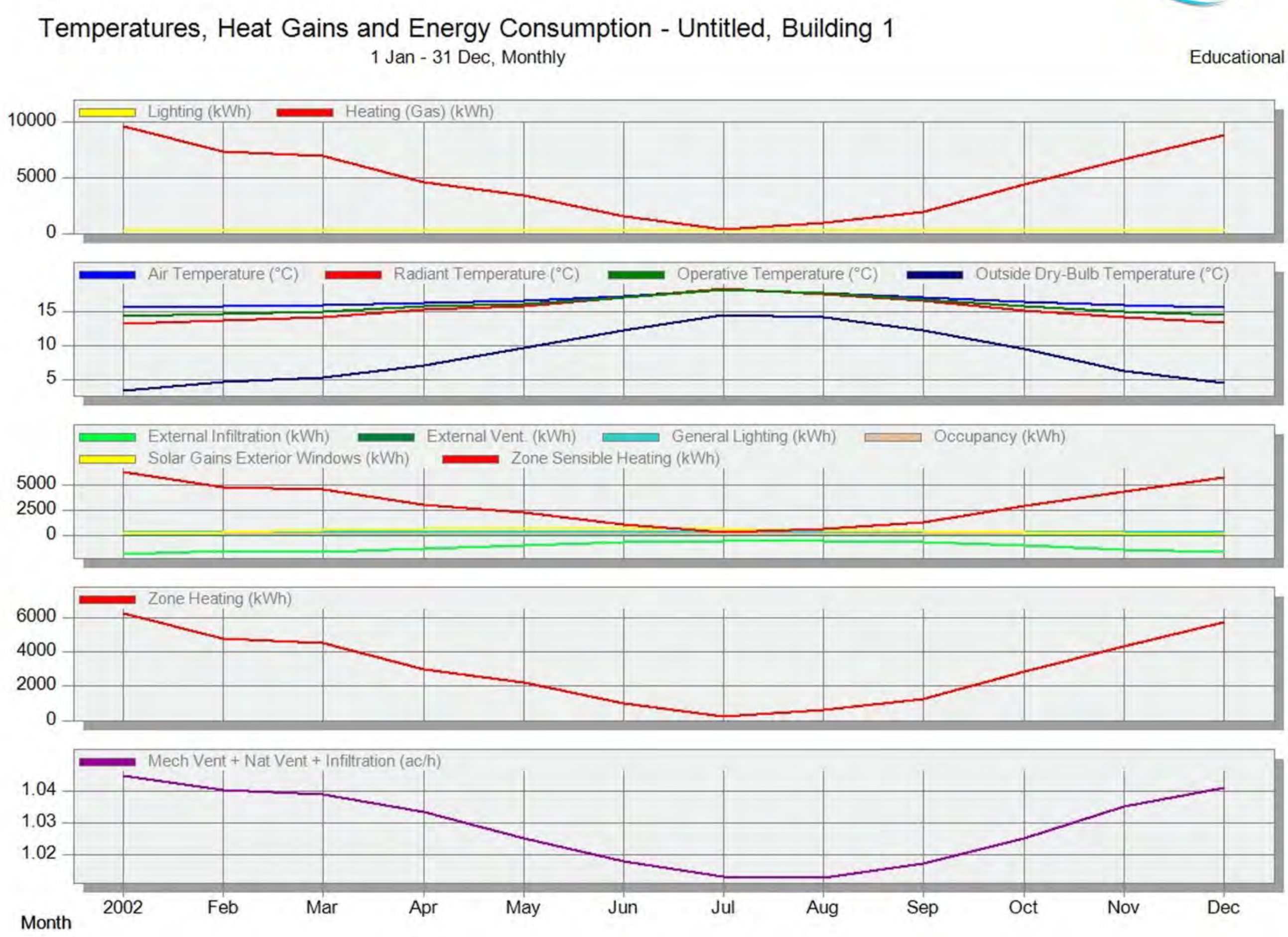
Figure A238. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.59
Operative Temperature (°C)	15.29
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.07
Walls (kW)	-8.98
Ceilings (int) (kW)	-4.21
Floors (int) (kW)	0.11
Ground Floors (kW)	1.60
Partitions (int) (kW)	-0.07
Roofs (kW)	-1.79
External Infiltration (kW)	-4.97
External Vent. (kW)	-14.92
Zone Sensible Heating (kW)	34.22

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 42.790 (kW)				
Ground Floor Total Design Heating Capacity = 38.320 (kW)				
Dining Room	15.80	2.53	**3.17**	230.2640
Hall	15.73	6.52	**8.15**	223.5700
Kitchen	15.81	3.13	**3.91**	222.7966
Sitting Room	15.01	4.60	**5.75**	253.8435
Breakfast Room	15.02	4.19	**5.24**	257.0654
Vestibule	15.78	1.09	**1.36**	266.7492
Bed Room	14.90	2.78	**3.47**	288.7489
Games Room	14.94	3.61	**4.51**	270.6416
Service	15.75	2.20	**2.76**	237.2880
Landing First Floor Total Design Heating Capacity = 2.750 (kW)				
Zone 1	13.35	2.20	**2.75**	401.3274

Figure A239. The heating design simulation and data of the house.



Lighting (kWh)	271.82	246.80	275.15	263.48	271.82	266.81	271.82	273.48	265.15	271.82	265.15	273.48
Heating (Gas) (kWh)	9651.17	7348.82	6949.08	4589.76	3469.99	1545.65	369.72	921.96	1893.82	4444.77	6674.13	8879.71
Air Temperature (°C)	15.65	15.80	15.97	16.40	16.70	17.38	18.28	17.89	17.15	16.51	16.03	15.72
Radiant Temperature (°C)	13.18	13.71	14.25	15.30	15.82	17.10	18.46	17.74	16.63	15.24	14.22	13.41
Operative Temperature (°C)	14.41	14.75	15.11	15.85	16.26	17.24	18.37	17.81	16.89	15.87	15.13	14.56
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1860.57	-1522.25	-1626.35	-1359.59	-1047.84	-718.96	-541.99	-527.23	-697.80	-1037.89	-1428.27	-1714.48
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.00	-0.09	-0.02	0.00	0.00	0.00	0.00
General Lighting (kWh)	271.82	246.80	275.15	263.48	271.82	266.81	271.82	273.48	265.15	271.82	265.15	273.48
Occupancy (kWh)	85.31	78.53	89.13	83.04	85.30	86.21	82.43	85.26	84.93	85.31	84.96	87.22
Solar Gains Exterior Windows (kWh)	161.40	270.91	475.82	566.88	594.50	582.64	613.12	519.42	406.32	268.13	185.10	107.44
Zone Sensible Heating (kWh)	6250.97	4758.78	4499.52	2971.62	2246.93	1001.02	239.47	597.27	1226.93	2878.79	4321.71	5750.89
Zone Heating (kWh)	6273.26	4776.73	4516.90	2983.34	2255.49	1004.67	240.32	599.28	1230.99	2889.10	4338.18	5771.81
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.02	1.04	1.04

Figure A240. The simulation detailed results of the house.

Case 81. A House Built in 1850

Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone.	1.889	Increase 21.15 cm Insulation
	Flat 2.200	Increase 32.45 cm Insulation
	Pitched 2.670	Increase 33.26 cm Insulation
Floors are suspended timber with fitted coverings throughout.	1.639	Increase 32 cm Insulation
Internal Walls are a mixture of masonry and timber frame construction	1.791	
Windows are a mixture of timber and plastic. The windows have a mixture of single and double glazing.		

* As a basis for a theory of possibility

Description

The subjects comprise a two storey semi-detached house which we

Ground floor: Entrance Lobby and Hall, Living room, Study, Kitchen, 1 Bedroom and Bathroom.

First floor: 2 Bedrooms.

Externally: Garden to the front and rear.

Weather Dry.

Heating and hot water

The property is heated by a gas fired boiler. Heating to some rooms is provided by water filled radiators.

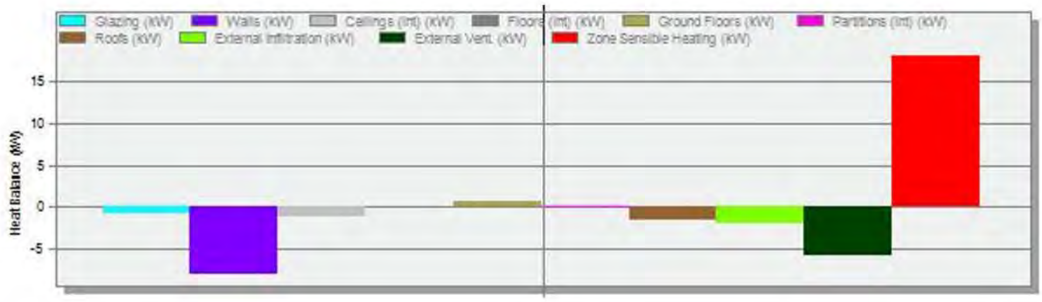
Hot water is stored in a storage cylinder.

Gross internal floor area(m²) 100 m^2

Address

BONNYRIGG EH2 9ED

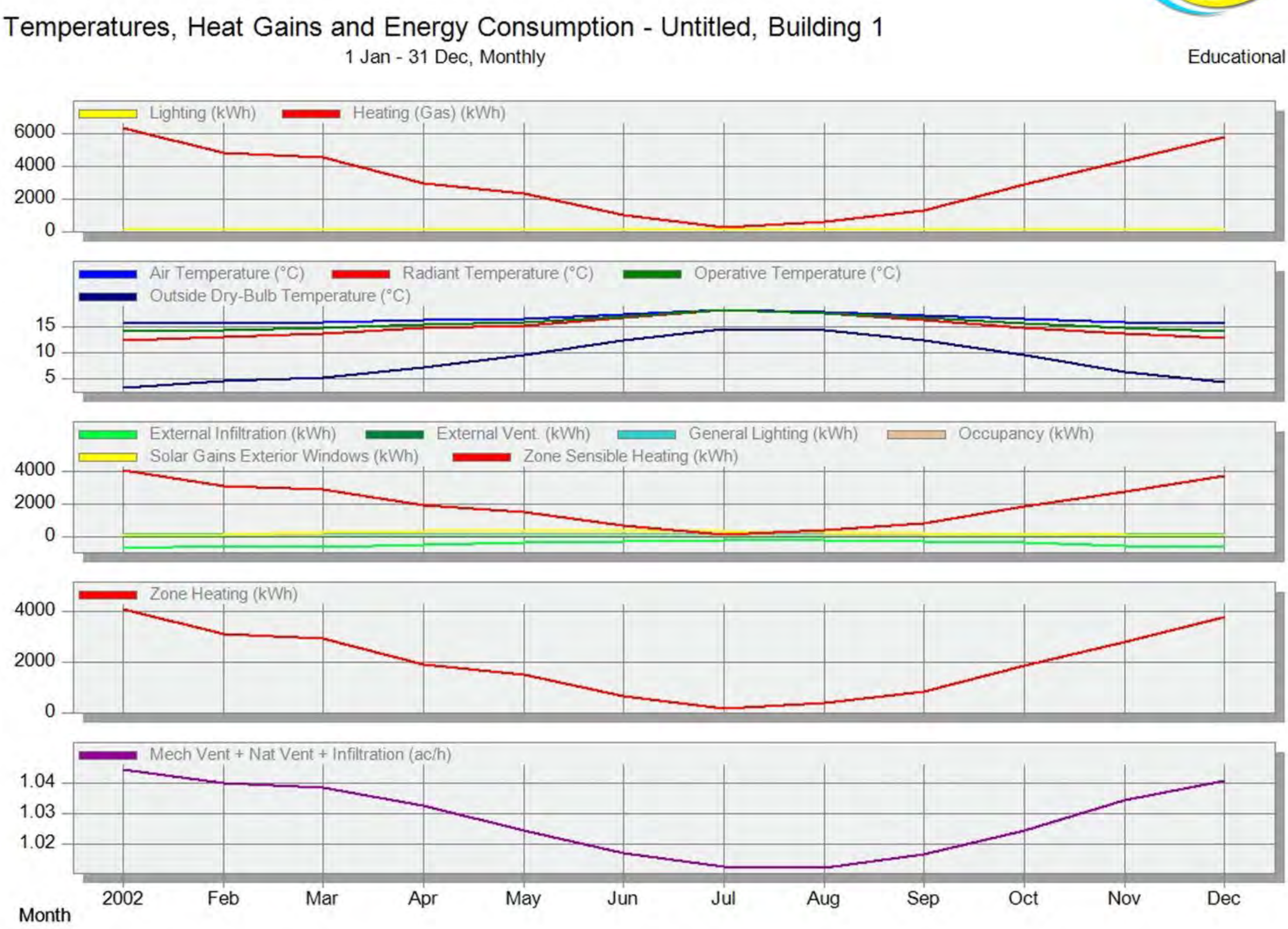
Figure A241. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.76
Operative Temperature (°C)	14.88
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-0.66
Walls (kW)	-7.96
Ceilings (int) (kW)	-1.04
Floors (int) (kW)	0.15
Ground Floors (kW)	0.67
Partitions (int) (kW)	-0.02
Roofs (kW)	-1.43
External Infiltration (kW)	-1.94
External Vent. (kW)	-5.81
Zone Sensible Heating (kW)	18.00

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 22.480 (kW)				
Ground Floor Total Design Heating Capacity = 16.360 (kW)				
Living Room	15.56	2.90	**3.62**	277.5963
Bed Room	13.39	1.91	**2.38**	618.6999
Kitchen	14.30	3.01	**3.77**	332.6681
Bed Room	15.58	2.61	**3.27**	244.3894
Corridor	14.97	1.49	**1.86**	470.7832
Bath Room	13.71	1.17	**1.46**	714.7049
First Floor Total Design Heating Capacity = 5.620 (kW)				
Bed Room	14.97	1.27	**1.58**	190.9784
Corridor	14.82	0.98	**1.22**	237.3322
Bed Room	14.60	2.26	**2.82**	181.3069
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	0.29	0.00	**0.00**	0.0000
Window Roof Total Design Heating Capacity = 0.170 (kW)				
Zone 1	12.94	0.14	**0.17**	1.#INF
Window Roof Total Design Heating Capacity = 0.330 (kW)				
Zone 1	13.93	0.26	**0.33**	3331.1397

Figure A242. The heating design simulation and data of the house.



Lighting (kWh)	125.07	113.56	126.60	121.23	125.07	122.77	125.07	125.84	122.00	125.07	122.00	125.84
Heating (Gas) (kWh)	6311.82	4806.42	4529.15	2934.21	2303.46	1033.64	231.07	613.58	1245.19	2891.10	4316.63	5793.64
Air Temperature (°C)	15.57	15.68	15.83	16.26	16.55	17.24	18.19	17.80	17.05	16.37	15.91	15.63
Radiant Temperature (°C)	12.47	13.02	13.55	14.70	15.26	16.66	18.19	17.44	16.23	14.72	13.61	12.75
Operative Temperature (°C)	14.02	14.35	14.69	15.48	15.91	16.95	18.19	17.62	16.64	15.55	14.76	14.19
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-720.95	-587.83	-626.70	-522.75	-401.02	-273.44	-205.74	-200.49	-267.10	-397.42	-550.40	-663.74
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.00	-0.04	-0.01	0.00	0.00	0.00	0.00
General Lighting (kWh)	125.07	113.56	126.60	121.23	125.07	122.77	125.07	125.84	122.00	125.07	122.00	125.84
Occupancy (kWh)	39.25	36.14	41.01	38.21	39.25	39.80	38.15	39.38	39.09	39.25	39.09	40.13
Solar Gains Exterior Windows (kWh)	73.58	132.45	233.16	299.94	311.79	307.61	319.85	267.74	199.80	126.24	86.75	49.63
Zone Sensible Heating (kWh)	4093.07	3116.28	2936.24	1901.91	1493.22	670.15	149.81	397.88	807.48	1874.48	2798.55	3756.83
Zone Heating (kWh)	4102.69	3124.17	2943.95	1907.24	1497.25	671.86	150.19	398.83	809.37	1879.21	2805.81	3765.87
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.02	1.02	1.01	1.01	1.02	1.02	1.03	1.04

Figure A243. The simulation detailed results of the house.

Case 82. A House Built in 1846

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone construction, partially externally rendered, and extended in brick construction.	1.897	Increase 21.16 cm Insulation
	Flat -	-
	Pitched 2.675	Increase 33 cm Insulation
Floors are suspended timber construction.	1.659	Increase 32 cm Insulation
Internal Walls are plastered on the hard and lined in plasterboard.	1.790	
Windows comprise a mixture of the original single glazed in timber frames and replacement double glazed.		

* As a basis for a theory of possibility

Description

The subjects comprise an end terraced house.

Ground floor: hall, sitting room, dining room, shower room with wash hand basin and WC, utility room, kitchen / breakfast room leading onto store.

First floor: Landing, 3 Bedrooms, with access off the third bedroom.

Weather Dry and sunny.

Heating and hot water

The property has the benefit of a partial oil fired central heating system, served by a Worcester Camray System Utility 12/18 boiler, located within the utility room. This provides hot water to the property, which is also supplemented by an electric immersion heater, fitted to the hot water tank located in the landing cupboard.

Gross internal floor area(m²) 200 m²

Address

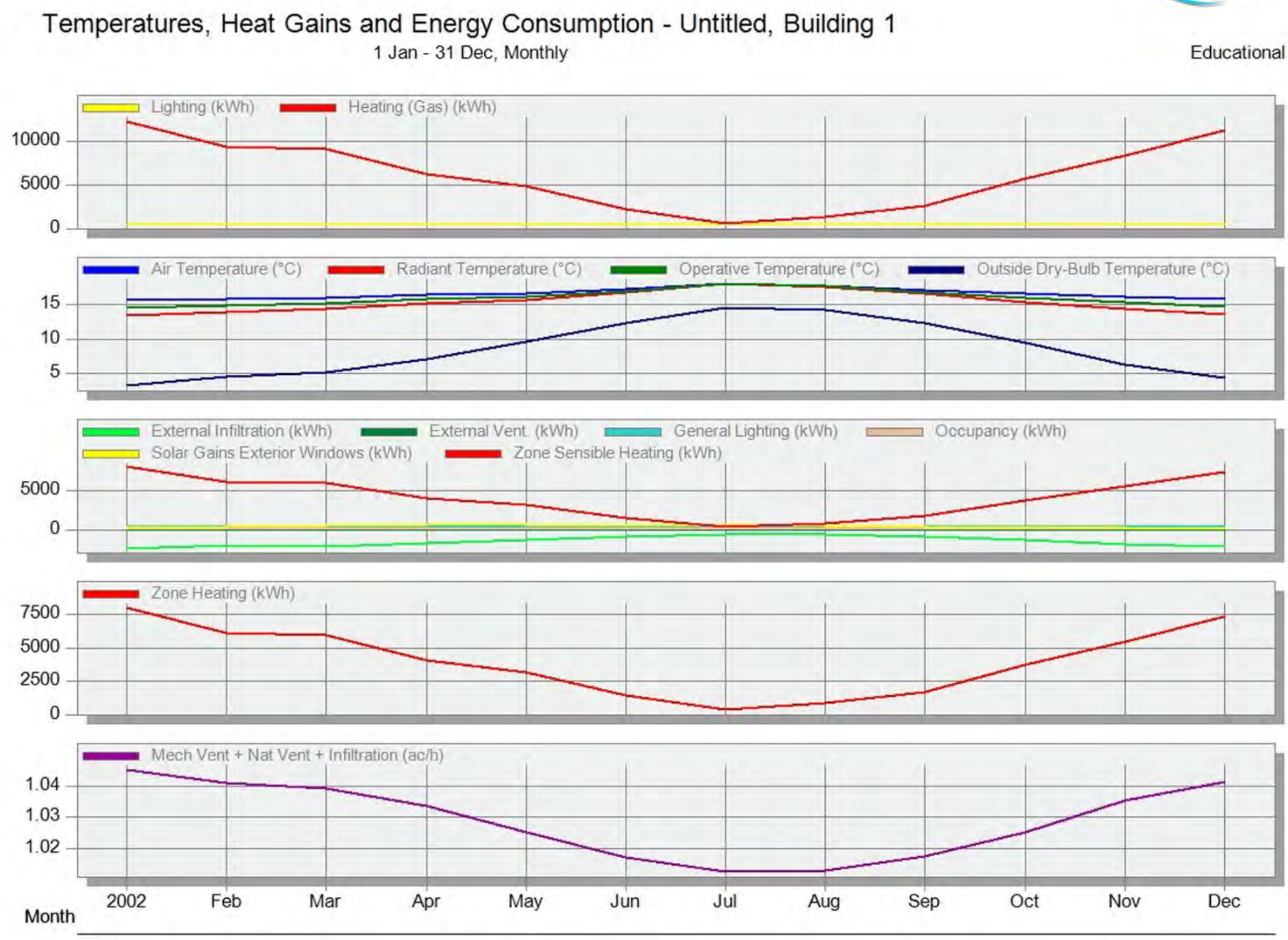
DUNS TD3 1WR

Figure A244. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.04
Operative Temperature (°C)	15.52
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.23
Walls (kW)	-13.67
Ceilings (int) (kW)	-5.14
Floors (int) (kW)	0.62
Ground Floors (kW)	1.44
Partitions (int) (kW)	-0.06
Floors (ext) (kW)	-0.01
External Infiltration (kW)	-6.26
External Vent. (kW)	-18.77
Zone Sensible Heating (kW)	42.96

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 53.730 (kW)				
Ground Floor Total Design Heating Capacity = 35.560 (kW)				
Store	14.34	3.76	**4.71**	345.2807
Utility	15.47	1.53	**1.91**	260.1367
Hall	16.73	2.30	**2.88**	178.1599
Bed Room	16.28	1.30	**1.63**	204.5576
Shop Unit	15.97	7.97	**9.96**	183.1945
Garage	14.42	4.70	**5.87**	271.6130
Kitchen	16.35	2.35	**2.93**	186.7407
Sitting Room	16.48	2.16	**2.70**	183.2558
Service 1	16.30	0.52	**0.65**	243.1101
Service 2	14.02	0.54	**0.68**	1326.9747
Service 3	14.13	0.76	**0.95**	803.4318
Service	13.96	0.55	**0.69**	1342.0044
First Floor Total Design Heating Capacity = 16.610 (kW)				
Bed Room 1	15.65	0.94	**1.18**	148.3651
Work Shop	14.81	5.82	**7.28**	143.3648
Bed Room 2	15.78	1.54	**1.92**	129.2596
Hall	15.97	1.56	**1.95**	125.6646
Attic	14.91	1.26	**1.58**	228.9489
Bed Room	15.11	2.16	**2.70**	155.4589

Figure A245. The heating design simulation and data of the house.



Lighting (kWh)	439.64	399.18	445.03	426.15	439.64	431.55	439.64	442.34	428.85	439.64	428.85	442.34
Heating (Gas) (kWh)	12278.83	9438.31	9098.63	6224.49	4811.22	2257.14	580.94	1280.92	2612.76	5734.68	8449.27	11267.81
Air Temperature (°C)	15.75	15.90	16.05	16.43	16.70	17.23	18.02	17.81	17.15	16.58	16.15	15.83
Radiant Temperature (°C)	13.45	13.93	14.37	15.26	15.73	16.80	18.04	17.57	16.56	15.36	14.46	13.68
Operative Temperature (°C)	14.60	14.92	15.21	15.85	16.22	17.02	18.03	17.69	16.86	15.97	15.30	14.76
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2364.74	-1936.91	-2065.22	-1718.26	-1321.73	-882.28	-636.82	-652.13	-881.80	-1321.85	-1820.65	-2181.72
External Vent. (kWh)	0.00	0.00	-0.31	-0.40	-0.08	-0.03	-0.89	-0.44	-0.38	0.00	-0.05	0.00
General Lighting (kWh)	439.64	399.18	445.03	426.15	439.64	431.55	439.64	442.34	428.85	439.64	428.85	442.34
Occupancy (kWh)	137.98	127.02	144.17	134.31	137.98	140.13	134.98	138.41	137.35	137.98	137.42	141.07
Solar Gains Exterior Windows (kWh)	203.07	322.66	523.93	608.82	600.25	559.23	597.66	532.43	434.48	302.73	233.77	136.10
Zone Sensible Heating (kWh)	7955.44	6114.52	5894.21	4031.97	3116.85	1462.43	376.25	830.04	1693.33	3715.90	5473.76	7300.22
Zone Heating (kWh)	7981.24	6134.90	5914.11	4045.92	3127.29	1467.14	377.61	832.60	1698.29	3727.54	5492.03	7324.08
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A246. The simulation detailed results of the house.

Case 83. A House Built in 1845

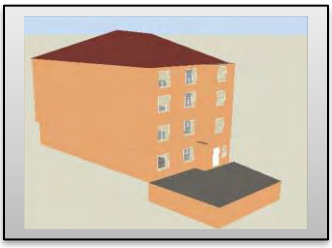
Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone construction.	1.881	Increase 21.3 cm Insulation
	Flat -	-
	Pitched 2.684	Increase 33 cm Insulation
Floors are suspended timber construction.	1.669	Increase 32 cm Insulation
Internal Walls are plastered on the hard.	1.792	
Windows are sash and case timber single glazed.		

* As a basis for a theory of possibility

Description

Lower ground and basement/garden flat contained within a 4 storey lower ground and basement intermediate terraced building.

Lower Ground Floor: Entrance Hall, Sitting room, Master Bedroom with En Suite, Bedroom, Bathroom and Separate WC. Basement/Garden Level: Open plan Kitchen/Dining room/Livingroom, Bedroom, Study/Bedroom, Utility Room and Shower Room.

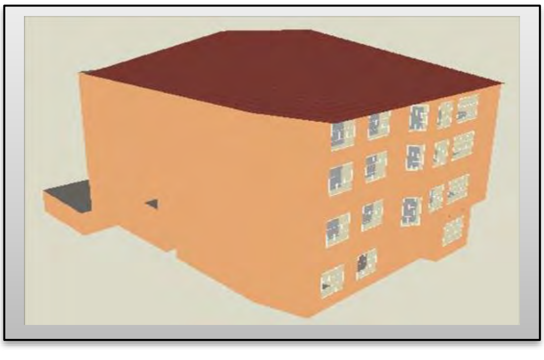


Weather Dry.

Heating and hot water

Gas fired boiler to hot water radiators.

Modern hot water tank.



Gross internal floor area(m²) 170 m^2

Address

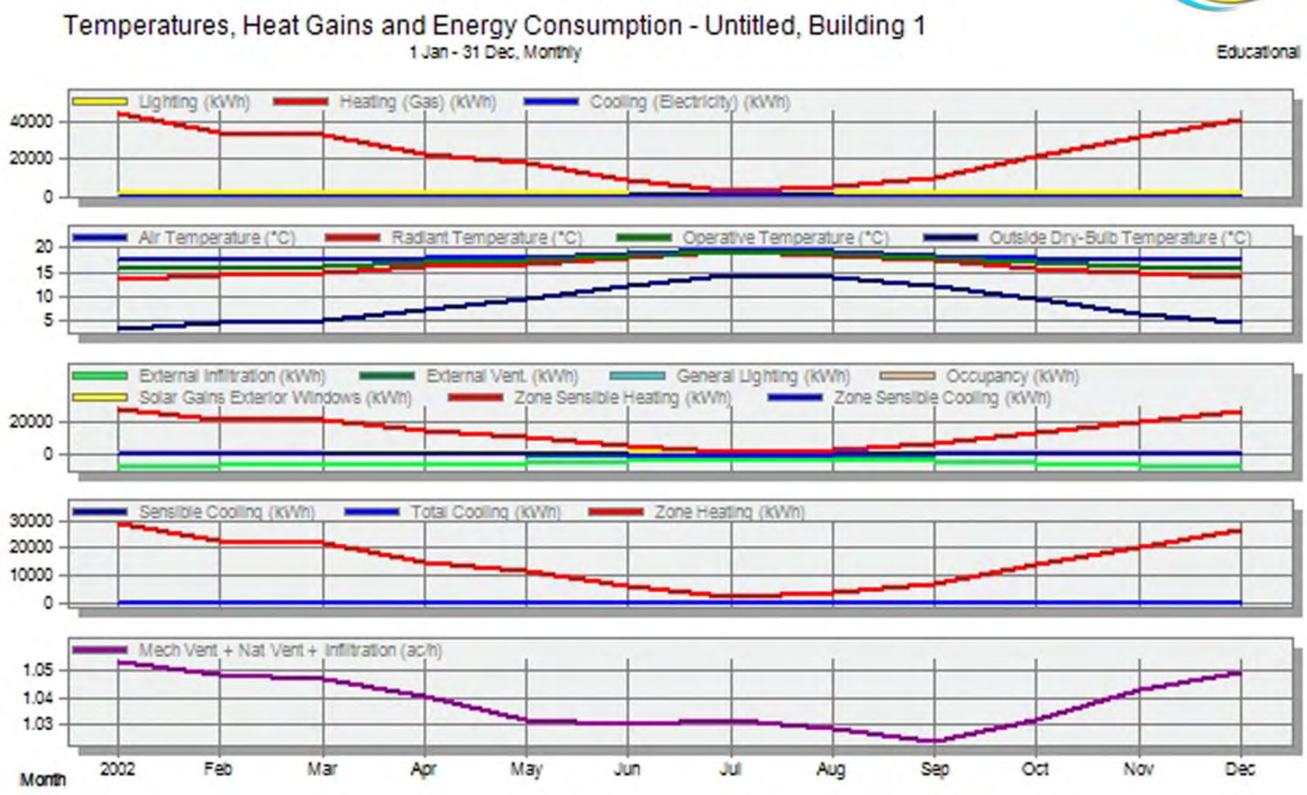
EDINBURGH EH3 6DT

Figure A247. The Software visualization of the house.

Air Temperature (°C)	19.56
Radiant Temperature (°C)	12.41
Operative Temperature (°C)	15.99
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-6.99
Walls (kW)	-31.34
Ceilings (int) (kW)	-1.67
Floors (int) (kW)	1.67
Ground Floors (kW)	0.60
Partitions (int) (kW)	0.00
Roofs (kW)	-15.39
Floors (ext) (kW)	-10.31
External Infiltration (kW)	-18.03
External Vent. (kW)	-54.09
Zone Sensible Heating (kW)	135.41

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 169.270 (kW)				
Cellar Total Design Heating Capacity = 9.670 (kW)				
Zone 1	15.38	7.74	**9.67**	222.4836
Third Floor Total Design Heating Capacity = 27.260 (kW)				
Bed Room	16.43	3.15	**3.94**	216.6230
Bed Room	17.11	4.29	**5.36**	169.1720
Hall	18.32	1.82	**2.27**	151.9153
Landing	18.91	0.61	**0.76**	128.6662
Utility Room	17.94	0.99	**1.24**	167.8846
Kitchen DiningRoom	16.83	9.42	**11.78**	169.0097
Service	17.20	1.53	**1.91**	201.1046
Roof 1 Total Design Heating Capacity = 24.580 (kW)				
Zone 1	13.34	19.66	**24.58**	130.1751
First Floor Total Design Heating Capacity = 33.100 (kW)				
Bed Room	16.47	3.73	**4.67**	256.6961
Bed Room	17.07	5.21	**6.51**	205.6281
Hall	18.40	2.20	**2.75**	183.5084
Landing	19.05	0.73	**0.92**	154.5121
Utility Room	17.99	1.20	**1.50**	203.3898
Kitchen DiningRoom	16.72	11.48	**14.35**	205.9607
Service	17.00	1.92	**2.40**	252.8931
Second Floor Total Design Heating Capacity = 32.350 (kW)				
Bed Room	16.56	3.68	**4.60**	253.3217
Bed Room	17.22	5.11	**6.39**	201.6378
Hall	18.52	2.15	**2.68**	179.2928
Landing	19.19	0.71	**0.89**	150.3829
Utility Room	18.11	1.18	**1.47**	199.1171
Kitchen DiningRoom	16.92	11.22	**14.03**	201.3332
Service	17.26	1.83	**2.29**	241.3310

Figure A248. The heating design simulation and data of the house.



Lighting (kWh)	1965.39	1776.66	1969.17	1902.48	1965.39	1906.26	1965.39	1967.28	1904.37	1965.39	1904.37	1967.28
Heating (Gas) (kWh)	44060.75	34307.38	32934.83	22469.24	17923.67	9001.75	2923.24	5635.10	10393.64	21666.65	31298.59	40927.40
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	1.81	8.04	2.41	0.00	0.00	0.00	0.00
Air Temperature (°C)	17.70	17.80	17.92	18.23	18.42	19.05	19.89	19.47	18.74	18.24	17.95	17.76
Radiant Temperature (°C)	13.85	14.42	15.01	16.16	16.70	18.12	19.60	18.79	17.54	16.06	14.98	14.12
Operative Temperature (°C)	15.77	16.11	16.46	17.20	17.56	18.59	19.74	19.13	18.14	17.15	16.46	15.94
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-7463.67	-6191.28	-6618.00	-5620.94	-4526.45	-3317.54	-2666.03	-2636.23	-3244.73	-4520.34	-5917.29	-6976.98
External Vent. (kWh)	0.00	0.00	0.00	-0.16	0.00	-18.73	-45.87	-29.93	-2.69	0.00	0.00	0.00
General Lighting (kWh)	1965.39	1776.66	1969.17	1902.48	1965.39	1906.26	1965.39	1967.28	1904.37	1965.39	1904.37	1967.28
Occupancy (kWh)	2246.96	2031.19	2250.89	2173.53	2244.88	2155.05	2165.19	2192.83	2173.50	2246.89	2177.16	2249.13
Solar Gains Exterior Windows (kWh)	580.45	1015.72	1870.12	2292.29	2490.24	2511.46	2574.88	2134.06	1612.60	1048.02	662.83	386.34
Zone Sensible Heating (kWh)	28571.14	22244.55	21351.00	14564.10	11615.82	5830.74	1891.50	3649.91	6735.17	14045.85	20293.80	26539.79
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-6.31	-23.90	-6.11	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-6.31	-23.90	-6.11	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-8.15	-36.18	-10.84	0.00	0.00	0.00	0.00
Zone Heating (kWh)	28639.49	22299.79	21407.64	14605.01	11650.38	5851.14	1900.11	3662.81	6755.87	14083.32	20344.08	26602.81
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.05	1.05	1.04	1.03	1.03	1.03	1.03	1.02	1.03	1.04	1.05

Figure A249. The simulation detailed results of the house.

Case 84. A House Built in 1840

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stone construction.	1.890	Increase 21 cm Insulation
	Flat 2.201	Increase 32.45 cm Insulation
	Pitched 2.686	Increase 33.27 cm Insulation
Floors are suspended timber construction.	1.671	Increase 32 cm Insulation
Internal Walls are of lath and plaster.	1.793	
Windows are of mixed age and pattern with the majority being timber framed sash and case pattern and single glazed.		

* As a basis for a theory of possibility

Description

The property comprises a substantial semi-detached villa arranged over three floors.

On ground floor: entrance vestibule and hallway, lounge, family room, kitchen/dining room with WC.

On first floor: landing, master bedroom, three further bedrooms and shower room.

Weather Dry.

Heating and hot water

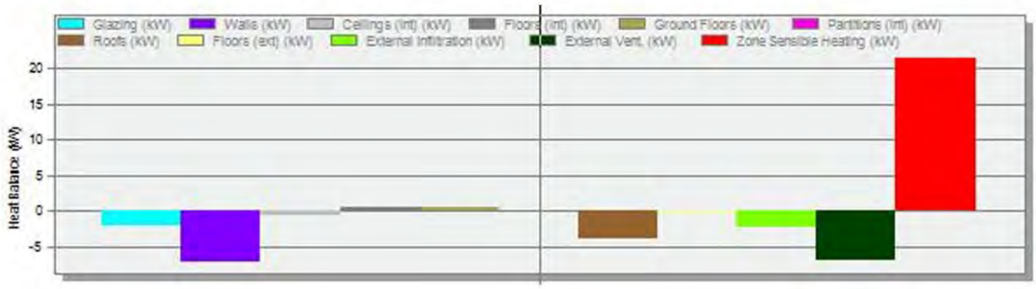
Central heating is from a gas fired Vaillant Ecotec Plus 637 boiler which is in a utility room unit. The boiler serves panelled radiators at ground and first floors and also serves an underfloor heating system at garden floor level. Hot water is from the gas fired boiler via a Santon Premier Plus hot water tank which is located adjacent.

Gross internal floor area(m²) 95 m²

Address

EDINBURGH EH14 7EQ

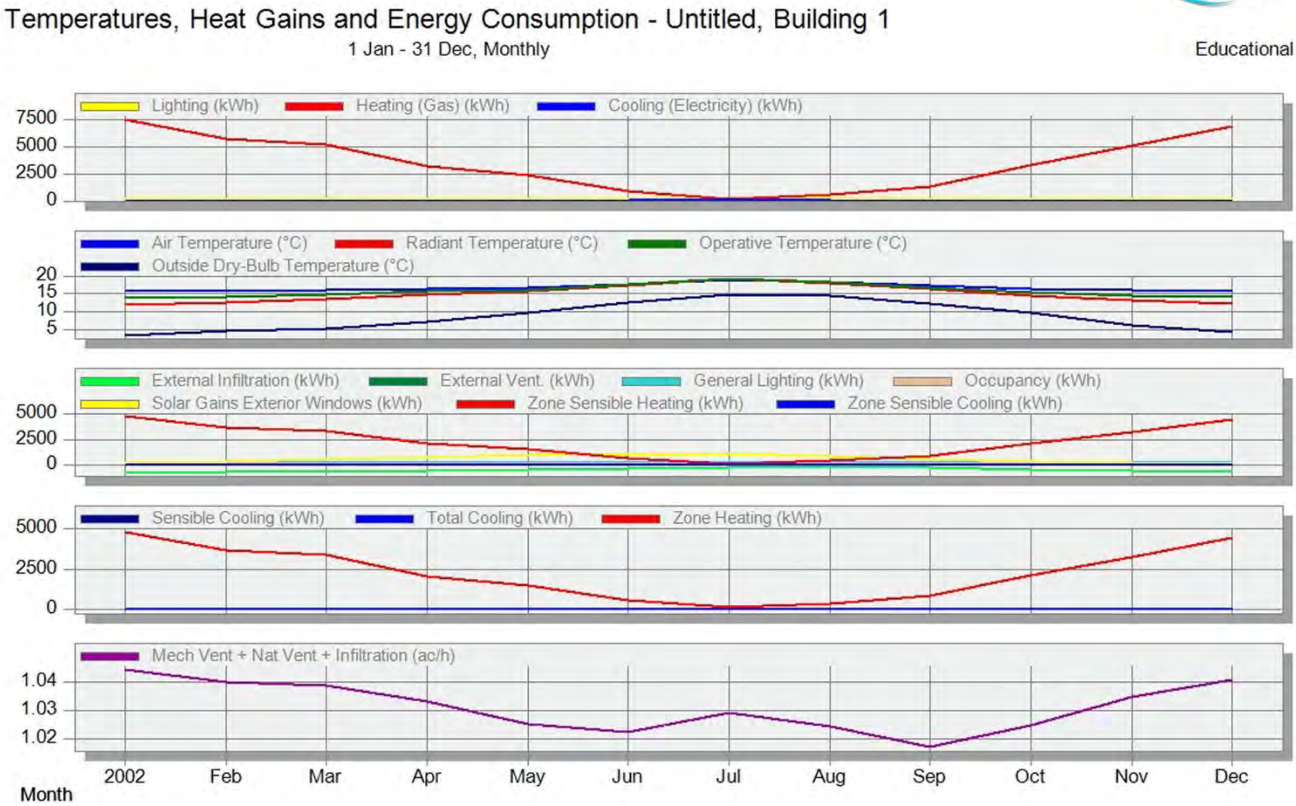
Figure A250. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	10.80
Operative Temperature (°C)	14.40
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.91
Walls (kW)	-7.15
Ceilings (int) (kW)	-0.59
Floors (int) (kW)	0.59
Ground Floors (kW)	0.58
Partitions (int) (kW)	0.00
Roofs (kW)	-3.73
Floors (ext) (kW)	-0.20
External Infiltration (kW)	-2.26
External Vent. (kW)	-6.79
Zone Sensible Heating (kW)	21.44

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 26.780 (kW)				
Ground Floor Total Design Heating Capacity = 11.070 (kW)				
Living Room	15.59	3.00	**3.74**	194.4136
Kitchen	13.66	2.01	**2.52**	382.5100
Bed Room	15.43	2.20	**2.74**	210.1668
Hall	15.28	1.66	**2.07**	244.7491
First Floor Total Design Heating Capacity = 8.910 (kW)				
Bed Room1	14.98	2.21	**2.76**	214.5601
Bed Room2	15.02	2.34	**2.92**	211.1572
Hall	15.58	0.85	**1.06**	219.0176
Bath Room	14.90	1.06	**1.32**	285.8097
CupBoard	14.86	0.68	**0.85**	345.8340
Roof 1 Total Design Heating Capacity = 6.800 (kW)				
Zone 1	12.93	5.44	**6.80**	154.9578

Figure A251. The heating design simulation and data of the house.



Lighting (kWh)	211.70	192.22	214.30	205.21	211.70	207.81	211.70	213.00	206.51	211.70	206.51	213.00
Heating (Gas) (kWh)	7451.60	5635.43	5203.94	3200.29	2303.21	902.99	158.72	553.78	1284.22	3305.91	5062.56	6861.66
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	1.19	3.53	1.52	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.57	15.70	15.89	16.36	16.70	17.68	19.01	18.25	17.12	16.33	15.88	15.63
Radiant Temperature (°C)	11.98	12.65	13.38	14.79	15.57	17.33	19.18	18.03	16.35	14.51	13.24	12.26
Operative Temperature (°C)	13.78	14.17	14.64	15.58	16.13	17.50	19.09	18.14	16.73	15.42	14.56	13.94
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-843.16	-689.73	-738.21	-620.22	-479.52	-340.07	-281.17	-258.54	-318.78	-468.12	-646.14	-776.33
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-1.42	-6.91	-3.86	0.00	0.00	0.00	0.00
General Lighting (kWh)	211.70	192.22	214.30	205.21	211.70	207.81	211.70	213.00	206.51	211.70	206.51	213.00
Occupancy (kWh)	66.44	61.17	69.39	64.52	66.11	65.54	61.62	64.80	65.85	66.44	66.17	67.93
Solar Gains Exterior Windows (kWh)	155.64	296.67	569.79	795.43	981.60	1022.70	1035.91	814.88	548.25	316.42	187.25	107.03
Zone Sensible Heating (kWh)	4832.43	3654.14	3374.04	2074.64	1492.94	585.17	102.78	358.91	832.54	2143.61	3282.45	4449.61
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-5.27	-14.49	-5.48	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-5.30	-14.55	-5.50	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-5.34	-15.89	-6.84	0.00	0.00	0.00	0.00
Zone Heating (kWh)	4843.54	3663.03	3382.56	2080.19	1497.09	586.94	103.17	359.96	834.74	2148.84	3290.66	4460.08
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.03	1.02	1.02	1.02	1.03	1.04

Figure A252. The simulation detailed results of the house.

Case 85. A House Built in 1835

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are to 600mm solid stonework, part rendered and part harled externally.	1.910	Increase 21.33 cm Insulation
	Flat -	-
	Pitched 2.691	Increase 33.2 cm Insulation
Floors are suspended timber overlaid in boarding.	1.673	Increase 32 cm Insulation
Internal Walls are to a mixture of plastered on hard and stud partitioning. **Windows** are to a mixture of single glazed and double glazed units to timber casement and u-PVC double glazed design.	1.795	

* As a basis for a theory of possibility

Description

The subjects comprise a purpose built two storey end terraced villa.

AT date of inspection the property was fully furnished, owner occupied with floors covered.

Ground floor: entrance hallway, living room, dining room, kitchen and WC compartment.

First floor: Four Bedrooms and Family Bathroom with WC.

Weather Dry and bright.

Heating and hot water

The property has a gas fired central heating system with the boiler wall mounted to a built in cupboard to first floor bathroom and this is ventilated externally. The boiler also supplies the hot water. Secondary heating is provided by the fireplaces.

Figure A253. The Software visualization of the house.

Gross internal floor area(m²) 170 m^2

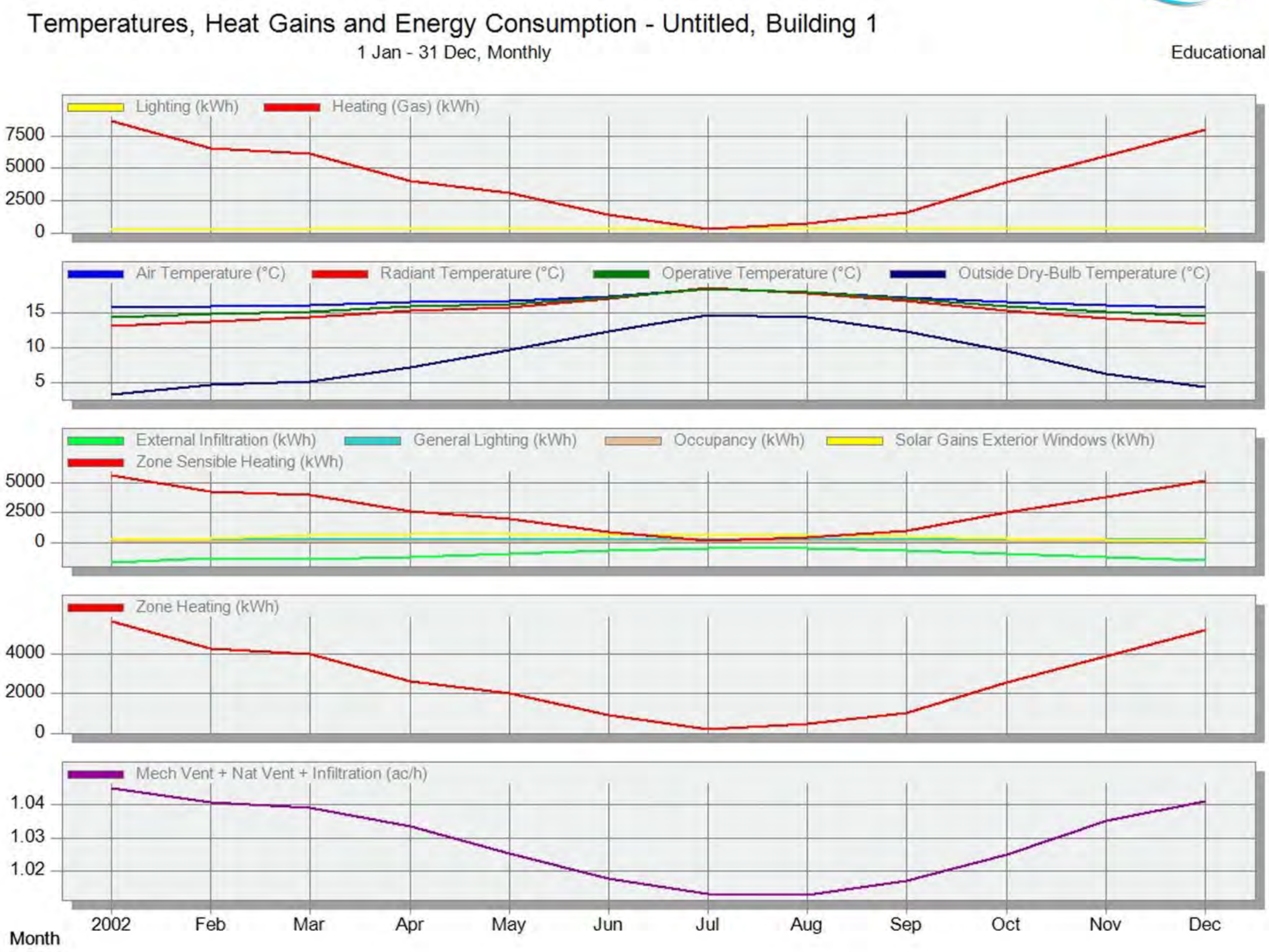
Address

AYTON, EYEMOUTH, TD14 5QZ

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.62
Operative Temperature (°C)	15.31
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.18
Walls (kW)	-9.95
Ceilings (int) (kW)	-2.75
Floors (int) (kW)	0.38
Ground Floors (kW)	0.74
Partitions (int) (kW)	0.00
External Infiltration (kW)	-4.27
External Vent. (kW)	-12.82
Zone Sensible Heating (kW)	29.82

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 37.280 (kW)				
Ground Floor Total Design Heating Capacity = 17.870 (kW)				
Sitting Room	15.63	4.25	**5.32**	206.3602
Vestibule	15.56	0.68	**0.85**	331.8670
Dining Room	15.47	2.85	**3.56**	226.5665
Hall	16.36	2.71	**3.39**	189.1190
Service	15.06	0.92	**1.16**	356.7809
Kitchen	15.44	2.87	**3.59**	228.6535
First Floor Total Design Heating Capacity = 19.410 (kW)				
Bed Room	14.80	4.60	**5.75**	223.2244
Bed Room	15.32	1.00	**1.25**	267.2976
Bed Room	14.71	3.10	**3.87**	246.3738
Hall	15.52	2.70	**3.38**	213.6584
Bed Room	14.73	3.10	**3.87**	246.3933
Service	14.46	1.03	**1.29**	397.6071
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.04	0.00	**0.00**	0.0000

Figure A254. The heating design simulation and data of the house.



Lighting (kWh)	263.82	239.54	267.05	255.72	263.82	258.96	263.82	265.43	257.34	263.82	257.34	265.43
Heating (Gas) (kWh)	8623.87	6515.71	6115.82	4032.21	3117.19	1358.18	257.73	745.51	1597.96	3943.85	5928.62	7972.99
Air Temperature (°C)	15.67	15.83	16.01	16.45	16.71	17.36	18.32	17.97	17.19	16.54	16.06	15.74
Radiant Temperature (°C)	13.15	13.71	14.26	15.30	15.76	17.02	18.49	17.82	16.66	15.24	14.22	13.37
Operative Temperature (°C)	14.41	14.77	15.14	15.87	16.23	17.19	18.40	17.89	16.93	15.89	15.14	14.55
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1603.06	-1313.47	-1404.99	-1176.69	-904.75	-618.66	-472.76	-465.54	-607.13	-898.51	-1233.31	-1477.35
General Lighting (kWh)	263.82	239.54	267.05	255.72	263.82	258.96	263.82	265.43	257.34	263.82	257.34	265.43
Occupancy (kWh)	82.80	76.22	86.51	80.59	82.80	83.86	80.10	82.63	82.42	82.80	82.46	84.65
Solar Gains Exterior Windows (kWh)	233.59	373.08	617.26	699.07	695.87	652.20	697.01	620.65	514.42	359.41	267.84	155.45
Zone Sensible Heating (kWh)	5586.67	4220.25	3960.93	2611.46	2019.15	879.84	166.89	483.01	1035.47	2555.11	3839.93	5164.77
Zone Heating (kWh)	5605.52	4235.21	3975.28	2620.94	2026.17	882.81	167.52	484.58	1038.67	2563.50	3853.60	5182.44
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A255. The simulation detailed results of the house.

Case 86. A House Built in 1825

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are 600 and 900mm in thickness and are of solid stone construction.	1.911	Increase 21 cm Insulation
	Flat 2.211	Increase 32 cm Insulation
	Pitched 2.859	Increase 33 cm Insulation
Floors are suspended timber overlaid in boarding.	1.733	Increase 32 cm Insulation
Internal Walls are brickwork plastered on the hard.	1.815	
Windows have original timber sash and case windows which are single glazed.		

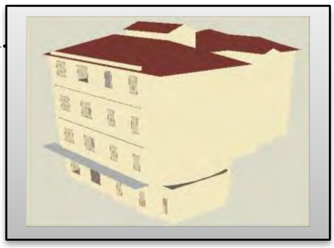
* As a basis for a theory of possibility

Description

Converted flat located at ground and first floor levels in a four storey and double basement mid terraced building. The flat forms part of the centre pavilion in a classical Georgian terrace and is within a grade A Listed building.

Ground Floor: Common Entrance Vestibule & Hallway, Internal Hallway, Drawing Room, Dining Room, Kitchen/Breakfast Room and WC Compartment.

First Floor: Landing, Bedroom 1 with En Suite Shower Room and 2 bedroom.



Weather Overcast.

Heating and hot water

The property has gas fired central heating to radiator outlets.

Domestic hot water is provided indirectly by the gas central heating boiler to a modern insulated hot water tank which is located behind cupboard units in the rear corner of the kitchen. There is an electrical immersion heater fitted to supplement hot water.

Gross internal floor area(m²) 314 m²

Address

EDINBURGH EH3 6DT

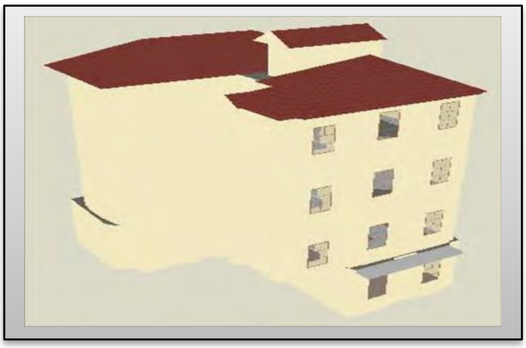
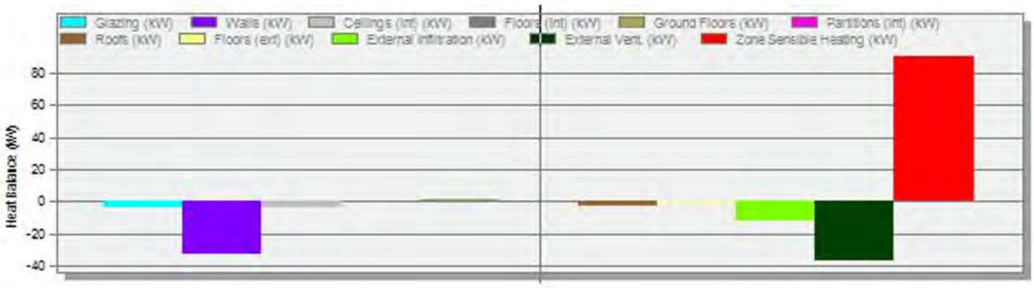


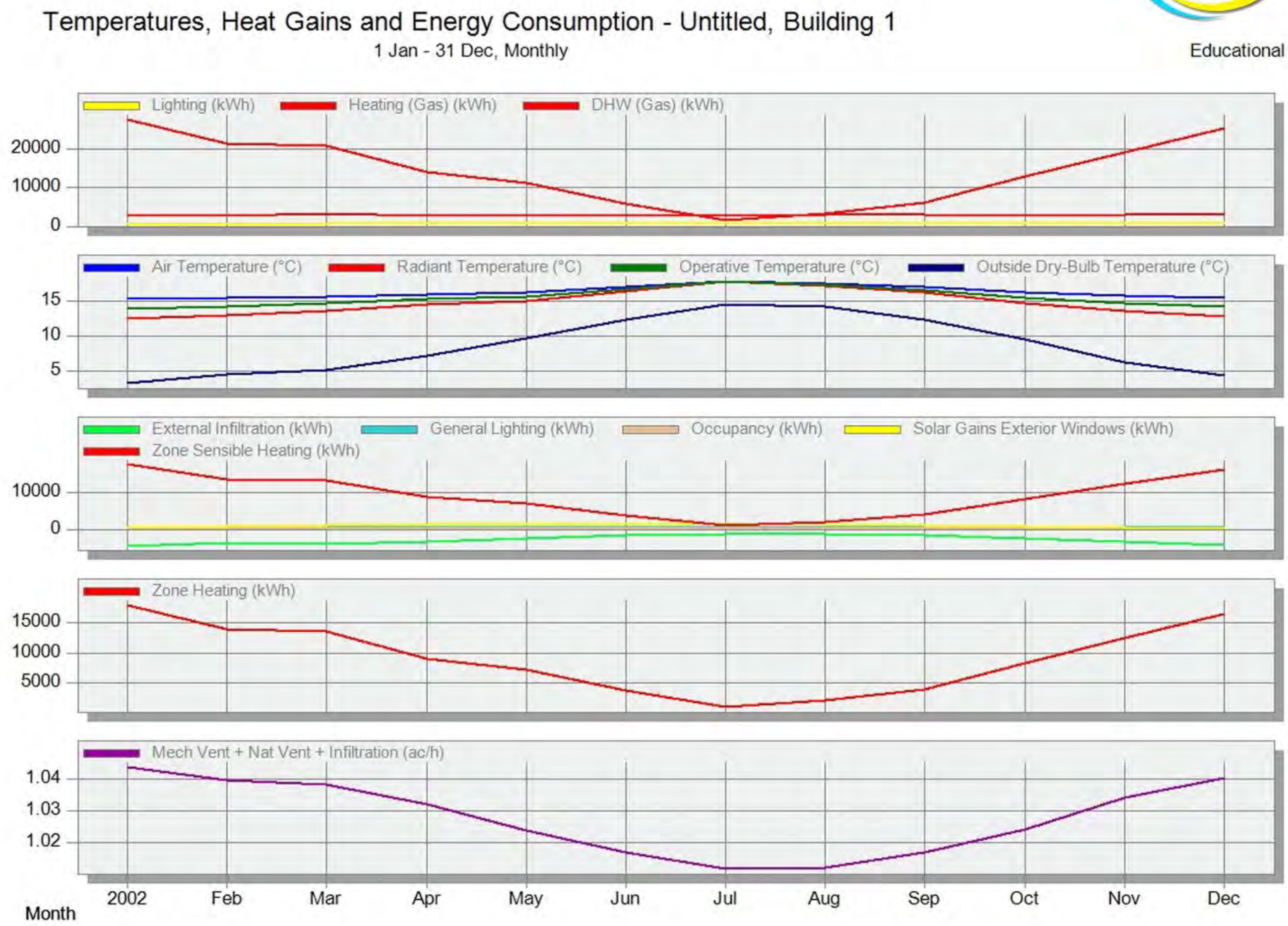
Figure A256. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.00
Operative Temperature (°C)	15.00
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.91
Walls (kW)	-33.04
Ceilings (int) (kW)	-3.21
Floors (int) (kW)	0.90
Ground Floors (kW)	1.10
Partitions (int) (kW)	0.00
Roofs (kW)	-2.13
Floors (ext) (kW)	-0.82
External Infiltration (kW)	-12.37
External Vent. (kW)	-37.10
Zone Sensible Heating (kW)	90.77

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 113.460 (kW)				
Ground Floor Total Design Heating Capacity = 26.770 (kW)				
Service	14.55	1.09	**1.37**	797.8901
Hall Landing	15.70	3.55	**4.44**	269.3203
Dining Room	15.46	6.33	**7.91**	269.2652
Kitchen	16.00	2.94	**3.68**	219.0403
Drawing Room	14.84	7.50	**9.37**	329.8659
First Floor Total Design Heating Capacity = 27.990 (kW)				
Service	15.87	1.16	**1.45**	241.2686
Service	17.07	0.45	**0.56**	178.4117
Bed Room	14.75	3.62	**4.53**	270.2040
Hall	16.25	0.99	**1.24**	155.0379
Bed Room	15.03	5.15	**6.44**	235.0724
Bed Room	13.21	2.80	**3.50**	467.5014
Bed Room	14.93	6.31	**7.88**	288.1208
Landing	15.85	1.91	**2.39**	372.9426
Second Floor Total Design Heating Capacity = 27.610 (kW)				
Service	15.91	1.16	**1.45**	240.3934
Service	17.11	0.44	**0.55**	177.5180
Bed Room	14.69	3.66	**4.58**	272.9996
Hall	16.25	1.00	**1.24**	155.3942
Bed Room	15.04	5.15	**6.44**	235.1814
Bed Room	14.01	2.41	**3.01**	402.2820
Bed Room	14.90	6.36	**7.94**	290.3164
Landing	15.85	1.92	**2.40**	374.2997
Third Floor Total Design Heating Capacity = 29.110 (kW)				
Service	15.23	1.29	**1.61**	270.8231
Service	16.55	0.45	**0.56**	179.5236
Bed Room	14.18	4.38	**5.47**	327.4608
Hall	15.76	0.96	**1.21**	150.5939

Figure A257. The heating design simulation and data of the house.



Lighting (kWh)	596.76	554.57	636.95	582.70	596.76	622.88	596.76	616.86	602.79	596.76	602.79	616.86
Heating (Gas) (kWh)	27609.30	21394.84	20947.58	13998.87	11224.27	5931.91	1633.02	3284.44	6215.71	12876.80	19153.96	25273.90
DHW (Gas) (kWh)	2816.23	2668.82	3139.49	2767.09	2816.23	3090.35	2816.23	2977.86	2928.72	2816.23	2928.72	2977.86
Air Temperature (°C)	15.37	15.54	15.72	16.00	16.27	17.04	17.80	17.58	16.98	16.22	15.76	15.50
Radiant Temperature (°C)	12.48	13.05	13.56	14.56	15.04	16.38	17.81	17.26	16.22	14.75	13.64	12.82
Operative Temperature (°C)	13.93	14.29	14.64	15.28	15.66	16.71	17.81	17.42	16.60	15.49	14.70	14.16
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-4525.17	-3700.06	-3957.28	-3243.56	-2458.08	-1681.85	-1188.81	-1213.54	-1686.93	-2486.09	-3456.68	-4186.20
General Lighting (kWh)	596.76	554.57	636.95	582.70	596.76	622.88	596.76	616.86	602.79	596.76	602.79	616.86
Occupancy (kWh)	143.93	136.40	160.46	141.42	143.93	157.88	142.54	150.58	149.67	143.93	149.68	152.20
Solar Gains Exterior Windows (kWh)	436.14	725.67	1236.13	1450.84	1464.21	1403.50	1457.31	1292.17	1040.63	709.53	501.40	292.97
Zone Sensible Heating (kWh)	17876.24	13849.92	13559.55	9057.74	7263.12	3839.24	1056.55	2126.07	4024.05	8334.94	12397.47	16363.62
Zone Heating (kWh)	17946.05	13906.65	13615.92	9099.26	7295.78	3855.74	1061.47	2134.89	4040.21	8369.92	12450.07	16428.04
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.02	1.02	1.01	1.01	1.02	1.02	1.03	1.04

Figure A258. The simulation detailed results of the house.

Case 87. A House Built in 1822

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are traditional solid stonework pointed externally.	1.918	Increase 21 cm Insulation
	Flat -	-
	Pitched 2.962	Increase 33.25 cm Insulation
Floors are suspended timber and solid masonry construction with partial fitted floor coverings present.	1.720	Increase 32 cm Insulation
Internal Walls are solid masonry as well as timber stud construction.	1.820	
Windows are of timber frame single glaze type.		

* As a basis for a theory of possibility

Description

The property comprises a second floor double upper flatted villa within a converted terraced townhouse.

Second Floor: Entrance Hall, Drawing Room with Study off, Dining room, Kitchen, Bathroom with WC.

Third Floor: 4 Bedrooms, 2 with shared En Suite Shower Room, further Bathroom with WC.

Weather Dry and clear.

Heating and hot water

The subjects benefit from two gas fired central heating systems servicing the second and third floor respectively

Gross internal floor area(m²) 232 m^2

Address

EDINBURGH EH3 6AR

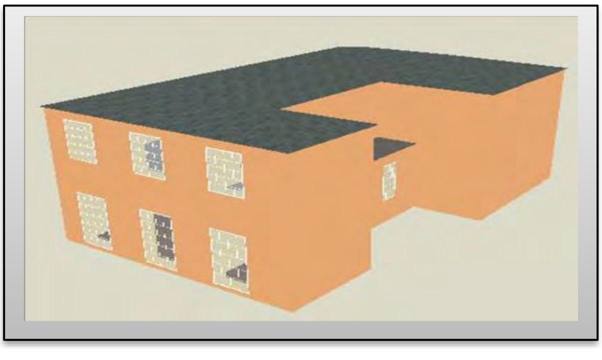
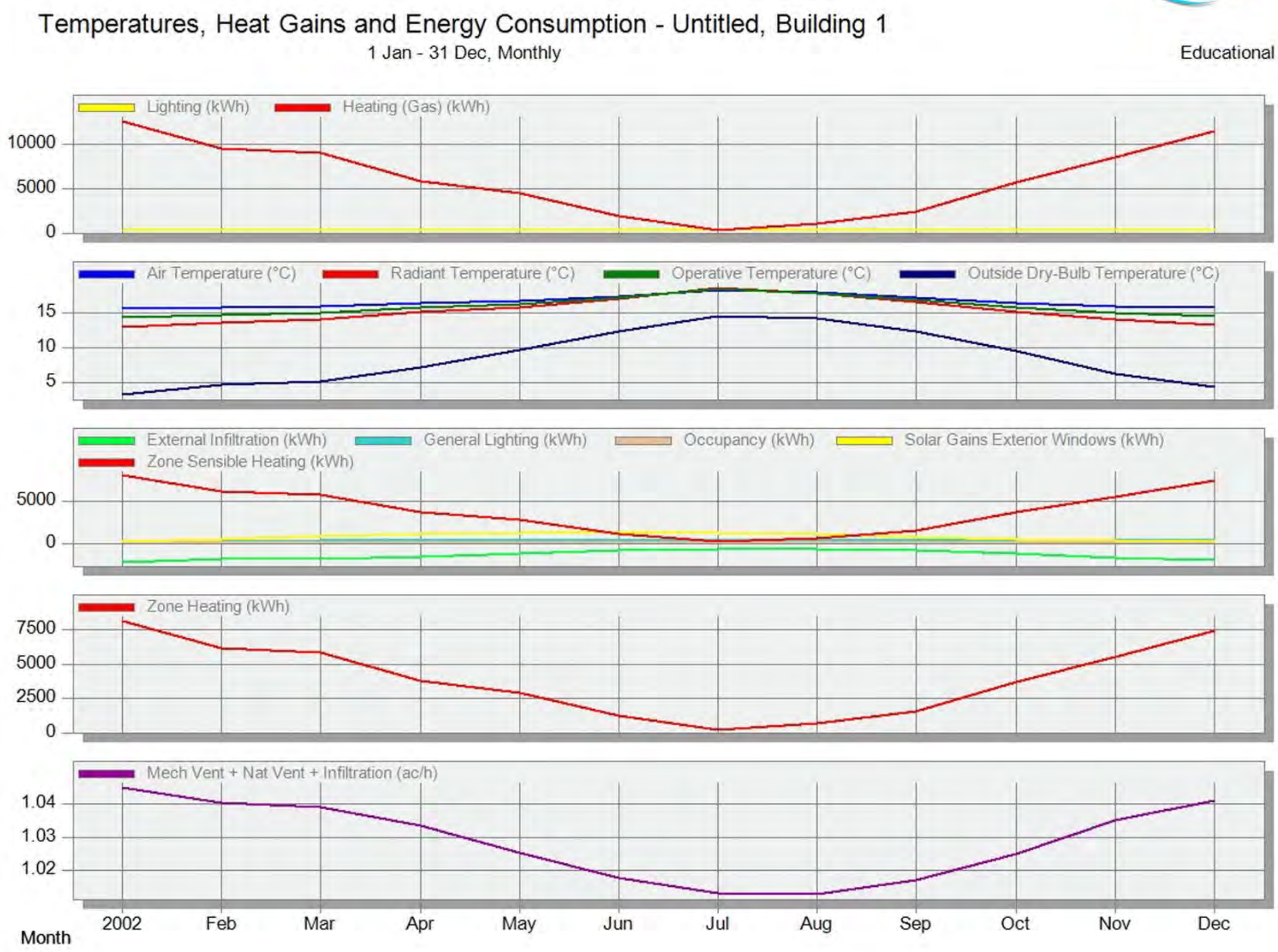


Figure A259. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.36
Operative Temperature (°C)	15.18
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.72
Walls (kW)	-14.11
Ceilings (int) (kW)	-3.44
Floors (int) (kW)	0.48
Ground Floors (kW)	1.18
Partitions (int) (kW)	0.00
Roofs (kW)	-0.24
External Infiltration (kW)	-5.68
External Vent. (kW)	-17.03
Zone Sensible Heating (kW)	41.45

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 51.800 (kW)				
Second Floor Total Design Heating Capacity = 27.560 (kW)				
Hall	16.50	2.29	**2.86**	212.8860
Kitchen	14.99	3.88	**4.85**	272.6217
Service	16.25	1.01	**1.26**	242.0311
Dining Room	15.43	3.78	**4.72**	242.2116
Landing	17.17	1.19	**1.48**	175.0800
Vestibule	14.34	1.21	**1.51**	531.0679
Sitting Room	15.25	6.39	**7.99**	232.0126
Study Room	14.23	2.31	**2.89**	386.7751
Third Floor Total Design Heating Capacity = 24.240 (kW)				
Corridor	15.32	1.58	**1.98**	302.8579
Double BedRoom 1	14.23	3.64	**4.55**	261.6077
Service 1	15.58	1.47	**1.84**	205.2306
Master BedRoom	14.72	5.37	**6.72**	208.9316
Double BedRoom 2	13.80	2.12	**2.65**	355.1063
Double BedRoom	14.90	3.70	**4.62**	217.9298
Landing	16.52	0.71	**0.89**	167.1748
Service	15.55	0.79	**0.99**	242.0486
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-0.13	0.00	**0.00**	0.0000

Figure A260. The heating design simulation and data of the house.



Lighting (kWh)	346.08	314.24	350.33	335.47	346.08	339.72	346.08	348.21	337.59	346.08	337.59	348.21
Heating (Gas) (kWh)	12478.64	9484.18	8932.81	5789.55	4403.28	1872.96	343.03	1063.49	2363.75	5708.85	8543.32	11483.89
Air Temperature (°C)	15.67	15.80	15.96	16.40	16.69	17.36	18.36	17.95	17.14	16.49	16.03	15.74
Radiant Temperature (°C)	12.99	13.54	14.08	15.20	15.73	17.06	18.57	17.81	16.57	15.12	14.08	13.23
Operative Temperature (°C)	14.33	14.67	15.02	15.80	16.21	17.21	18.47	17.88	16.85	15.80	15.05	14.48
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2130.38	-1740.98	-1858.47	-1555.75	-1199.01	-821.78	-634.17	-614.19	-799.60	-1185.99	-1633.32	-1962.69
General Lighting (kWh)	346.08	314.24	350.33	335.47	346.08	339.72	346.08	348.21	337.59	346.08	337.59	348.21
Occupancy (kWh)	108.62	99.99	113.49	105.71	108.62	109.97	104.76	108.46	108.13	108.62	108.18	111.05
Solar Gains Exterior Windows (kWh)	322.37	551.21	946.20	1225.84	1315.31	1303.01	1349.96	1121.98	827.07	520.26	378.52	220.08
Zone Sensible Heating (kWh)	8086.43	6144.79	5786.93	3750.36	2852.83	1213.56	222.17	689.15	1531.94	3699.27	5534.97	7441.36
Zone Heating (kWh)	8111.12	6164.72	5806.33	3763.21	2862.13	1217.42	222.97	691.27	1536.44	3710.75	5553.16	7464.53
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.02	1.04	1.04

Figure A261. The simulation detailed results of the house.

Case 88. A House Built in 1811

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of 800mm stone, strapped and plaster lined internally.	1.913	Increase 21 cm Insulation
	Flat 2.236	Increase 32.5 cm Insulation
	Pitched 2.877	Increase 33.2 cm Insulation
Floors are suspended timber or solid concrete character.	1.735	Increase 32 cm Insulation
Internal Walls are of a lath and plaster, plaster or plasterboard character.	1.816	
Windows are a combination of timber framed sash and case or casement with some metal framed casement windows provided.		

* As a basis for a theory of possibility

Description

The property comprises a two storeyed detached house.

Ground Floor - Vestibule, lounge, living room, dining room, breakfast room, study, hallway, two kitchens, bedroom, conservatory, toilet, shower room/WC.

First Floor - Landing, study, five bedrooms, three bathrooms (with WC), shower room/WC.

Weather Dry and bright.

Heating and hot water

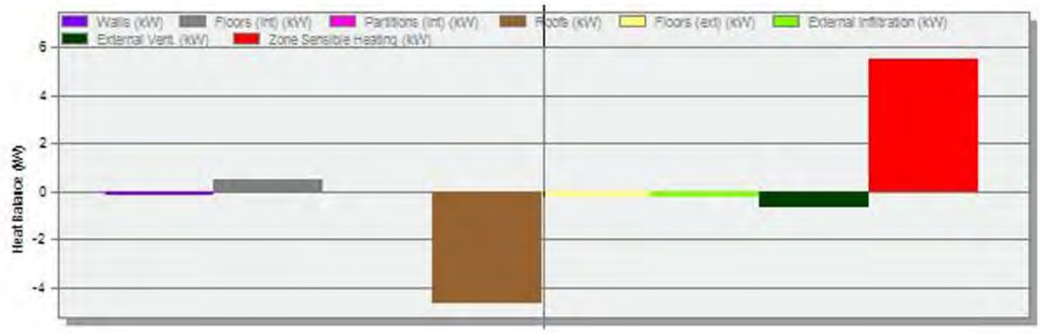
There is a gas fired central heating system serving panel radiators. The boiler for this is a Potterton Suprima 120L unit located within a kitchen cupboard and vented externally by means of a balanced flue. The central heating boiler provides hot water to individual radiators, some fitted with thermostatic valves. The central heating boiler also provides domestic hot water. This is augmented by an electric immersion heater.

Gross internal floor area(m²) 304 m²

Address

DALKEITH EH22 3LX

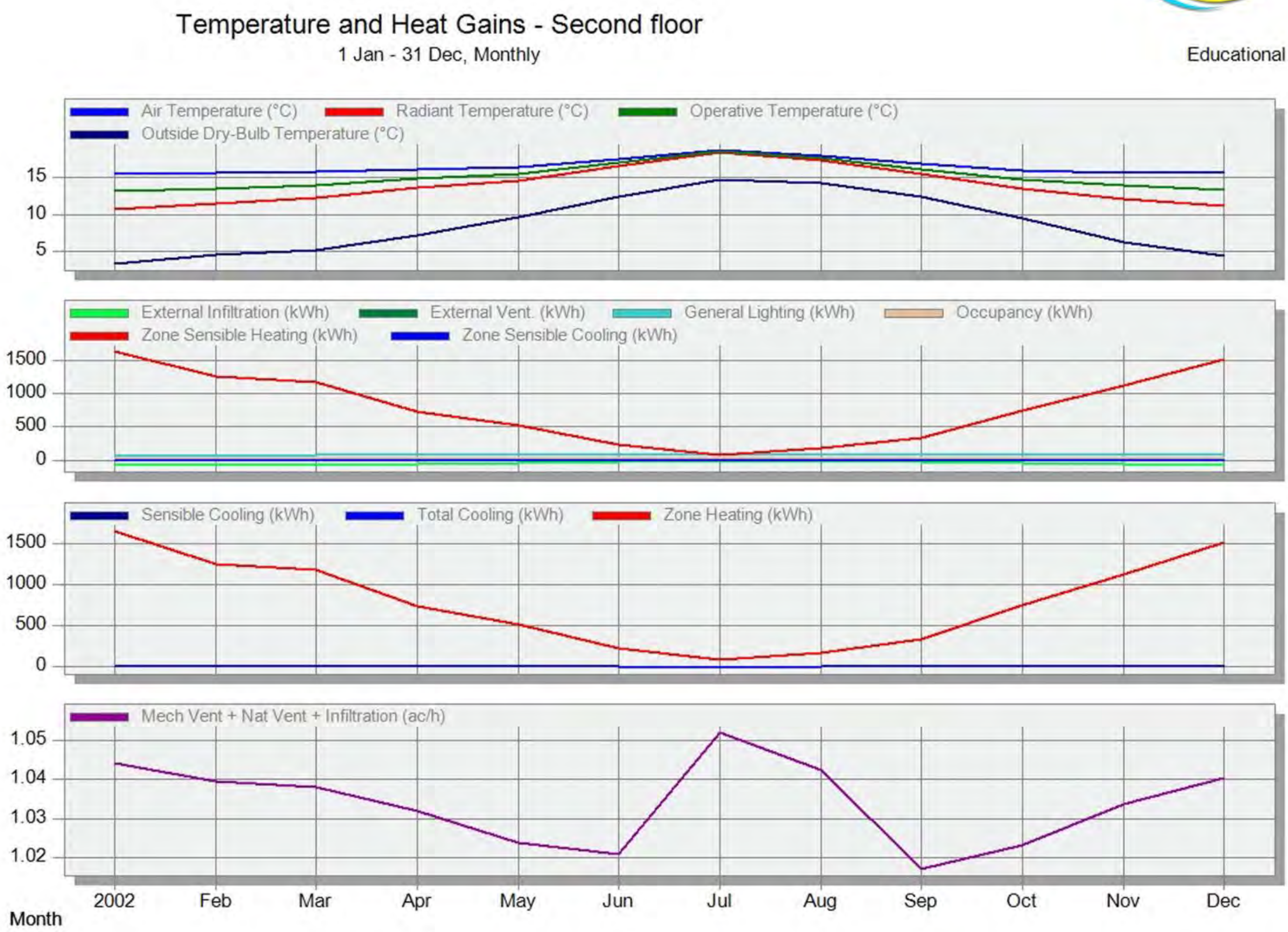
Figure 262. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	9.18
Operative Temperature (°C)	13.59
Outside Dry-Bulb Temperature (°C)	-5.60
Walls (kW)	-0.14
Floors (int) (kW)	0.47
Partitions (int) (kW)	-0.00
Roofs (kW)	-4.70
Floors (ext) (kW)	-0.27
External Infiltration (kW)	-0.23
External Vent. (kW)	-0.68
Zone Sensible Heating (kW)	5.54

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Vestibule	14.64	2.72	**3.39**	314.8357
Drawing Room	15.33	4.71	**5.89**	246.0223
Dining Room	16.05	3.85	**4.82**	210.0710
Kitchen	16.67	0.73	**0.91**	218.6821
Bed Room	16.28	2.34	**2.93**	209.3044
Dining Room2	16.11	2.72	**3.40**	213.8568
Study Room	16.24	1.55	**1.94**	222.8338
Conservatory	15.76	2.61	**3.26**	247.3630
Kitchen2	15.23	3.54	**4.42**	258.6524
Lounge	14.53	3.01	**3.76**	330.5591
Service	15.54	0.42	**0.53**	529.6878
Roof 1 Total Design Heating Capacity = 9.610 (kW)				
Zone 1	12.77	7.68	**9.61**	163.3906
First Floor Total Design Heating Capacity = 5.950 (kW)				
Bed Room	13.66	2.53	**3.17**	202.6908
Service	14.50	1.24	**1.54**	160.1077
Corridor	14.83	0.99	**1.24**	214.5612
Roof 2 Total Design Heating Capacity = 3.450 (kW)				
Zone 1	12.45	2.76	**3.45**	153.0636
Second floor Total Design Heating Capacity = 6.930 (kW)				
Bed Room	13.05	1.61	**2.01**	158.0403
Bed Room	13.82	0.95	**1.19**	156.9442
Hall	13.77	1.20	**1.51**	137.2617
Bed Room	13.99	0.92	**1.15**	151.8497
Service	13.75	0.85	**1.07**	144.7383
Parapet Total Design Heating Capacity = 0.730 (kW)				
Zone 1	12.62	0.58	**0.73**	150.8513
Parapet Total Design Heating Capacity = 0.240 (kW)				
Zone 1	12.49	0.19	**0.24**	392.6463

Figure A263. The heating design simulation and data of the house.



Air Temperature (°C)	15.51	15.55	15.70	16.02	16.30	17.38	18.72	17.96	16.77	15.95	15.63	15.52
Radiant Temperature (°C)	10.77	11.44	12.16	13.60	14.50	16.46	18.33	17.22	15.43	13.46	12.10	11.10
Operative Temperature (°C)	13.14	13.50	13.93	14.81	15.40	16.92	18.53	17.59	16.10	14.71	13.86	13.31
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-84.22	-68.18	-72.66	-59.82	-45.43	-33.10	-27.98	-24.85	-29.63	-43.90	-62.75	-77.17
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.09	-1.52	-1.05	-0.07	0.00	0.00	0.00
General Lighting (kWh)	75.36	68.43	76.29	73.05	75.36	73.98	75.36	75.83	73.52	75.36	73.52	75.83
Occupancy (kWh)	23.65	21.77	24.68	22.96	23.59	23.21	21.92	22.93	23.39	23.65	23.55	24.18
Zone Sensible Heating (kWh)	1651.08	1259.74	1184.00	739.61	520.19	230.18	86.64	176.12	336.11	747.10	1124.26	1515.21
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.89	-3.35	-1.29	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.89	-3.36	-1.29	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-0.90	-3.76	-1.61	0.00	0.00	0.00	0.00
Zone Heating (kWh)	1652.74	1261.12	1185.38	740.70	521.18	230.79	86.88	176.52	336.74	748.19	1125.65	1516.80
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.02	1.02	1.05	1.04	1.02	1.02	1.03	1.04

Figure A264. The simulation detailed results of the house.

Case 89. A House Built in 1807

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid stonework.	1.926	Increase 21 cm Insulation
	Flat -	-
	Pitched 2.928	Increase 33 cm Insulation
Floors are suspended timber or solid concrete character.	1.802	Increase 32 cm Insulation
Internal Walls are a mixture of lath and plaster or plasterboard. **Windows** are timber frame single glazed.	1.832	

* As a basis for a theory of possibility

Description

The subjects form a mid-terraced house over two storeys. The accommodation within comprises:

Ground floor: hall, living room, lounge, dining room, kitchen and conservatory.

First floor: Upper hall, four bedrooms, en-suite shower room and family bathroom.

Weather Dry and sunny.

Heating and hot water

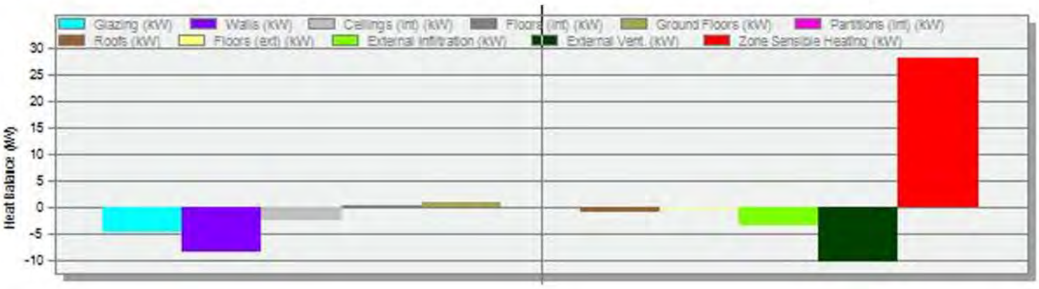
The property has full gas central heating. A British Gas / Worcester combi boiler, located in the kitchen, serves panel radiators throughout the property and provides hot water.

Gross internal floor area(m²) 129 m^2

Address

EAST LOTHIAN EH32 0RA

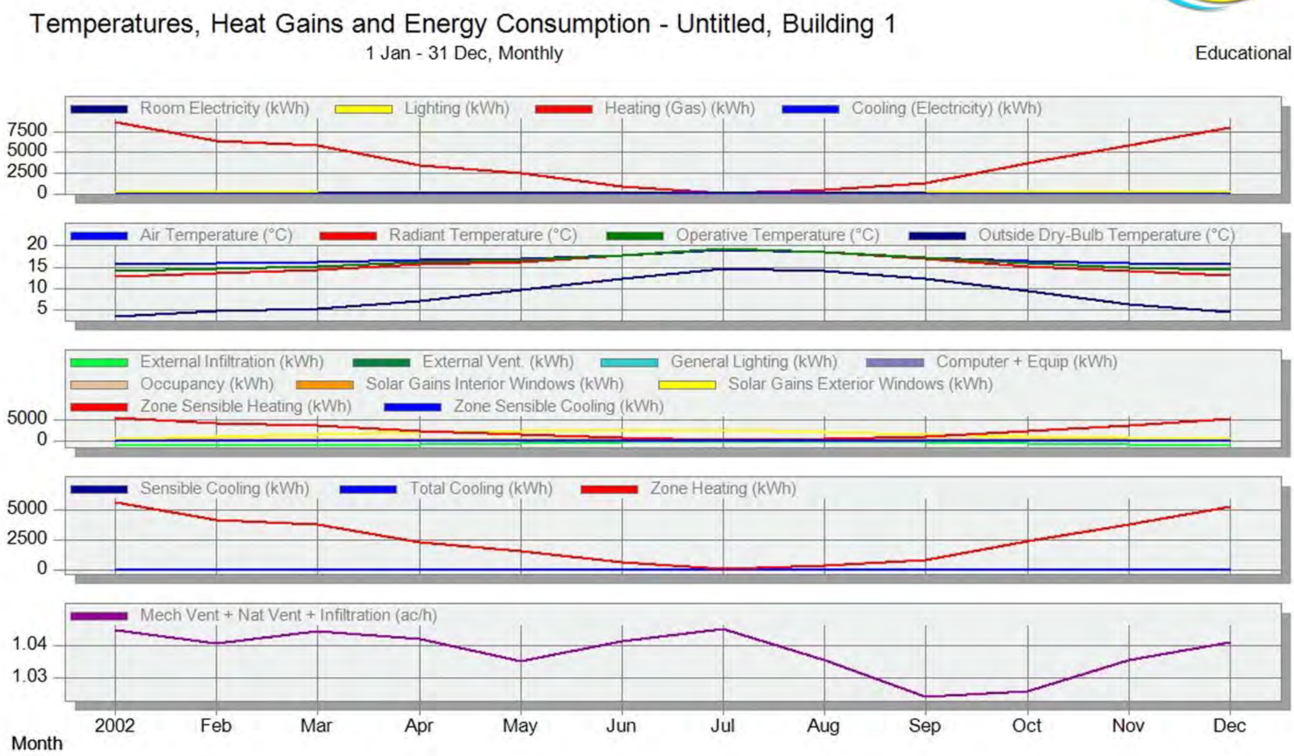
Figure A265. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.88
Operative Temperature (°C)	14.94
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-4.55
Walls (kW)	-8.24
Ceilings (int) (kW)	-2.34
Floors (int) (kW)	0.42
Ground Floors (kW)	0.91
Partitions (int) (kW)	0.00
Roofs (kW)	-0.70
Floors (ext) (kW)	-0.17
External Infiltration (kW)	-3.43
External Vent. (kW)	-10.28
Zone Sensible Heating (kW)	28.28

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 35.340 (kW)				
Ground Floor Total Design Heating Capacity = 13.520 (kW)				
Dining Room	16.10	1.59	**1.99**	194.8070
Kitchen	15.44	2.65	**3.31**	221.2185
Family Room	15.51	2.89	**3.62**	213.3595
Hall	16.65	0.70	**0.87**	206.5788
Living Room	15.36	2.99	**3.73**	220.3451
Conservatory Total Design Heating Capacity = 3.690 (kW)				
Zone 1	13.73	2.95	**3.69**	317.8791
First Floor Total Design Heating Capacity = 15.290 (kW)				
Bed Room	14.60	1.99	**2.49**	271.3568
Double BedRoom	14.70	3.18	**3.97**	234.4939
Service	16.42	0.53	**0.66**	188.9678
Hall	16.00	0.82	**1.03**	244.9935
Master BedRoom	14.58	3.26	**4.08**	240.5439
Bed Room	14.50	1.69	**2.12**	294.1412
Service	15.00	0.75	**0.94**	340.0868
Roof Conservatory Total Design Heating Capacity = 2.840 (kW)				
Zone 1	11.19	2.28	**2.84**	465.5751
Main Roof Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.12	0.00	**0.00**	0.0000

Figure A266. The heating design simulation and data of the house.



Room Electricity (kWh)	151.49	136.83	151.49	146.60	151.49	146.60	151.49	151.49	146.60	151.49	146.60	151.49
Lighting (kWh)	231.05	209.79	233.88	223.96	231.05	226.80	231.05	232.46	225.38	231.05	225.38	232.46
Heating (Gas) (kWh)	8713.08	6422.62	5809.61	3497.71	2426.93	897.97	109.23	472.56	1308.31	3694.53	5826.80	8059.27
Cooling (Electricity) (kWh)	0.00	0.00	0.01	1.40	1.56	4.91	12.94	3.94	0.19	0.00	0.00	0.00
Air Temperature (°C)	15.70	15.88	16.15	16.73	17.10	17.93	19.22	18.58	17.44	16.62	16.11	15.75
Radiant Temperature (°C)	12.85	13.54	14.30	15.65	16.35	17.81	19.51	18.56	16.95	15.23	14.05	13.07
Operative Temperature (°C)	14.27	14.71	15.22	16.19	16.72	17.87	19.37	18.57	17.19	15.93	15.08	14.41
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1288.18	-1057.58	-1138.20	-966.45	-757.61	-542.21	-457.16	-426.81	-507.15	-727.77	-993.16	-1186.53
External Vent. (kWh)	0.00	-0.04	-7.78	-12.10	-11.58	-23.45	-28.41	-16.96	-5.37	-0.32	-0.23	0.00
General Lighting (kWh)	231.05	209.79	233.88	223.96	231.05	226.80	231.05	232.46	225.38	231.05	225.38	232.46
Computer + Equip (kWh)	151.49	136.83	151.49	146.60	151.49	146.60	151.49	151.49	146.60	151.49	146.60	151.49
Occupancy (kWh)	72.52	66.68	75.38	69.89	71.55	71.28	66.80	70.07	71.58	72.45	72.18	74.14
Solar Gains Interior Windows (kWh)	2.33	4.14	7.29	9.19	9.54	9.30	9.80	8.33	6.27	3.98	2.71	1.57
Solar Gains Exterior Windows (kWh)	513.03	891.55	1616.00	2068.83	2348.70	2328.29	2463.78	2007.54	1456.18	903.40	603.49	343.35
Zone Sensible Heating (kWh)	5648.30	4162.95	3765.25	2266.74	1572.81	581.83	70.71	306.20	848.02	2395.10	3776.72	5224.23
Zone Sensible Cooling (kWh)	0.00	0.00	-0.03	-6.28	-7.01	-21.89	-55.74	-15.67	-0.85	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	-0.02	-6.30	-7.03	-21.96	-55.87	-15.71	-0.86	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	-0.02	-6.30	-7.03	-22.11	-58.24	-17.74	-0.86	0.00	0.00	0.00
Zone Heating (kWh)	5663.50	4174.70	3776.25	2273.51	1577.50	583.68	71.00	307.16	850.40	2401.45	3787.42	5238.53
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.04	1.03	1.04	1.05	1.04	1.02	1.03	1.04	1.04

Figure A267. The simulation detailed results of the house.

Case 90. A House Built in 1803

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stonework construction.	1.980	Increase 22 cm Insulation
	Flat -	-
	Pitched 2.944	Increase 33.24 cm Insulation
Floors are suspended timber or solid concrete character.	1.831	Increase 32.14 cm Insulation
Internal Walls are of original solid masonry type plastered on the hard with some timber framed sections.	1.826	
Windows are of original style timber sash and casement single glazed units.		

* As a basis for a theory of possibility

Description

The subjects comprise a purpose-built top/third floor flat within a traditional four storey and basement Georgian tenement block.

Weather Dry.

Heating and hot water

Central heating is by way of a gas boiler located in the kitchen.

Domestic water is assumed supplied from the central heating system via a hot water cylinder, believed to be located behind the panel in the kitchen.

Gross internal floor area(m²) 158 m^2

Address

EDINBURGH EH7 4AW

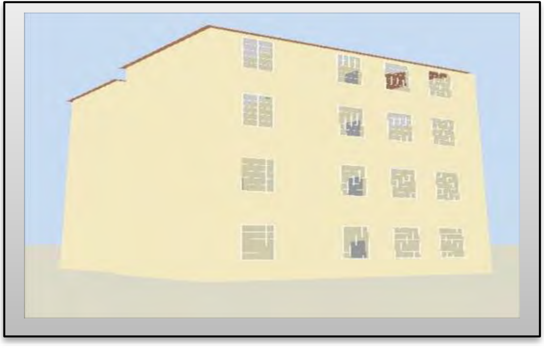
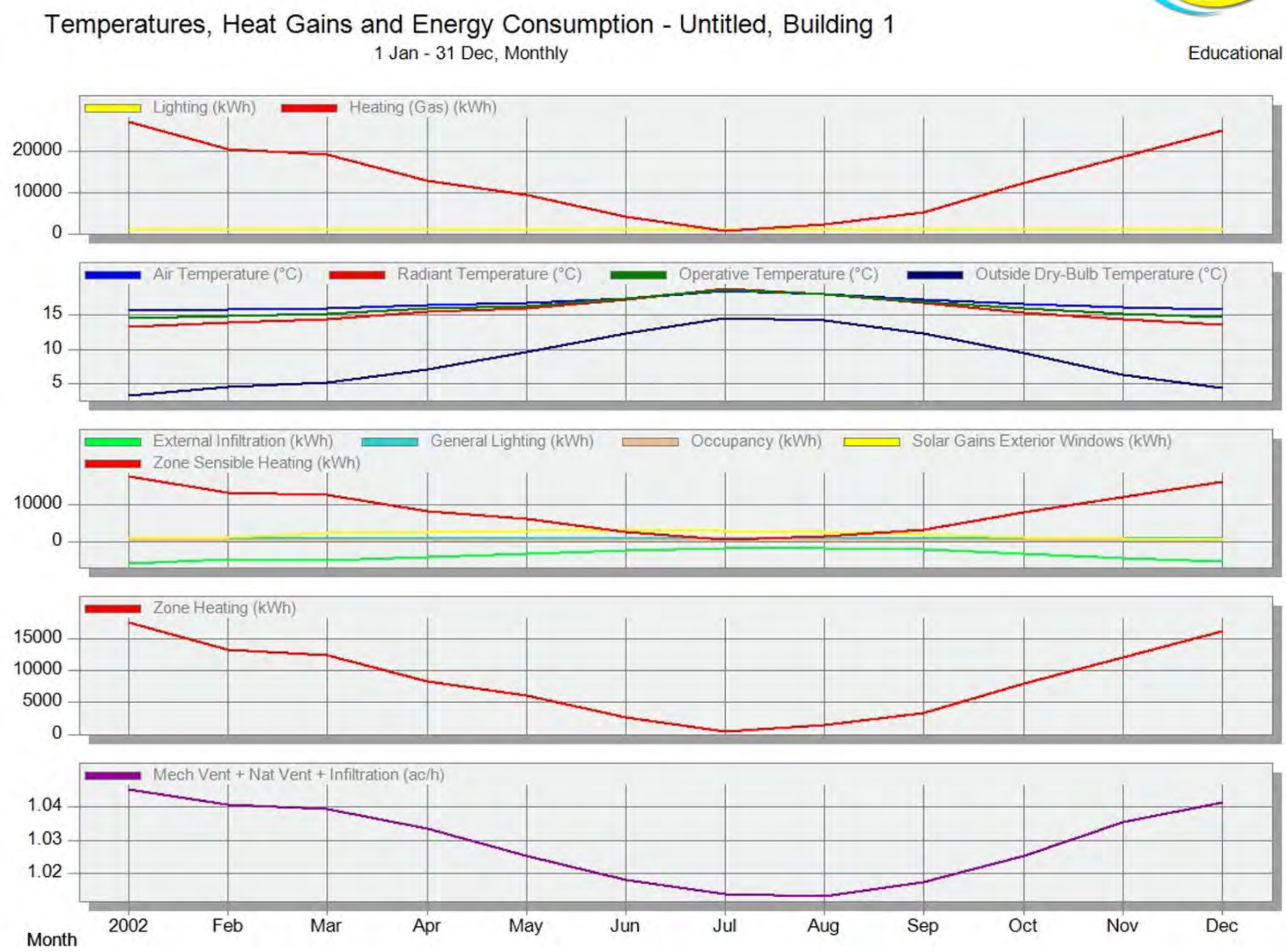


Figure A268. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.85
Operative Temperature (°C)	15.43
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-7.00
Walls (kW)	-28.20
Ceilings (int) (kW)	-4.55
Floors (int) (kW)	1.03
Ground Floors (kW)	1.18
Partitions (int) (kW)	0.00
Roofs (kW)	-0.03
External Infiltration (kW)	-15.12
External Vent. (kW)	-45.36
Zone Sensible Heating (kW)	97.80

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Living Room	15.54	4.08	**5.10**	239.4033
Bed Room 1	15.42	5.72	**7.15**	224.9188
Service 1	14.82	0.70	**0.87**	419.8444
Kitchen	15.56	3.10	**3.87**	241.0998
Hall	17.05	1.13	**1.41**	191.3877
Service	17.45	0.47	**0.58**	171.1973
Bed Room 2	16.27	2.19	**2.74**	207.1625
Bed Room 3	15.13	3.65	**4.56**	249.6865
Corridor	16.97	2.02	**2.52**	188.6993
Bed Room	16.36	1.77	**2.21**	211.3573
Vestibule	15.53	0.67	**0.84**	330.0650
First Floor Total Design Heating Capacity = 31.210 (kW)				
Living Room	15.20	5.84	**7.30**	214.0926
Bed Room 1	15.13	5.59	**6.99**	219.9276
Service 1	14.65	0.70	**0.87**	421.3527
Kitchen	15.33	3.04	**3.79**	236.3495
Hall	16.60	1.89	**2.36**	185.6082
Service	17.32	0.45	**0.56**	163.9737
Bed Room 2	16.07	2.12	**2.66**	200.7696
Bed Room 3	14.86	3.60	**4.49**	245.9246
Bed Room	16.09	1.75	**2.19**	209.6281
Second Floor Total Design Heating Capacity = 29.020 (kW)				
Living Room	15.21	5.42	**6.77**	198.5582
Bed Room 1	15.09	5.23	**6.54**	205.8684
Service 1	14.64	0.65	**0.81**	390.8742
Kitchen	15.30	2.83	**3.54**	220.6817
Hall	16.53	1.76	**2.20**	173.3140
Service	17.27	0.42	**0.52**	152.7784
Bed Room 2	16.00	1.99	**2.49**	187.8890
Bed Room 3	14.91	3.32	**4.15**	227.0206

Figure A269. The heating design simulation and data of the house.



Lighting (kWh)	922.72	837.80	934.04	894.41	922.72	905.74	922.72	928.38	900.07	922.72	900.07	928.38
Heating (Gas) (kWh)	26978.01	20493.55	19286.46	12721.41	9497.59	3981.40	740.72	2225.01	5068.05	12378.33	18703.61	25005.24
Air Temperature (°C)	15.71	15.86	16.04	16.46	16.75	17.46	18.50	18.06	17.20	16.55	16.09	15.78
Radiant Temperature (°C)	13.31	13.85	14.39	15.42	15.94	17.27	18.78	18.01	16.75	15.33	14.32	13.51
Operative Temperature (°C)	14.51	14.86	15.22	15.94	16.34	17.37	18.64	18.04	16.97	15.94	15.20	14.65
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-5698.71	-4668.32	-4989.98	-4177.06	-3227.72	-2242.28	-1760.43	-1696.13	-2161.62	-3192.05	-4379.71	-5252.94
General Lighting (kWh)	922.72	837.80	934.04	894.41	922.72	905.74	922.72	928.38	900.07	922.72	900.07	928.38
Occupancy (kWh)	289.60	266.60	302.57	281.92	289.60	292.29	277.35	287.58	288.20	289.60	288.42	296.09
Solar Gains Exterior Windows (kWh)	776.40	1294.59	2329.83	2728.14	2934.23	2905.86	3020.79	2548.24	1994.66	1331.14	880.15	513.76
Zone Sensible Heating (kWh)	17472.72	13270.43	12487.63	8236.36	6149.88	2578.28	479.57	1441.17	3283.05	8017.00	12111.03	16194.28
Zone Heating (kWh)	17535.71	13320.81	12536.20	8268.91	6173.43	2587.91	481.47	1446.25	3294.24	8045.91	12157.35	16253.41
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A270. The simulation detailed results of the house.

Case 91. A House Built in 1800

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional stone construction to most elevations with rendered gable.	1.939	Increase 22.2 cm Insulation
	Flat 2.251	Increase 32.3 cm Insulation
	Pitched 2.956	Increase 33.2 cm Insulation
Floors are suspended timber with some solid areas.	1.817	Increase 32 cm Insulation
Internal Walls are plastered and decorated.	1.661	
Windows are timber sash and casement windows with single glazing.		

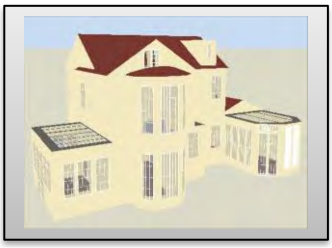
* As a basis for a theory of possibility

Description

Detached villa.

Ground Floor - Entrance vestibule, hallway, living room with sun room off, dining room, kitchen/dining room, further kitchen, conservatory and WC. apartment.

First Floor - Landing, drawing room, 3 bedrooms and bathroom. Second Floor - Landing, 3 bedrooms and shower room. Basement Level - Wine cellar.



Weather Overcast.

Heating and hot water

Gas fired back boiler to Rayburn stove in kitchen serving panel radiators throughout property via boxed in circulating tank, also equipped with electrical immersion heater.

Gross internal floor area(m²) 313 m^2

Address

DALKEITH EH22 1BU

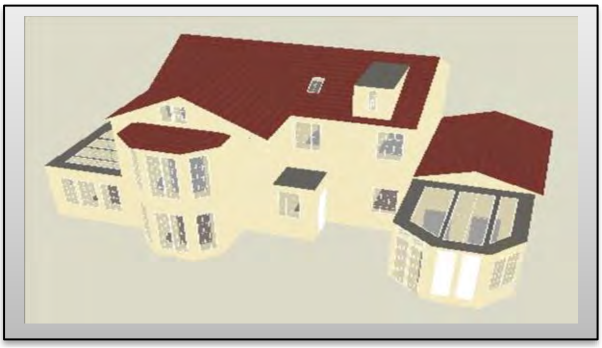
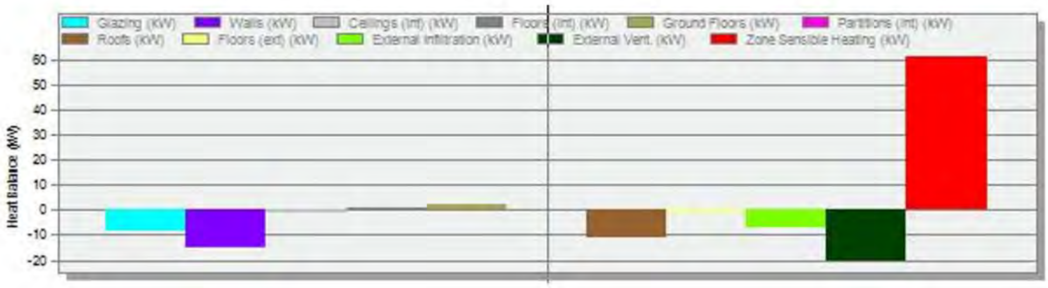


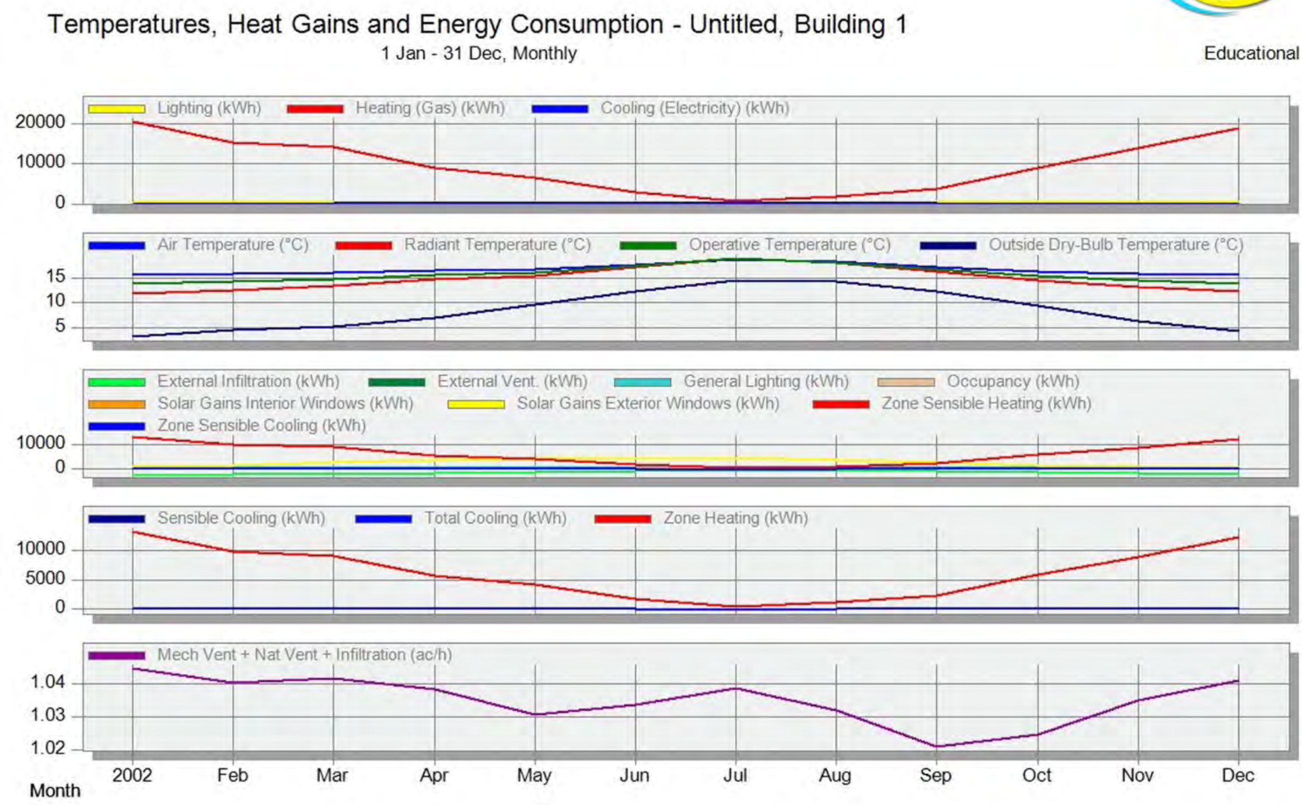
Figure A271. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	10.53
Operative Temperature (°C)	14.27
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-8.55
Walls (kW)	-14.83
Ceilings (int) (kW)	-1.44
Floors (int) (kW)	1.00
Ground Floors (kW)	1.94
Partitions (int) (kW)	0.00
Roofs (kW)	-10.75
Floors (ext) (kW)	-1.42
External Infiltration (kW)	-6.84
External Vent. (kW)	-20.53
Zone Sensible Heating (kW)	61.27

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Sun Room	12.41	5.86	**7.32**	470.1230
Lounge	15.78	6.04	**7.55**	214.0438
Hall	15.75	3.77	**4.72**	238.0569
Kitchen	15.54	4.51	**5.63**	232.7480
Utility Room	14.66	2.99	**3.74**	343.1219
Dining Room	15.20	3.19	**3.99**	269.9763
Service	15.97	0.41	**0.51**	378.2179
Conservatory	12.35	4.90	**6.12**	473.5633
First Floor Total Design Heating Capacity = 15.750 (kW)				
Hall	15.17	0.92	**1.15**	668.5199
Service	15.38	0.48	**0.60**	445.8697
Bed Room	15.69	1.60	**2.00**	240.6233
Bed Room	15.04	3.10	**3.88**	262.4615
Service	14.66	1.32	**1.65**	416.0257
Bed Room	15.16	2.05	**2.56**	283.4843
Drawing Room	15.73	3.13	**3.91**	212.9781
Drawing Room Total Design Heating Capacity = 4.720 (kW)				
Zone 4	13.68	3.77	**4.72**	332.9145
Main Roof SecondFloor Total Design Heating Capacity = 11.340 (kW)				
Service	12.48	1.82	**2.27**	194.7598
Bed Room	13.59	2.49	**3.12**	163.8540
Landing Hall	14.01	1.37	**1.71**	155.6009
Bed Room	12.29	3.39	**4.24**	190.7451
Roof BedRoom Total Design Heating Capacity = 4.590 (kW)				
Zone 1	12.34	3.67	**4.59**	162.0905

Figure A272. The heating design simulation and data of the house.



Lighting (kWh)	486.90	442.09	492.87	471.96	486.90	477.94	486.90	489.89	474.95	486.90	474.95	489.89
Heating (Gas) (kWh)	20394.22	15303.96	14106.86	8886.38	6478.71	2781.21	660.44	1699.69	3632.53	8959.19	13834.85	18829.32
Cooling (Electricity) (kWh)	0.00	0.00	0.00	2.79	4.85	15.46	38.22	14.83	0.40	0.00	0.00	0.00
Air Temperature (°C)	15.60	15.72	15.93	16.38	16.68	17.52	18.75	18.15	17.12	16.33	15.90	15.64
Radiant Temperature (°C)	11.93	12.63	13.40	14.77	15.49	17.11	18.88	17.91	16.36	14.52	13.22	12.20
Operative Temperature (°C)	13.76	14.18	14.67	15.57	16.08	17.31	18.82	18.03	16.74	15.42	14.56	13.92
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2556.39	-2092.16	-2247.09	-1888.51	-1466.05	-1030.42	-839.60	-789.66	-979.16	-1419.93	-1957.68	-2351.83
External Vent. (kWh)	0.00	0.00	-7.32	-12.52	-11.61	-24.45	-35.34	-21.22	-5.46	0.00	0.00	0.00
General Lighting (kWh)	486.90	442.09	492.87	471.96	486.90	477.94	486.90	489.89	474.95	486.90	474.95	489.89
Occupancy (kWh)	152.82	140.67	159.32	148.03	151.95	151.36	143.37	149.44	151.28	152.79	152.17	156.24
Solar Gains Interior Windows (kWh)	0.14	0.21	0.35	0.42	0.41	0.38	0.41	0.36	0.28	0.20	0.16	0.10
Solar Gains Exterior Windows (kWh)	886.82	1583.26	2944.47	3745.90	4288.93	4222.25	4484.35	3685.95	2680.94	1656.97	1047.81	590.51
Zone Sensible Heating (kWh)	13224.53	9922.47	9145.48	5759.75	4198.37	1801.63	427.63	1101.24	2354.24	5808.05	8969.07	12209.03
Zone Sensible Cooling (kWh)	0.00	0.00	-0.01	-12.50	-21.70	-68.97	-164.00	-58.75	-1.77	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	-0.01	-12.56	-21.85	-69.32	-164.76	-58.96	-1.80	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	-0.01	-12.56	-21.85	-69.58	-171.99	-66.74	-1.80	0.00	0.00	0.00
Zone Heating (kWh)	13256.24	9947.57	9169.46	5776.15	4211.16	1807.78	429.28	1104.80	2361.15	5823.48	8992.65	12239.06
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.04	1.03	1.03	1.04	1.03	1.02	1.02	1.03	1.04

Figure A273. The simulation detailed results of the house.

Case 92. A House Built in 1798

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are mostly of stone construction although part of the east most wing appears to be of brick or concrete block construction.	1.990	Increase 22.1 cm Insulation
	Flat -	-
	Pitched 2.941	Increase 33.16 cm Insulation
Floors are partly of solid construction but mostly of suspended timber construction.	1.825	Increase 32.14 cm Insulation
Internal Walls are mainly of plaster faced solid (probably brick) construction.	1.842	
Windows are of timber framed windows, some of which have been fitted with double glazed sealed units.		

* As a basis for a theory of possibility

Description

The subjects form a detached house .

On ground floor: Entrance vestibule, hallway, lounge, dining room and study, passage to mid-off hallway with kitchen and shower apartment off, utility room off kitchen with conservatory off utility room.

On first floor: Landing, drawing room, three bedrooms and two bathrooms.

Weather Dry.

Heating and hot water

Central heating takes the form of a gas fired wall mounted boiler located in a cupboard off the hallway within the east wing and ventilated by means of a balanced flue to the outside, serving panel and column type radiators through small and micro bore piping around the house. The temperature throughout the house is controlled by individual thermostats fitted to some of the radiators.

Gross internal floor area(m²) 448 m²

Address

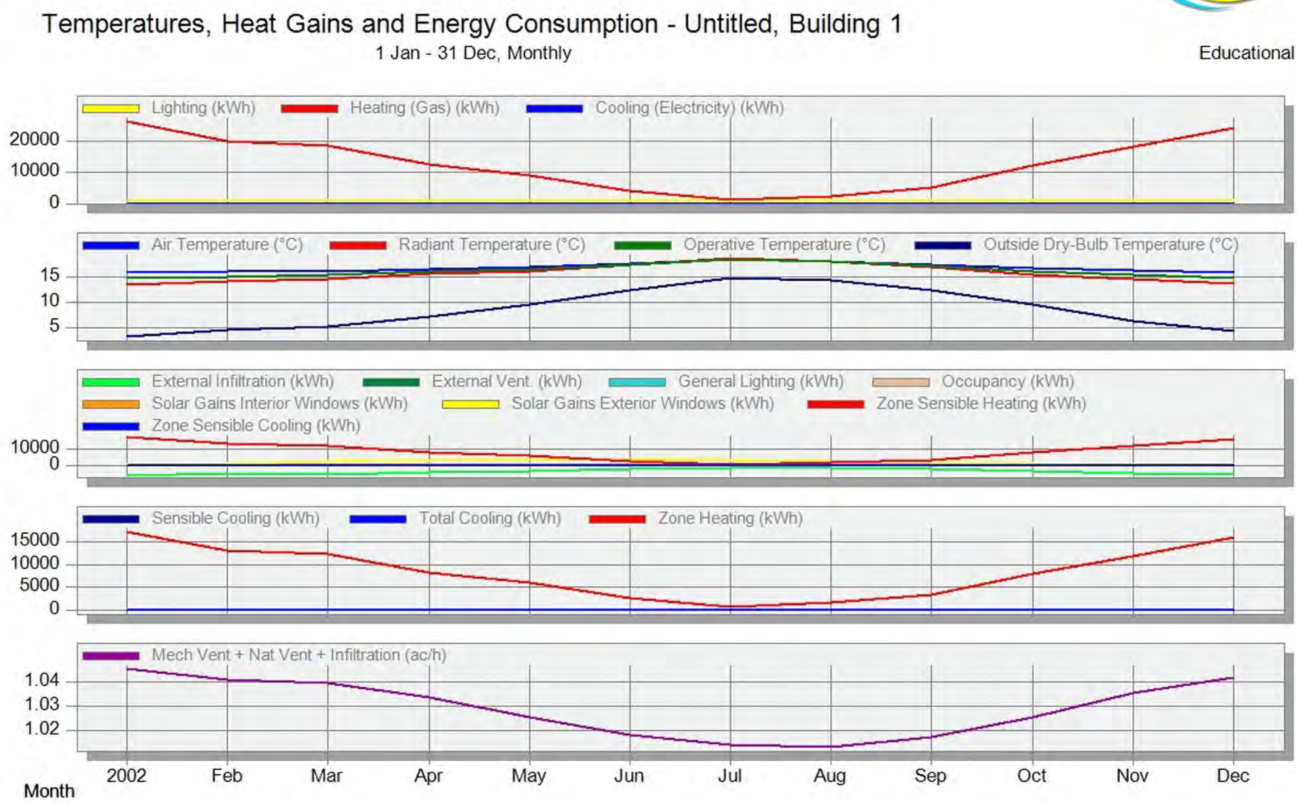
ESKBANK EH22 3NJ

Figure 274. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	12.95
Operative Temperature (°C)	15.48
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-8.39
Walls (kW)	-22.06
Ceilings (int) (kW)	-9.69
Floors (int) (kW)	0.99
Ground Floors (kW)	2.98
Partitions (int) (kW)	-0.21
Roofs (kW)	-0.97
External Infiltration (kW)	-15.72
External Vent. (kW)	-47.15
Zone Sensible Heating (kW)	99.91

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Kitchen	15.84	5.56	**6.95**	208.4370
Bed Room	15.75	2.62	**3.28**	246.4117
Bed Room	15.75	2.00	**2.49**	236.1468
Corridor	16.40	1.19	**1.49**	238.6031
Bed Room	16.38	1.93	**2.41**	203.5734
Service	15.82	0.98	**1.22**	260.8455
Utility Room	17.04	1.67	**2.08**	176.9179
Service	16.77	0.63	**0.79**	207.3641
Service	16.66	1.30	**1.63**	197.3899
Service	16.64	0.86	**1.08**	206.5483
Laundry Room	13.65	2.60	**3.25**	373.2646
Conservatory	13.90	3.68	**4.60**	333.6313
Bed Room	16.11	1.64	**2.05**	221.0128
Service	15.51	1.11	**1.39**	277.8230
Sun Room	14.09	4.34	**5.42**	355.5413
Corridor	17.34	0.57	**0.72**	176.2978
Hall	16.94	4.82	**6.02**	178.6389
Dining Room	16.81	4.88	**6.10**	176.0905
Bed Room	14.32	6.36	**7.95**	267.5559
Service	16.32	1.13	**1.42**	225.1519
Service	17.46	0.47	**0.58**	174.3330
Vestibule	15.74	1.19	**1.49**	260.2046
Study Room	15.10	4.15	**5.19**	244.9372
Sitting Room	15.27	7.31	**9.13**	222.1430
Entrance Total Design Heating Capacity = 0.560 (kW)				
Zone 1	14.08	0.45	**0.56**	1153.0372
First Floor Total Design Heating Capacity = 44.960 (kW)				
Service	14.59	5.19	**6.49**	241.6050
Bed Room	14.68	3.53	**4.41**	262.4999
Corridor	15.69	0.85	**1.07**	270.6594

Figure A275. The heating design simulation and data of the house.



Lighting (kWh)	872.20	791.94	882.91	845.45	872.20	856.15	872.20	877.56	850.80	872.20	850.80	877.56
Heating (Gas) (kWh)	26448.43	19982.85	18862.21	12561.12	9249.25	4184.51	1134.07	2484.06	5222.68	12126.42	18356.39	24462.34
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.77	15.92	16.07	16.45	16.74	17.45	18.33	17.96	17.18	16.55	16.12	15.84
Radiant Temperature (°C)	13.49	14.03	14.54	15.51	16.03	17.28	18.54	17.89	16.76	15.41	14.46	13.70
Operative Temperature (°C)	14.63	14.97	15.31	15.98	16.39	17.36	18.44	17.93	16.97	15.98	15.29	14.77
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-5945.03	-4867.88	-5193.19	-4327.08	-3340.50	-2314.27	-1740.02	-1704.97	-2225.50	-3306.11	-4559.82	-5483.40
External Vent. (kWh)	0.00	0.00	0.00	-0.00	0.00	0.00	-0.38	-0.01	-0.01	0.00	0.00	0.00
General Lighting (kWh)	872.20	791.94	882.91	845.45	872.20	856.15	872.20	877.56	850.80	872.20	850.80	877.56
Occupancy (kWh)	273.75	252.00	285.97	266.38	273.64	275.46	263.30	272.25	272.21	273.74	272.62	279.88
Solar Gains Interior Windows (kWh)	1.27	2.16	3.76	4.36	4.60	4.42	4.64	4.04	3.23	2.14	1.47	0.84
Solar Gains Exterior Windows (kWh)	735.23	1328.42	2417.58	3012.72	3217.59	3199.77	3288.67	2755.38	2080.28	1323.32	854.32	489.86
Zone Sensible Heating (kWh)	17127.60	12938.34	12211.16	8129.70	5986.28	2708.47	734.02	1608.14	3381.76	7851.52	11884.66	15841.00
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	17191.48	12988.86	12260.44	8164.73	6012.01	2719.93	737.15	1614.64	3394.75	7882.17	11931.66	15900.52
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1.02	1.03	1.04	1.04

Figure A276. The simulation detailed results of the house.

Case 93. House Built in 1795

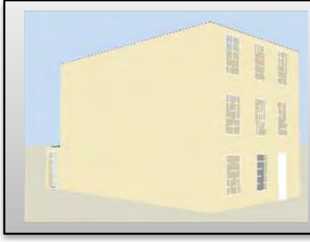
Material	U-Value W/m^2K	How to reach Zero Carbon home (theoretically*)
Main Walls are of stone construction.	2.006	Increase 22.11 cm Insulation
	Flat -	-
	Pitched 2.942	Increase 33.24 cm Insulation
Floors are of suspended timber construction.	1.844	Increase 32.16 cm Insulation
Internal Walls are plasterboard.	1.851	
Windows are of timber single glazed sash and case window.		

* As a basis for a theory of possibility

Description

On ground floor: Entrance vestibule, hallway, lounge, dining room and study, passage to mid-off hallway with kitchen and shower apartment off, utility room off kitchen with conservatory off utility room.

On first floor (entered by a stone staircase from the hallway): Landing, drawing room, three bedrooms and two bathrooms.



Weather Dry.

Heating and hot water

Central heating takes the form of a gas fired hot water is supplied from two circulating tanks heated by the gas fired central heating boiler.

Gross internal floor area(m²) 370 m^2

Address

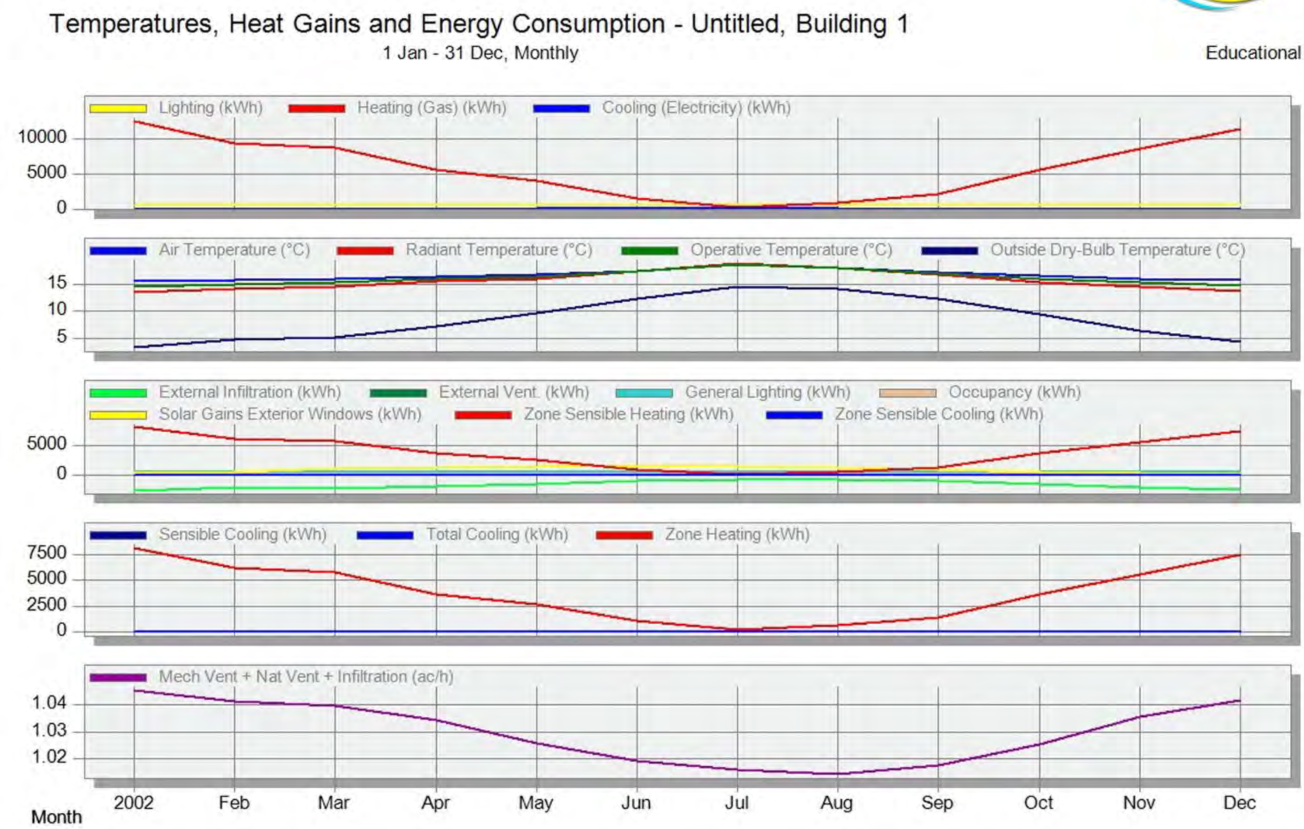
EDINBURGH EH6 3WP

Figure A277. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	13.28
Operative Temperature (°C)	15.64
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.42
Walls (kW)	-12.93
Ceilings (int) (kW)	-4.01
Floors (int) (kW)	0.78
Ground Floors (kW)	1.07
Partitions (int) (kW)	0.00
External Infiltration (kW)	-6.73
External Vent. (kW)	-20.18
Zone Sensible Heating (kW)	45.29

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 56.620 (kW)				
Ground Floor Total Design Heating Capacity = 17.720 (kW)				
Sitting Room	16.06	4.57	**5.71**	132.6121
Veslibule	15.66	1.63	**2.03**	160.0201
Hall	16.53	3.01	**3.76**	129.0198
Kitchen	16.20	3.25	**4.06**	131.2875
Service	16.51	0.41	**0.52**	164.2652
Store Room	15.39	1.32	**1.64**	178.8321
SunRoom Total Design Heating Capacity = 1.600 (kW)				
Sun room	12.94	1.28	**1.60**	358.4414
First Floor Total Design Heating Capacity = 17.220 (kW)				
Master Bedroom	15.73	3.98	**4.98**	127.4619
Ensuite Bathroom	15.35	1.91	**2.38**	154.7288
Hall	16.13	1.76	**2.20**	125.4864
Drawing Room	15.72	4.45	**5.56**	126.5400
Study Room	15.31	1.68	**2.10**	159.5416
Second Floor Total Design Heating Capacity = 20.080 (kW)				
Bedroom2	14.87	3.56	**4.45**	157.0634
Bedroom3	14.78	2.16	**2.70**	174.8487
Hall	15.62	2.62	**3.28**	141.5533
Ensuite Bathroom 1	16.52	0.51	**0.64**	131.6046
Ensuite Bathroom	16.54	0.51	**0.64**	131.0315
Bedroom1	14.90	3.19	**3.99**	158.9009
Bedroom4	14.87	2.02	**2.53**	180.0451
Bathroom	15.63	0.79	**0.99**	170.5757
Dressing Room	15.42	0.69	**0.86**	190.3294

Figure A278. The heating design simulation and data of the house.



Lighting (kWh)	632.15	573.97	639.90	612.76	632.15	620.51	632.15	636.03	616.63	632.15	616.63	636.03
Heating (Gas) (kWh)	12545.43	9514.88	8884.96	5667.31	4124.53	1573.06	214.34	862.54	2141.38	5627.31	8638.23	11581.43
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.05	0.33	1.41	0.11	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.77	15.96	16.15	16.60	16.86	17.60	18.70	18.20	17.28	16.66	16.20	15.86
Radiant Temperature (°C)	13.64	14.16	14.69	15.71	16.18	17.48	18.95	18.17	16.89	15.57	14.63	13.85
Operative Temperature (°C)	14.70	15.06	15.42	16.15	16.52	17.54	18.82	18.18	17.08	16.12	15.42	14.86
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2543.50	-2091.27	-2238.24	-1881.40	-1454.82	-1020.45	-817.43	-777.74	-972.35	-1437.94	-1967.76	-2349.74
External Vent. (kWh)	0.00	0.00	0.00	-0.32	-0.12	-0.86	-1.82	-0.65	0.00	0.00	0.00	0.00
General Lighting (kWh)	632.15	573.97	639.90	612.76	632.15	620.51	632.15	636.03	616.63	632.15	616.63	636.03
Occupancy (kWh)	198.40	182.64	207.27	193.09	198.35	199.41	187.70	195.68	197.34	198.40	197.59	202.85
Solar Gains Exterior Windows (kWh)	317.66	561.98	1058.48	1303.93	1438.14	1454.51	1492.88	1227.73	920.04	583.10	362.46	210.41
Zone Sensible Heating (kWh)	8126.72	6163.15	5754.98	3671.24	2672.10	1019.03	138.79	558.79	1387.66	3646.60	5595.81	7502.34
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	-0.21	-1.47	-5.87	-0.40	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	-0.21	-1.47	-5.87	-0.40	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	-0.21	-1.48	-6.36	-0.52	0.00	0.00	0.00	0.00
Zone Heating (kWh)	8154.53	6184.67	5775.23	3683.75	2680.94	1022.49	139.32	560.65	1391.90	3657.75	5614.85	7527.93
Mech Vent + Nat Vent + Infiltration (ac/h)	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.01	1.02	1.03	1.04	1.04

Figure A279. The simulation detailed results of the house.

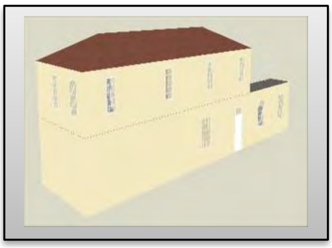
Case 94. A House Built in 1770

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of solid sandstone wall construction, being approximately 0.6m thick, pointed externally.	2.020	Increase 22.13 cm Insulation
	Flat 2.277	Increase 32.5 cm Insulation
	Pitched 2.945	Increase 33.19 cm Insulation
Floors are of suspended timber construction.	1.855	Increase 32.17 cm Insulation
Internal Walls are of lath and plaster wall Construction.	1.854	
Windows are single glazed timber framed window units.		

* As a basis for a theory of possibility

Description

Grade 2, B listed two storey mid terraced villa, contained within a converted courtyard style development.



Weather Dry and sunny.

Heating and hot water

A Baxi Solo 2 PF wall mounted boiler within a cupboard off the master bedroom provides a system of water filled radiators and also provides the domestic hot water cylinder located within a cupboard off the dining/hall area.

Gross internal floor area(m²) 245 m^2

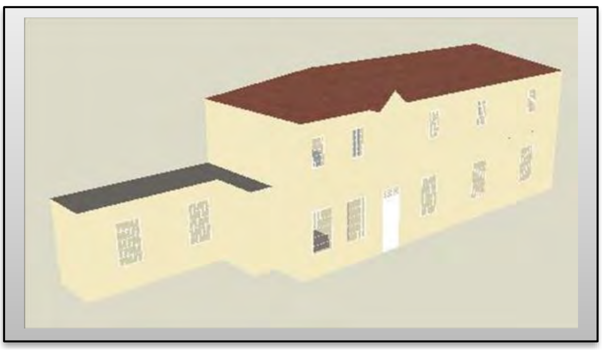
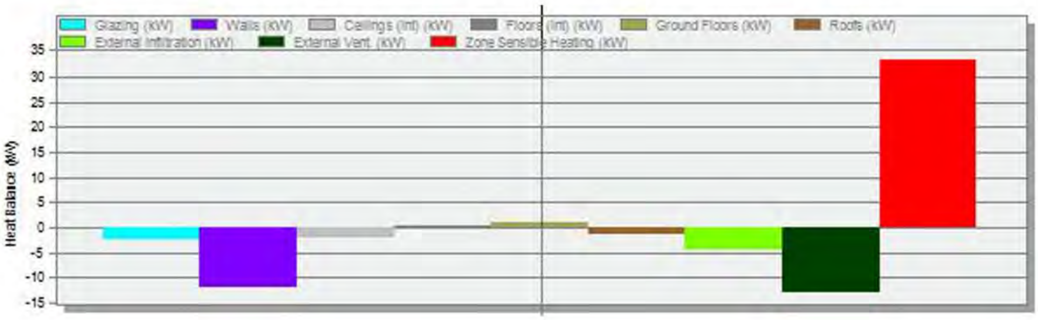


Figure A280. The Software visualization of the house.

Address

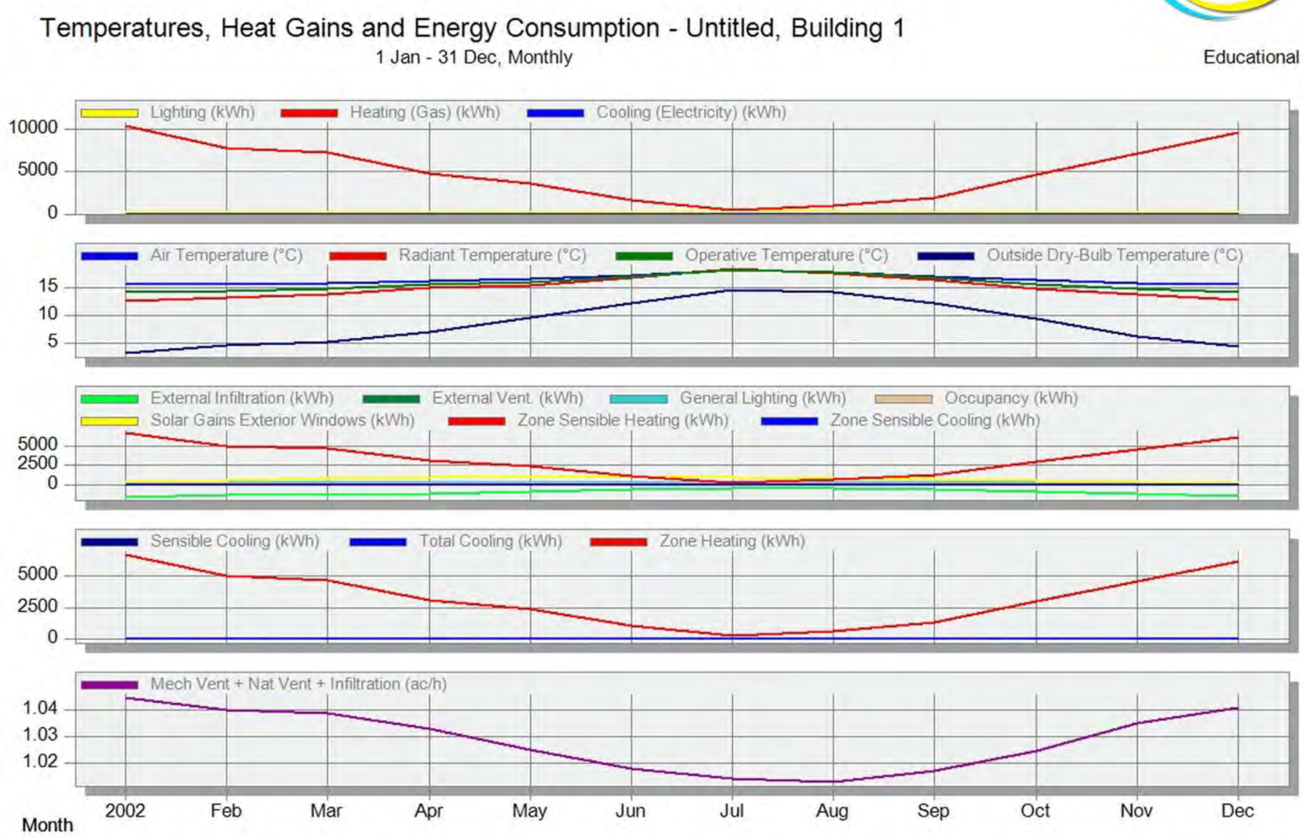
GLENROTHES KY7 6NR



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.89
Operative Temperature (°C)	14.95
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.40
Walls (kW)	-11.86
Ceilings (int) (kW)	-2.12
Floors (int) (kW)	0.31
Ground Floors (kW)	1.04
Roofs (kW)	-1.22
External Infiltration (kW)	-4.28
External Vent. (kW)	-12.85
Zone Sensible Heating (kW)	33.26

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 41.590 (kW)				
First Flloor Total Design Heating Capacity = 17.360 (kW)				
Corridor	14.76	2.37	**2.96**	269.2929
Master BedRoom	14.88	3.14	**3.92**	199.9128
Storage	14.32	1.88	**2.35**	255.4453
Bed Room	15.36	1.99	**2.48**	195.5992
Attic	14.41	1.84	**2.31**	251.0818
Bed Room	14.33	2.32	**2.90**	247.0361
Service	15.27	0.35	**0.44**	326.7194
Ground Floor Total Design Heating Capacity = 24.230 (kW)				
Vestibule	15.74	0.38	**0.47**	401.1604
Garage	15.75	2.63	**3.29**	233.5699
Sitting Room	15.65	3.27	**4.09**	228.6210
Dining Kitchen	14.73	4.42	**5.53**	264.2933
Corridor	16.50	0.83	**1.04**	232.7327
Living Room	15.21	3.66	**4.57**	247.7206
Hall	13.78	2.27	**2.84**	449.0482
Bed Room	12.97	1.92	**2.40**	515.9776
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-4.58	0.00	**0.00**	0.0000
Roof 2 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-1.51	0.00	**0.00**	0.0000

Figure A281. The heating design simulation and data of the house.



Lighting (kWh)	265.19	240.79	268.45	257.06	265.19	260.31	265.19	266.82	258.69	265.19	258.69	266.82
Heating (Gas) (kWh)	10307.90	7738.89	7233.99	4718.62	3647.14	1658.49	400.75	962.61	1952.28	4670.43	7056.37	9546.14
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.62	15.75	15.92	16.34	16.61	17.35	18.30	17.92	17.12	16.42	15.96	15.68
Radiant Temperature (°C)	12.73	13.34	13.93	15.04	15.54	16.94	18.41	17.71	16.50	14.95	13.85	12.96
Operative Temperature (°C)	14.18	14.54	14.92	15.69	16.07	17.15	18.36	17.81	16.81	15.68	14.91	14.32
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1600.97	-1308.12	-1397.26	-1166.80	-894.88	-619.04	-471.29	-460.23	-599.98	-886.26	-1224.43	-1473.75
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.28	0.00	0.00	0.00	0.00	0.00
General Lighting (kWh)	265.19	240.79	268.45	257.06	265.19	260.31	265.19	266.82	258.69	265.19	258.69	266.82
Occupancy (kWh)	83.23	76.62	86.96	81.02	83.23	84.02	80.32	82.93	82.83	83.23	82.89	85.10
Solar Gains Exterior Windows (kWh)	320.34	512.32	855.18	969.58	985.84	930.66	988.50	871.16	715.28	497.17	366.43	213.47
Zone Sensible Heating (kWh)	6680.65	5014.51	4686.65	3056.32	2362.48	1074.41	259.56	623.70	1265.11	3026.07	4571.83	6186.58
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	6700.13	5030.28	4702.10	3067.10	2370.64	1078.02	260.49	625.70	1268.98	3035.78	4586.64	6204.99
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.02	1.02	1.01	1.01	1.02	1.02	1.03	1.04

Figure A282. The simulation detailed results of the house.

Case 95. A House Built in 1765

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are traditional sandstone construction, pointed finish.	2.081	Increase 22.3 cm Insulation
	Flat -	-
	Pitched 2.930	Increase 33.2 cm Insulation
Floors are mostly of suspended timber construction.	1.848	Increase 32 cm Insulation
Internal Walls are finished in a combination of lath and plaster, plasterboard and plaster on the hard.	1.866	
Windows are timber framed single glazed.		

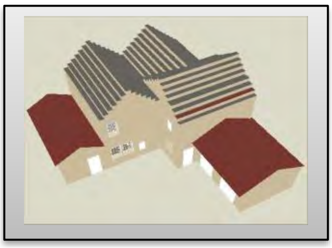
* As a basis for a theory of possibility

Description

Detached two storey stone built house.

Ground Floor: Drawing Room, Sittingroom, Dining Room, Kitchen, Entrance Vestibule and Hallway.

First Floor: 4 Bedrooms, Bathroom with WC Facility, Shower Room.



Weather Rain showers.

Heating and hot water

Space heating is provided by a gas fired central heating system. The central heating boiler is located in the kitchen and serves individual wall mounted radiators l ocated throughout the Property. Thermostatic controls are fitted to individual radiators.
Domestic hot water is understood to be provided by way of the Aga in conjunction with the hot water cyli nder housed in the first floor hallway cupboard.

Gross internal floor area (m²) 230 m^2 **approx.**

Address

EDINBURGH EH13 0PB

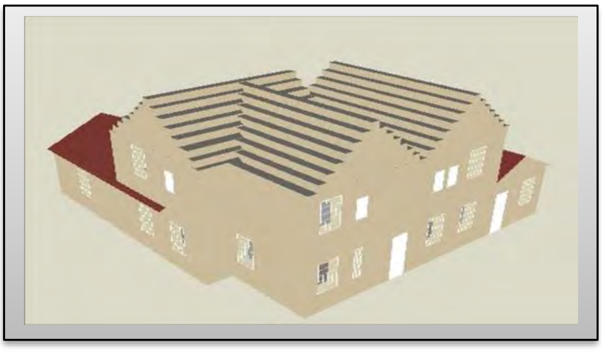
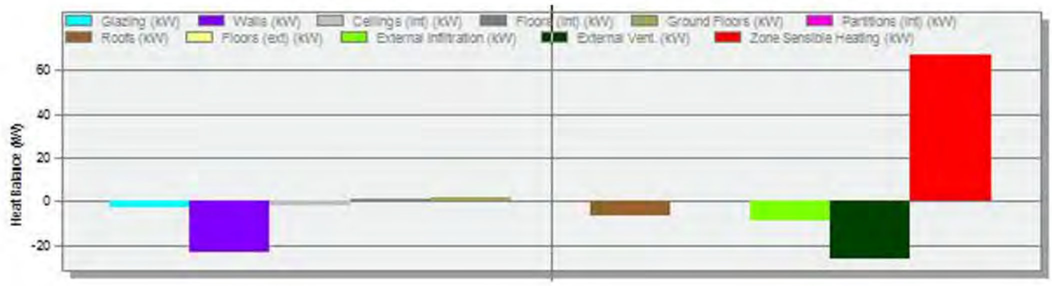


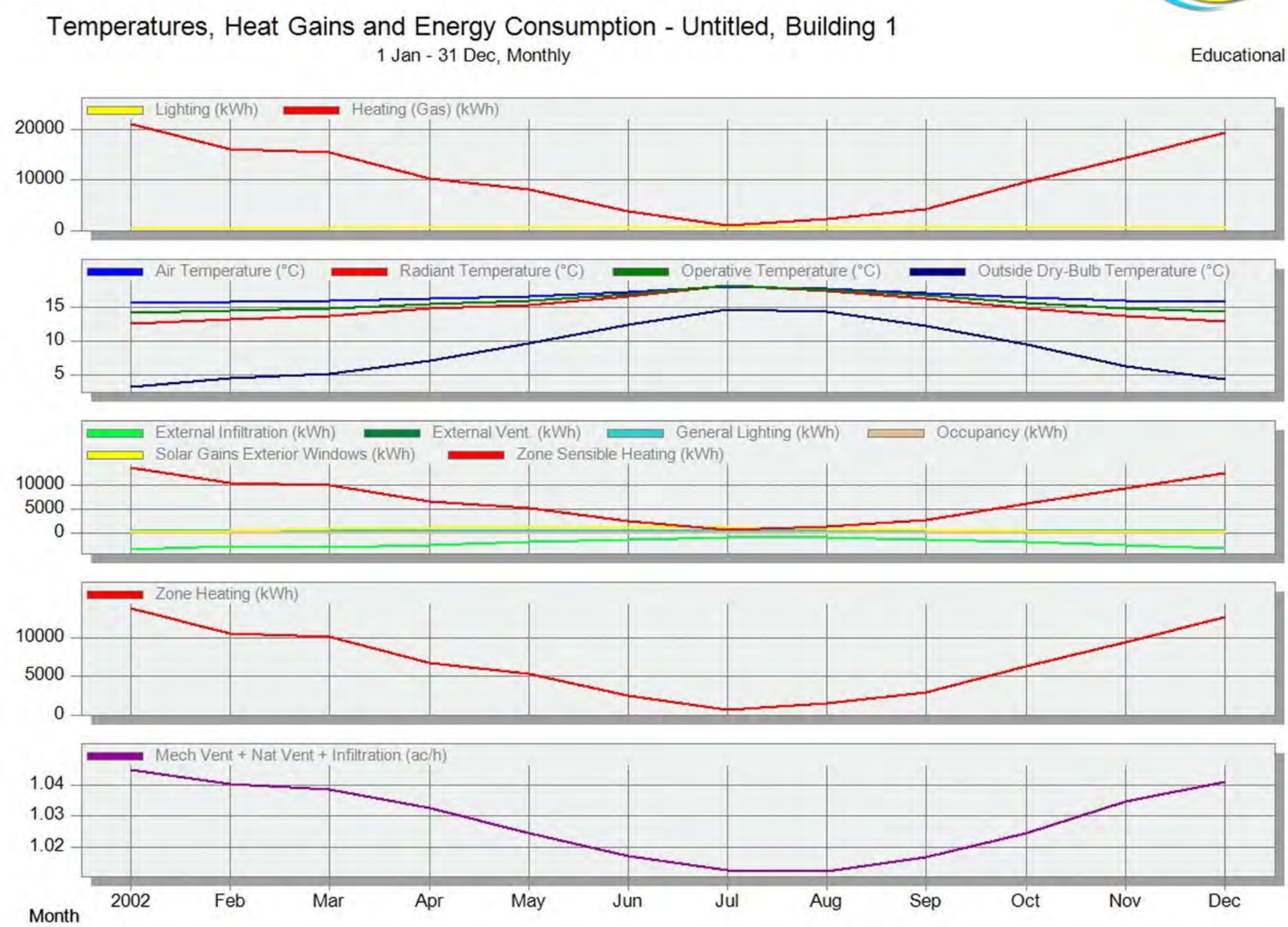
Figure A283. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.80
Operative Temperature (°C)	14.90
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.73
Walls (kW)	-23.38
Ceilings (int) (kW)	-2.15
Floors (int) (kW)	1.21
Ground Floors (kW)	1.79
Partitions (int) (kW)	0.00
Roofs (kW)	-6.72
Floors (ext) (kW)	-0.01
External Infiltration (kW)	-8.88
External Vent. (kW)	-26.63
Zone Sensible Heating (kW)	67.41

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Drawing Room	15.83	5.18	**6.47**	211.4689
Garage	13.99	6.48	**8.10**	307.2854
Vestibule	14.77	1.21	**1.51**	410.3182
Hall	16.70	2.10	**2.62**	196.1790
Service	16.32	1.14	**1.43**	226.9607
Sitting Room	15.14	2.90	**3.63**	273.1282
Dining Room	16.39	2.65	**3.31**	207.1855
Stables	14.35	4.09	**5.11**	306.4410
Kitchen	15.61	2.11	**2.63**	257.5779
Stables	14.18	2.27	**2.84**	384.4479
First Floor Total Design Heating Capacity = 23.040 (kW)				
Bed Room	14.79	5.55	**6.93**	243.1458
Service	14.59	1.21	**1.51**	410.4722
Hall	16.63	1.51	**1.89**	184.7008
Kitchen	15.94	1.18	**1.47**	233.9511
Bed Room	14.68	2.98	**3.73**	280.5084
Bed Room	15.26	2.36	**2.95**	284.5672
Service	15.60	0.69	**0.86**	307.6168
Bed Room	14.91	2.96	**3.70**	267.5713
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-3.77	0.00	**0.00**	0.0000
Roof 4 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-6.52	0.00	**0.00**	0.0000
Roof Total Design Heating Capacity = 8.510 (kW)				
Zone 1	13.26	6.81	**8.51**	292.7165
Roof Total Design Heating Capacity = 6.400 (kW)				
Zone 1	12.78	5.12	**6.40**	489.9513
Roof Total Design Heating Capacity = 8.630 (kW)				
Zone 1	13.19	6.90	**8.63**	3251.0869

Figure A284. The heating design simulation and data of the house.



Lighting (kWh)	452.68	411.02	458.23	438.79	452.68	444.35	452.68	455.46	441.57	452.68	441.57	455.46
Heating (Gas) (kWh)	21105.96	16253.00	15529.00	10374.93	8073.03	3820.80	999.23	2219.37	4338.25	9658.46	14461.54	19359.38
Air Temperature (°C)	15.66	15.78	15.90	16.24	16.52	17.16	18.08	17.74	17.03	16.38	15.97	15.72
Radiant Temperature (°C)	12.64	13.17	13.68	14.74	15.29	16.62	18.14	17.44	16.29	14.82	13.76	12.91
Operative Temperature (°C)	14.15	14.47	14.79	15.49	15.90	16.89	18.11	17.59	16.66	15.60	14.87	14.32
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3325.05	-2709.95	-2878.96	-2376.86	-1814.52	-1225.60	-913.67	-898.21	-1210.98	-1810.05	-2528.59	-3059.97
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-0.02	0.00	0.00	0.00	0.00	0.00
General Lighting (kWh)	452.68	411.02	458.23	438.79	452.68	444.35	452.68	455.46	441.57	452.68	441.57	455.46
Occupancy (kWh)	142.08	130.79	148.43	138.27	142.06	144.10	138.37	142.62	141.44	142.08	141.49	145.26
Solar Gains Exterior Windows (kWh)	275.93	482.02	853.91	1099.76	1177.38	1172.92	1219.95	1004.66	742.25	464.43	322.92	186.16
Zone Sensible Heating (kWh)	13679.98	10532.39	10061.57	6718.74	5227.73	2474.61	647.13	1437.84	2810.60	6256.31	9369.59	12546.87
Zone Heating (kWh)	13718.87	10564.45	10093.85	6743.70	5247.47	2483.52	649.50	1442.59	2819.86	6278.00	9400.00	12583.60
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.02	1.02	1.01	1.01	1.02	1.02	1.03	1.04

Figure A285. The simulation detailed results of the house.

Case 96. A House Built in 1750

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone construction with extension to the rear formed in cavity brick externally rendered.	2.102	Increase 22.21 cm Insulation
	Flat -	-
	Pitched 2.949	Increase 33.24 cm Insulation
Floors are of solid concrete construction and suspended timber construction.	1.850	Increase 32.12 cm Insulation
Internal Walls are of plasterboard and plastered on the hard construction.	1.888	
Windows are of timber and single glazed Construction.		

* As a basis for a theory of possibility

Description

The property is a three storey mid-terraced house.

Ground floor: entrance vestibule, hallway, living room and kitchen/diner.

First floor: landing, master bedroom with en-suite shower room (with WC and wash hand basin), 2 further bedrooms and shower room.

Attic floor level: upper landing and 2 further bedrooms.

Weather Dry and overcast.

Heating and hot water

The property has the benefit of a gas fired central heating system provided by means of a Scottish Gas 330 condensing regular boiler to panelled radiators. This provides domestic hot water to the property although this can be supplemented by means of an electric immersion heater fitted to the insulated hot water tank.

Gross internal floor area(m²) 121 m^2

Address

EDBURGH TD8 6BD

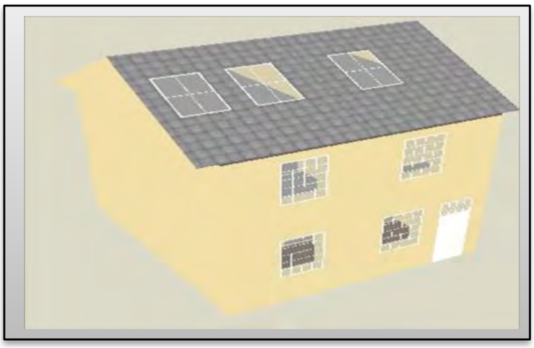
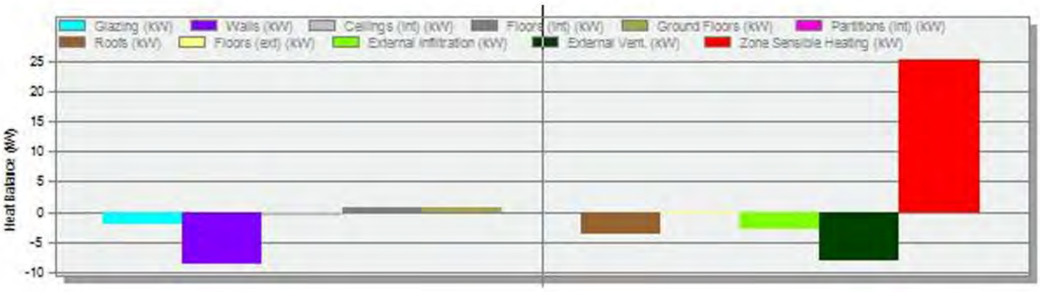


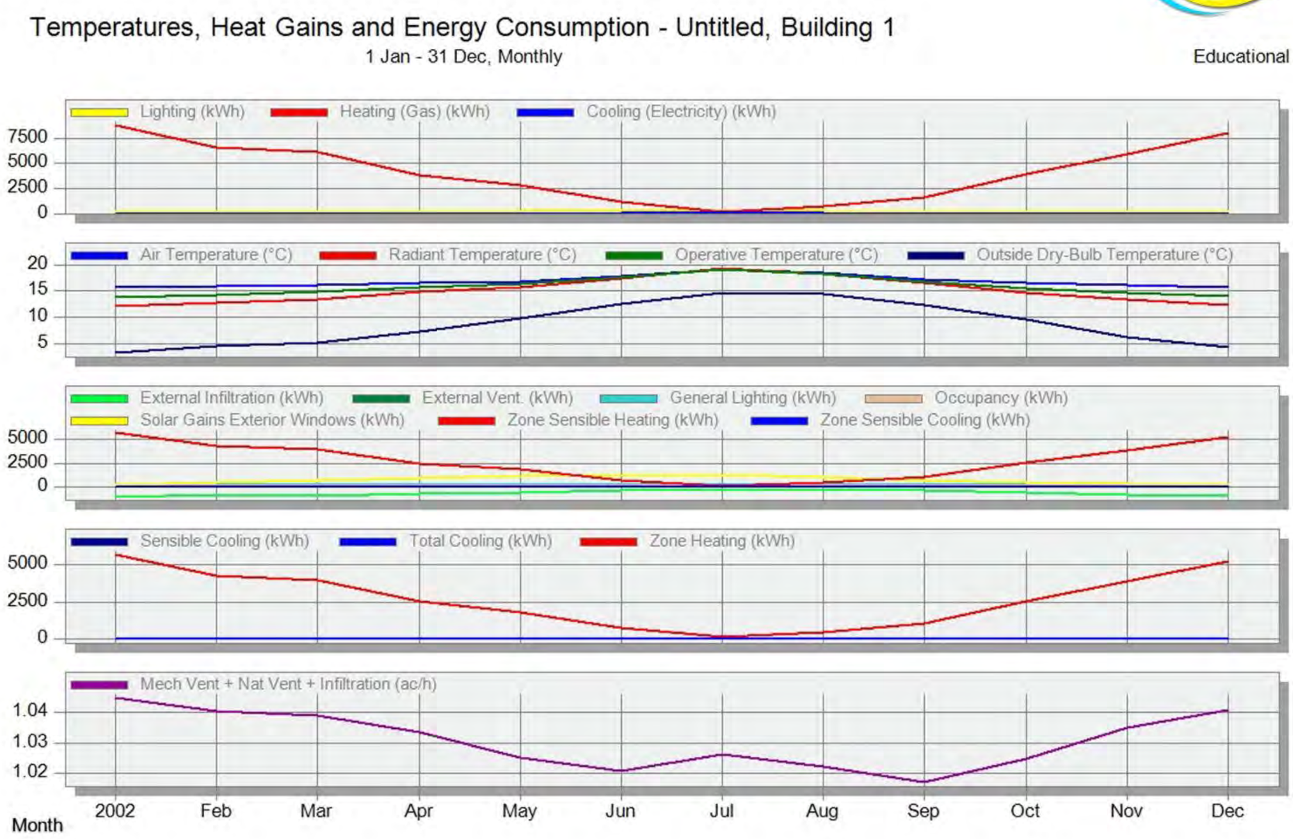
Figure A286. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	10.64
Operative Temperature (°C)	14.32
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.00
Walls (kW)	-8.81
Ceilings (int) (kW)	-0.60
Floors (int) (kW)	0.60
Ground Floors (kW)	0.57
Partitions (int) (kW)	0.00
Roofs (kW)	-3.83
Floors (ext) (kW)	-0.38
External Infiltration (kW)	-2.76
External Vent. (kW)	-8.29
Zone Sensible Heating (kW)	25.44

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 31.790 (kW)				
Ground Floor Total Design Heating Capacity = 11.190 (kW)				
Vestibule	14.67	0.49	**0.61**	672.2633
Living Room	15.44	3.85	**4.82**	220.5626
Hall	15.77	1.32	**1.65**	243.0659
Breakfasting Kitchen	14.81	3.29	**4.11**	274.7808
First Floor Total Design Heating Capacity = 11.420 (kW)				
Bed Room 1	14.88	1.95	**2.43**	264.9712
Bed Room 2	15.16	2.51	**3.14**	234.3389
Hall	16.62	0.61	**0.76**	178.5001
Service 1	15.58	0.43	**0.54**	333.1860
Bed Room	14.75	1.82	**2.27**	280.7423
Service	14.63	1.23	**1.53**	343.0172
Corridor	15.36	0.60	**0.75**	342.0098
Roof 1 Total Design Heating Capacity = 9.180 (kW)				
Bedroom	12.77	3.71	**4.64**	182.3954
Bedroom	12.82	3.63	**4.54**	178.3514

Figure A287. The heating design simulation and data of the house.



Lighting (kWh)	225.97	205.18	228.74	219.04	225.97	221.81	225.97	227.36	220.43	225.97	220.43	227.36
Heating (Gas) (kWh)	8763.34	6612.47	6136.01	3853.32	2785.31	1137.93	220.82	701.18	1567.74	3927.87	5985.60	8092.63
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	1.01	2.54	0.87	0.00	0.00	0.00	0.00
Air Temperature (°C)	15.59	15.71	15.90	16.33	16.66	17.61	18.87	18.19	17.08	16.32	15.89	15.64
Radiant Temperature (°C)	11.92	12.62	13.35	14.72	15.52	17.25	19.04	17.96	16.31	14.48	13.19	12.19
Operative Temperature (°C)	13.76	14.17	14.63	15.52	16.09	17.43	18.96	18.07	16.70	15.40	14.54	13.92
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-1032.47	-844.67	-904.38	-758.21	-585.24	-412.65	-334.04	-312.80	-389.87	-573.39	-790.55	-950.19
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.91	-6.52	-3.85	0.00	0.00	0.00	0.00
General Lighting (kWh)	225.97	205.18	228.74	219.04	225.97	221.81	225.97	227.36	220.43	225.97	220.43	227.36
Occupancy (kWh)	70.92	65.29	74.09	68.96	70.66	70.21	66.30	69.40	70.39	70.92	70.63	72.51
Solar Gains Exterior Windows (kWh)	240.59	408.32	740.28	952.02	1180.93	1204.65	1236.48	1001.10	704.42	444.82	282.04	162.99
Zone Sensible Heating (kWh)	5683.00	4287.51	3978.28	2497.99	1805.36	737.39	143.00	454.44	1016.33	2546.80	3880.78	5247.80
Zone Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-4.46	-10.03	-3.11	0.00	0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-4.49	-10.07	-3.13	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	-4.52	-11.42	-3.93	0.00	0.00	0.00	0.00
Zone Heating (kWh)	5696.17	4298.11	3988.41	2504.66	1810.45	739.65	143.53	455.77	1019.03	2553.12	3890.64	5260.21
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.03	1.02	1.02	1.02	1.03	1.04

Figure A288. The simulation detailed results of the house.

Case 97. A House Built in 1745

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone construction pointed externally.	2.109	Increase 22.4 cm Insulation
	Flat -	-
	Pitched 2.951	Increase 32 cm Insulation
Floors are of suspended timber construction.	1.875	Increase 32.1 cm Insulation
Internal Walls are of lath and plaster, plasterboard and also plastered on the hard.	1.911	
Windows are of timber framed sash and case pattern.		

* As a basis for a theory of possibility

Description

The property comprises a substantial two storey attic and basement detached villa.

On ground floor: entrance porch and hallway, drawing room, lounge, dining room, kitchen/breakfast room, rear hall, WC apartment and conservatory with WC apartment off.

On first floor: landing, bedroom/study, master bedroom with en-suite dressing room and en-suite bathroom, one bedroom and shower room.

Weather Sunny and overcast.

Heating and hot water

Central heating to the main house is supplied from a gas fired Potterton Kingfisher boiler which is housed within an outbuilding.

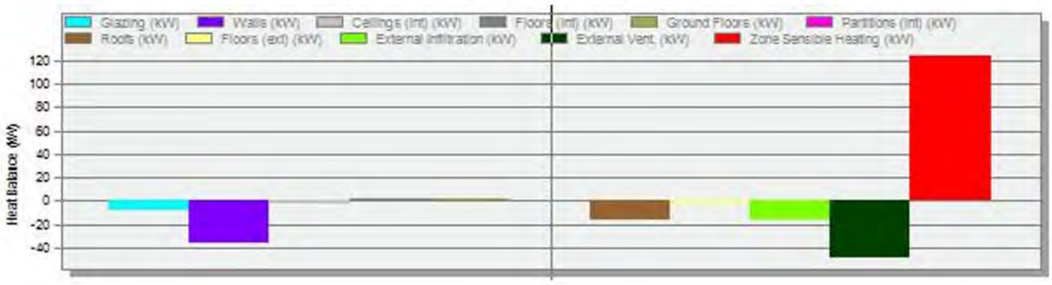
The boiler serves radiators throughout and also supplies a hot water source. There are hot water tanks in the first floor landing

Gross internal floor area(m²) 576 m²

Address

INVERESK
MUSSELBURGH EH21 7TD

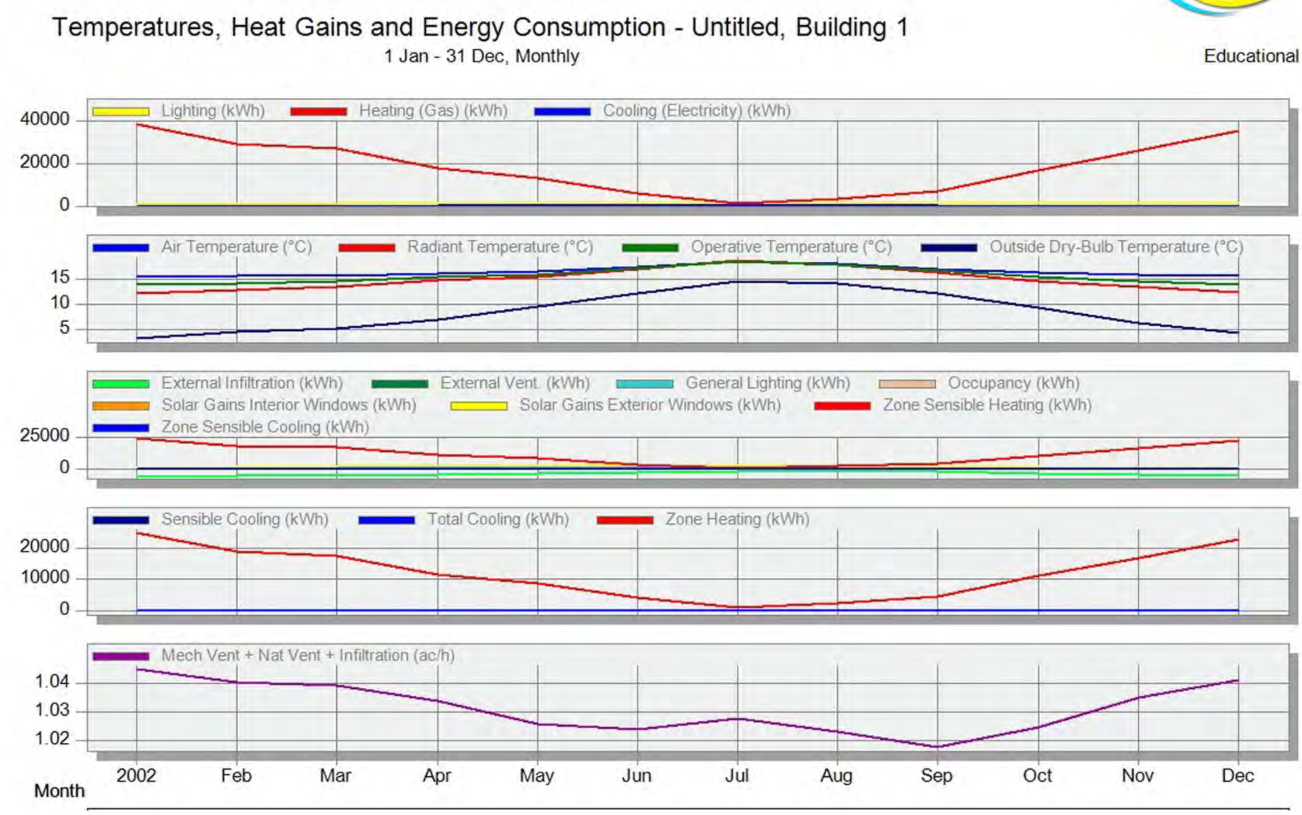
Figure A89. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.23
Operative Temperature (°C)	14.62
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-7.49
Walls (kW)	-35.64
Ceilings (int) (kW)	-2.81
Floors (int) (kW)	2.44
Ground Floors (kW)	2.51
Partitions (int) (kW)	-0.04
Roofs (kW)	-16.38
Floors (ext) (kW)	-2.01
External Infiltration (kW)	-16.38
External Vent. (kW)	-49.15
Zone Sensible Heating (kW)	124.66

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (k...	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 155.840 (kW)				
Lower Ground Floor Total Design Heating Capacity = 42.020 (kW)				
Living Room	15.73	6.06	**7.58**	187.2269
Landing	15.96	2.61	**3.26**	200.1794
Corridor	16.81	2.41	**3.02**	168.7402
Bed Room 1	15.23	7.00	**8.75**	235.9575
Bed Room	16.55	1.66	**2.08**	173.1460
Kitchen DiningRoom	15.24	5.96	**7.44**	224.2467
Service 1	14.44	1.20	**1.50**	858.6430
Service	13.29	2.29	**2.86**	700.9634
Boiler Room	13.59	1.39	**1.74**	1119.2561
Coal Shed	13.06	3.03	**3.79**	578.9572
Dove Coop Total Design Heating Capacity = 6.170 (kW)				
Zone 1	13.02	4.93	**6.17**	433.3446
Ground Floor Total Design Heating Capacity = 48.440 (kW)				
Orangery	12.38	4.55	**5.68**	432.2695
Family Room	15.51	6.80	**8.50**	202.4270
Hall	16.35	4.14	**5.17**	177.4878
Sitting Room	13.97	8.99	**11.24**	273.9090
Dining Room	14.87	6.58	**8.23**	249.0311
Kitchen BreakfastRo...	15.84	2.98	**3.73**	210.2299
Service 1	12.92	2.48	**3.10**	534.8103
Vestibule	13.25	1.15	**1.44**	937.0509
Service	12.49	1.08	**1.35**	1391.2115
First Floor Total Design Heating Capacity = 36.180 (kW)				
Zone 1	14.80	28.94	**36.18**	228.9434

Figure A290. The heating design simulation and data of the house.



Lighting (kWh)	1106.99	1005.12	1120.58	1073.04	1106.99	1086.62	1106.99	1113.78	1079.83	1106.99	1079.83	1113.78
Heating (Gas) (kWh)	38287.17	29016.68	27166.69	17610.73	13345.56	6049.47	1449.97	3475.00	7058.40	16936.49	25995.19	35219.23
Cooling (Electricity) (kWh)	0.00	0.00	0.00	1.42	1.41	11.47	30.88	12.32	0.35	0.00	0.00	0.00
Air Temperature (°C)	15.61	15.71	15.87	16.27	16.59	17.44	18.60	18.06	17.09	16.31	15.89	15.65
Radiant Temperature (°C)	12.29	12.91	13.58	14.83	15.46	17.04	18.81	17.88	16.43	14.68	13.49	12.55
Operative Temperature (°C)	13.95	14.31	14.73	15.55	16.02	17.24	18.71	17.97	16.76	15.50	14.69	14.10
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-6122.16	-4992.03	-5322.00	-4428.04	-3405.75	-2354.98	-1856.24	-1785.51	-2285.20	-3360.72	-4662.11	-5631.82
External Vent. (kWh)	0.00	0.00	-3.13	-6.01	-4.31	-20.01	-49.53	-27.87	-3.04	0.00	0.00	0.00
General Lighting (kWh)	1106.99	1005.12	1120.58	1073.04	1106.99	1086.62	1106.99	1113.78	1079.83	1106.99	1079.83	1113.78
Occupancy (kWh)	347.44	319.82	362.66	337.20	345.91	345.54	328.61	341.57	344.33	347.42	346.00	355.22
Solar Gains Interior Windows (kWh)	0.17	0.28	0.47	0.55	0.54	0.50	0.54	0.48	0.39	0.27	0.20	0.12
Solar Gains Exterior Windows (kWh)	868.25	1451.75	2473.49	2977.76	3093.34	2975.87	3142.39	2682.09	2092.66	1390.17	1005.41	579.76
Zone Sensible Heating (kWh)	24814.15	18801.29	17599.25	11403.82	8640.79	3916.71	938.88	2250.62	4571.95	10970.33	16840.54	22823.86
Zone Sensible Cooling (kWh)	0.00	0.00	-0.01	-6.37	-6.30	-50.97	-128.84	-46.68	-1.58	-0.00	0.00	0.00
Sensible Cooling (kWh)	0.00	0.00	-0.01	-6.41	-6.35	-51.24	-129.36	-46.86	-1.60	-0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	-0.01	-6.41	-6.35	-51.60	-138.95	-55.42	-1.60	-0.00	0.00	0.00
Zone Heating (kWh)	24886.66	18860.84	17658.35	11446.97	8674.61	3932.15	942.48	2258.75	4587.96	11008.72	16896.88	22892.50
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.03	1.02	1.02	1.02	1.03	1.04

Figure A291. The simulation detailed results of the house.

Case 98. A House Built in 1725

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone construction externally rendered.	2.112	Increase 22.22 cm Insulation
	Flat -	-
	Pitched 2.962	Increase 33.25 cm Insulation
Floors are of solid masonry and suspended timber construction.	1.906	Increase 32.22 cm Insulation
Internal Walls are of plasterboard and also plastered on the hard.	1.928	
Windows are a mixture of the original single glazed sash and casement style units in timber frames and replacement double glazed.		

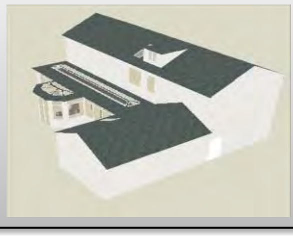
* As a basis for a theory of possibility

Description

The property is a three storey mid terraced house. The accommodation within comprises:

Ground floor - entrance hallway, living room, sitting room, kitchen/diner, utility room, bathroom with WC and wash hand basin and conservatory.

First floor - landing, two bedrooms, dressing room and shower room with WC, wash hand basin and bidet.



Weather Overcast.

Heating and hot water

The property has the benefit of a gas fired central heating system provided by means of a Worcester Greenstar 42 CDI condensing combination boiler to panelled radiators. This provides domestic hot water to the property on demand.

Gross internal floor area(m²) 190 m²

Address

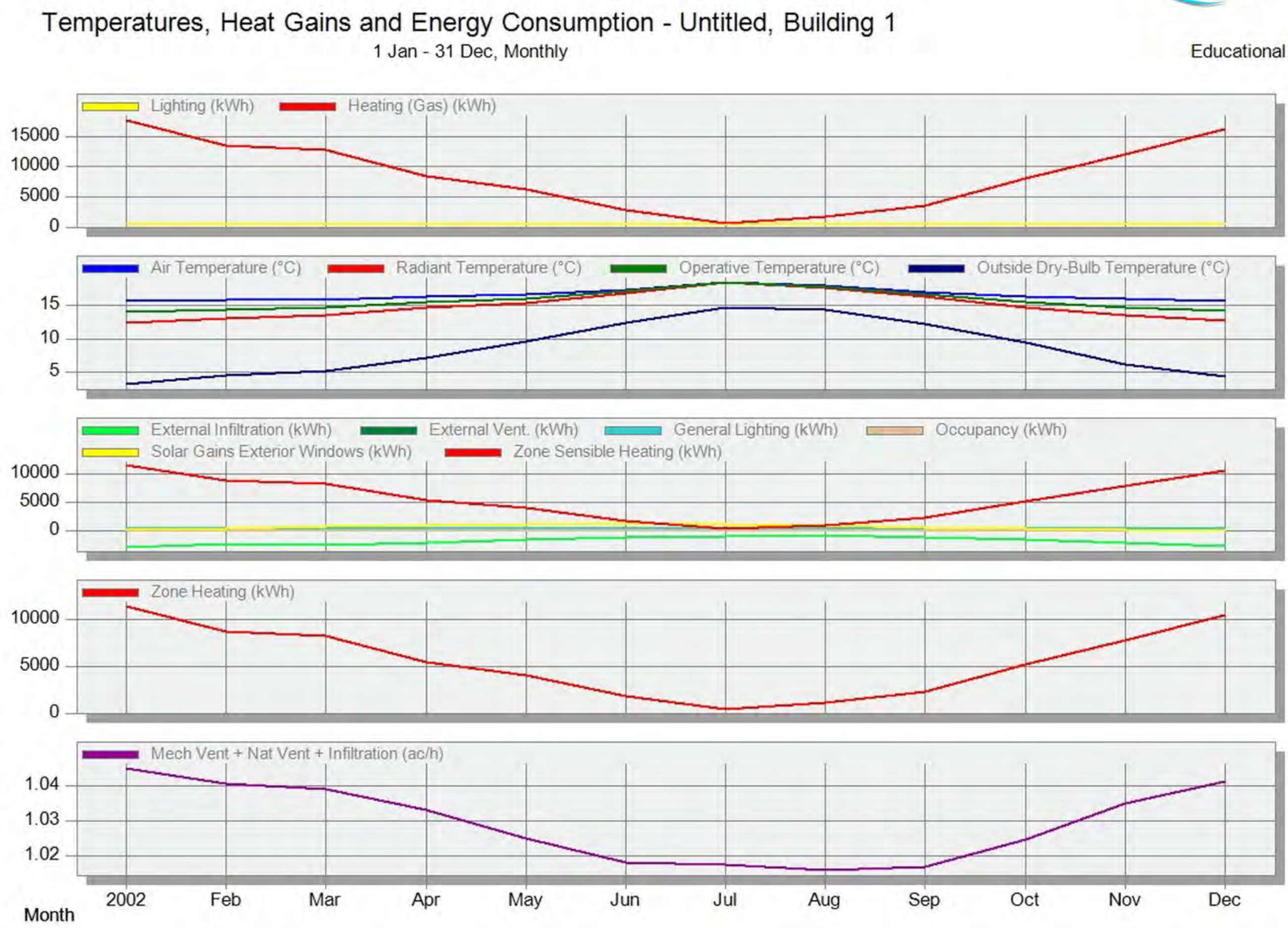
EARLSTON TD4 6BU

Figure A292. The Software visualization of the house.

Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.47
Operative Temperature (°C)	14.74
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-2.79
Walls (kW)	-16.05
Ceilings (int) (kW)	-2.53
Floors (int) (kW)	1.26
Ground Floors (kW)	1.77
Partitions (int) (kW)	0.00
Roofs (kW)	-8.75
Floors (ext) (kW)	-0.41
External Infiltration (kW)	-7.23
External Vent. (kW)	-21.69
Zone Sensible Heating (kW)	56.24

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 70.280 (kW)				
Ground Floor Total Design Heating Capacity = 37.000 (kW)				
Hall	17.09	2.68	**3.35**	171.0057
Lounge	15.42	4.39	**5.48**	238.4044
Vestibule	15.64	1.47	**1.84**	290.2947
Dining Room	16.37	4.10	**5.12**	193.8783
Service	15.16	2.59	**3.23**	294.2343
Kitchen	15.12	4.79	**5.99**	247.0047
Conservatory	14.37	7.54	**9.43**	306.3554
Utility	14.12	2.05	**2.56**	472.4817
First Floor Total Design Heating Capacity = 20.280 (kW)				
Corridor	15.90	2.19	**2.74**	212.6578
Bed Room	14.39	4.70	**5.88**	281.8331
Dressing Room	15.20	2.28	**2.85**	291.7779
Bed Room	14.44	4.83	**6.03**	278.2408
Service	15.86	2.22	**2.78**	215.1875
Roof 1 Total Design Heating Capacity = 12.540 (kW)				
Bed Room	12.99	3.00	**3.75**	157.8660
Bed Room	13.00	2.91	**3.63**	159.0683
Corridor Hall	13.53	4.13	**5.16**	127.0589

Figure A293. The heating design simulation and data of the house.



Lighting (kWh)	508.81	461.99	515.05	493.20	508.81	499.45	508.81	511.93	496.33	508.81	496.33	511.93
Heating (Gas) (kWh)	17586.29	13422.80	12698.18	8334.75	6193.27	2736.72	696.93	1671.11	3503.45	8011.80	12029.80	16160.61
Air Temperature (°C)	15.64	15.75	15.90	16.27	16.57	17.35	18.38	17.92	17.03	16.34	15.93	15.70
Radiant Temperature (°C)	12.42	13.00	13.58	14.73	15.40	16.88	18.40	17.62	16.25	14.69	13.57	12.68
Operative Temperature (°C)	14.03	14.38	14.74	15.50	15.98	17.11	18.39	17.77	16.64	15.52	14.75	14.19
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2714.34	-2218.17	-2364.68	-1967.27	-1516.00	-1036.78	-779.18	-766.95	-1005.72	-1501.27	-2076.35	-2500.95
External Vent. (kWh)	0.00	0.00	0.00	0.00	0.00	-0.50	-5.42	-3.57	0.00	0.00	0.00	0.00
General Lighting (kWh)	508.81	461.99	515.05	493.20	508.81	499.45	508.81	511.93	496.33	508.81	496.33	511.93
Occupancy (kWh)	159.69	147.01	166.83	155.34	159.48	159.83	152.67	158.03	158.60	159.69	159.04	163.27
Solar Gains Exterior Windows (kWh)	263.06	475.11	859.80	1091.28	1208.67	1213.62	1214.65	1010.30	736.01	471.91	304.90	176.65
Zone Sensible Heating (kWh)	11399.18	8699.06	8228.52	5399.61	4011.94	1772.64	451.28	1082.67	2270.28	5191.82	7795.40	10474.48
Zone Heating (kWh)	11431.09	8724.82	8253.82	5417.59	4025.62	1778.87	453.00	1086.22	2277.24	5207.67	7819.37	10504.40
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.03	1.02	1.02	1.02	1.02	1.02	1.04	1.04

Figure A294. The simulation detailed results of the house.

Case 99. A House Built in 1710

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone construction.	2.119	Increase 22.78 cm Insulation
	Flat 2.319	Increase 32.5 cm Insulation
	Pitched 2.996	Increase 33 cm Insulation
Floors are of solid masonry and suspended timber construction.	1.952	Increase 32.2 cm Insulation
Internal Walls are of lath and plaster and solid construction.	1.940	
Windows are of traditional timber frames single glazed double hung sash and casement design.		

* As a basis for a theory of possibility

Description

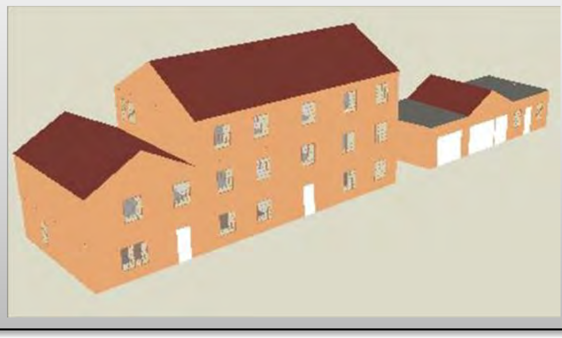
The property comprise substantial detached house.

Ground Floor –reception Hall, morning Room, dining Room, Kitchen/Diner, Utility Room, Bathroom with WC and Wash Hand Basin and Conservatory First Floor –Drawing room, principal Bedrooms and Shower Room with WC, Wash Hand Basin and Bidet.

Weather Dry.

Heating and hot water

The property has the benefit of a gas fired central heating system with two Worcester Greenstar boiler housed in the utility room. Hot water is supplied by the AGA and supplemented by the central heating boilers.

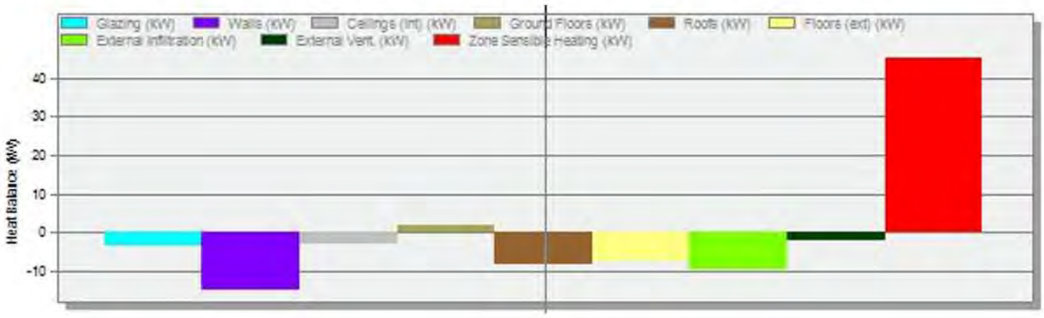


Gross internal floor area(m²) 521 m^2

Address

INVERESK EAST LOTHIAN
EH21 7TD

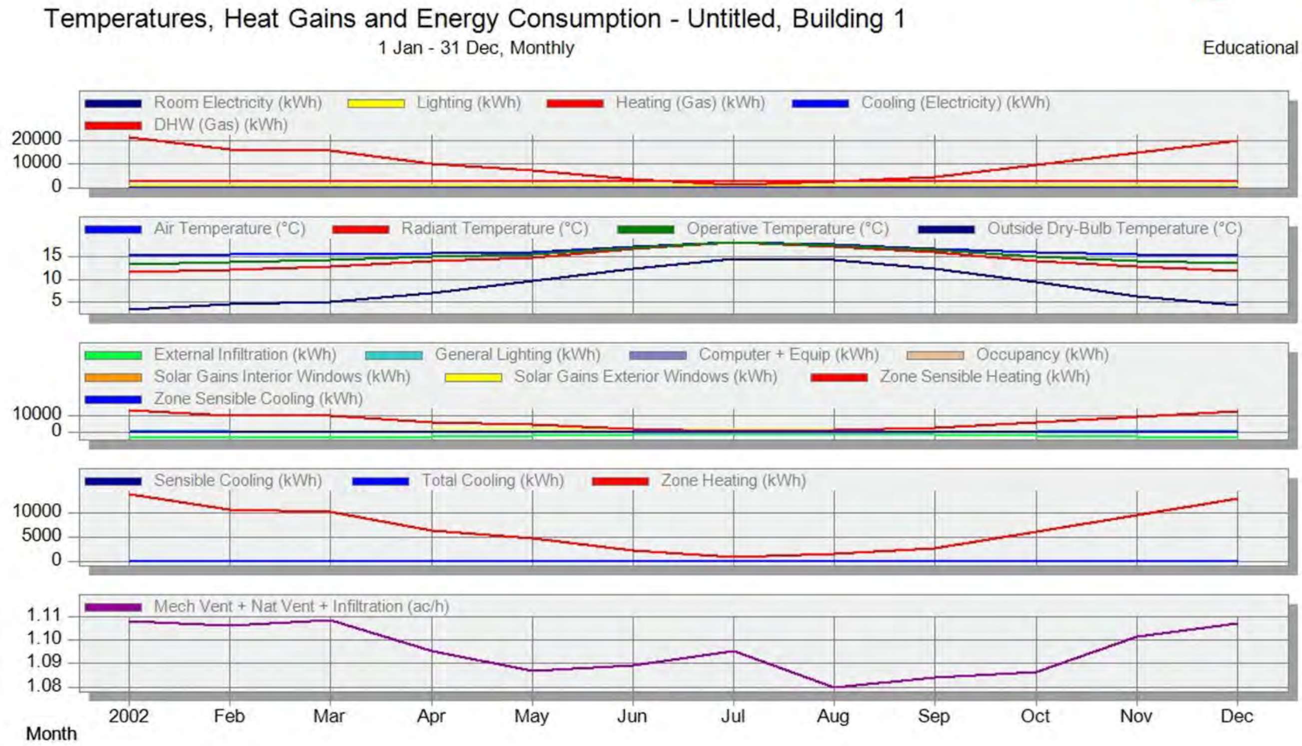
Figure A295. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	10.36
Operative Temperature (°C)	14.18
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-3.21
Walls (kW)	-14.67
Ceilings (int) (kW)	-2.80
Ground Floors (kW)	2.10
Roofs (kW)	-8.19
Floors (ext) (kW)	-7.16
External Infiltration (kW)	-9.32
External Vent. (kW)	-1.83
Zone Sensible Heating (kW)	44.97

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 56.190 (kW)				
Ground Floor Total Design Heating Capacity = 28.340 (kW)				
Hall	15.15	4.06	**5.08**	110.3939
Morning Room	14.19	5.47	**6.84**	138.6170
Service	14.26	1.41	**1.76**	233.9073
Family Room	15.47	2.34	**2.92**	107.0047
Dining Room	15.15	2.42	**3.03**	120.6827
Laundry Room	15.29	1.38	**1.72**	133.5938
Utility Room	14.39	1.80	**2.24**	180.0394
Kitchen	14.64	3.80	**4.75**	129.3512
Second Floor Total Design Heating Capacity = 27.850 (kW)				
Sitting Room	13.37	3.46	**4.33**	174.7605
Service	12.61	2.12	**2.65**	289.9345
Landing Hall	14.00	2.10	**2.62**	164.3978
Bed Room	13.07	3.62	**4.52**	190.5142
Bed Room	13.05	4.26	**5.32**	178.7932
Bed Room	13.83	2.52	**3.15**	163.9640
Bed Room	12.99	4.21	**5.26**	182.4938
Roof 3 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-2.61	0.00	**0.00**	0.0000

Figure A296. The heating design simulation and data of the house.



Room Electricity (kWh)	178.45	165.30	189.09	174.06	178.45	184.71	178.45	183.77	179.38	178.45	179.38	183.77
Lighting (kWh)	547.67	508.94	584.54	534.76	547.67	571.64	547.67	566.11	553.20	547.67	553.20	566.11
Heating (Gas) (kWh)	21436.84	16294.91	15674.48	9977.80	7436.85	3676.87	1354.32	2397.17	4341.42	9440.75	14740.01	19742.53
Cooling (Electricity) (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	2.87	0.00	0.00	0.00	0.00	0.00
DHW (Gas) (kWh)	2584.53	2449.25	2881.19	2539.43	2584.53	2836.10	2584.53	2732.86	2687.77	2584.53	2687.77	2732.86
Air Temperature (°C)	15.32	15.44	15.64	15.89	16.13	17.25	18.33	17.76	16.89	15.94	15.59	15.43
Radiant Temperature (°C)	11.58	12.27	12.93	14.19	14.80	16.66	18.27	17.32	16.02	14.10	12.83	11.92
Operative Temperature (°C)	13.45	13.86	14.28	15.04	15.47	16.96	18.30	17.54	16.45	15.02	14.21	13.68
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.19	7.12	9.63	12.36	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-3394.89	-2765.30	-2957.02	-2412.66	-1813.31	-1322.01	-1034.80	-957.99	-1242.69	-1793.13	-2558.82	-3133.81
General Lighting (kWh)	547.67	508.94	584.54	534.76	547.67	571.64	547.67	566.11	553.20	547.67	553.20	566.11
Computer + Equip (kWh)	178.45	165.30	189.09	174.06	178.45	184.71	178.45	183.77	179.38	178.45	179.38	183.77
Occupancy (kWh)	132.09	125.18	147.23	129.61	131.99	142.70	127.49	135.15	136.92	132.09	137.37	139.67
Solar Gains Interior Windows (kWh)	0.12	0.23	0.42	0.58	0.64	0.65	0.65	0.54	0.38	0.23	0.14	0.08
Solar Gains Exterior Windows (kWh)	312.34	573.32	1019.15	1347.51	1469.12	1483.05	1526.84	1242.32	899.21	546.72	370.98	213.05
Zone Sensible Heating (kWh)	13635.76	10329.13	9905.82	6277.68	4677.13	2298.64	841.99	1497.52	2710.23	5954.68	9335.86	12533.58
Zone Sensible Cooling (kWh)	0.00	0.00	-1.24	-3.62	-3.72	-20.50	-43.36	-19.12	-5.99	-0.05	-0.03	0.00
Sensible Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-5.44	0.00	0.00	0.00	0.00	0.00
Total Cooling (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	-7.19	0.00	0.00	0.00	0.00	0.00
Zone Heating (kWh)	13933.94	10591.69	10188.42	6485.57	4833.95	2389.97	880.30	1558.16	2821.92	6136.49	9581.01	12832.64
Mech Vent + Nat Vent + Infiltration (ac/h)	1.11	1.11	1.11	1.10	1.09	1.09	1.10	1.08	1.08	1.09	1.10	1.11

Figure A297. The simulation detailed results of the house.

Case 100. A House Built in 1540

Material	U-Value W/m²K	How to reach Zero Carbon home (theoretically*)
Main Walls are of traditional solid stone construction.	2.375	Increase 23.5 cm Insulation
	Flat -	-
	Pitched 3.153	Increase 33 cm Insulation
Floors are of solid construction and suspended timber construction.	2.238	Increase 32.4 cm Insulation
Internal Walls have a plasterboard finish or are of exposed stonework.	2.216	
Windows, with the exception of two small single glazed windows, the property is double glazed.		

* As a basis for a theory of possibility

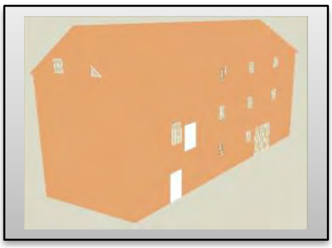
Description

The subjects form a detached house over three storeys.

The accommodation within comprises: Ground floor: hall, rear hall, kitchen / dining room and utility room.

First floor: upper hall, sitting room, lounge area and WC apartment.

Second floor: Landing, four bedrooms, en-suite bathroom.



Weather Dry.

Heating and hot water

The property has full oil fired central heating. A Rayburn within the kitchen serves panel radiators throughout the property and, in conjunction with an immersion system, provides hot water. A lagged hot water cylinder is located within a cupboard off the sitting room.

Gross internal floor area(m²) 240 m^2

Address

EAST LOTHIAN EH42 1XS

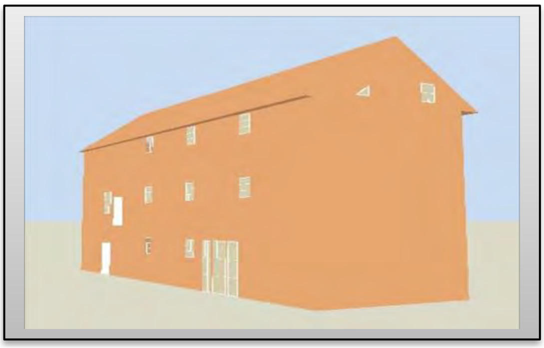
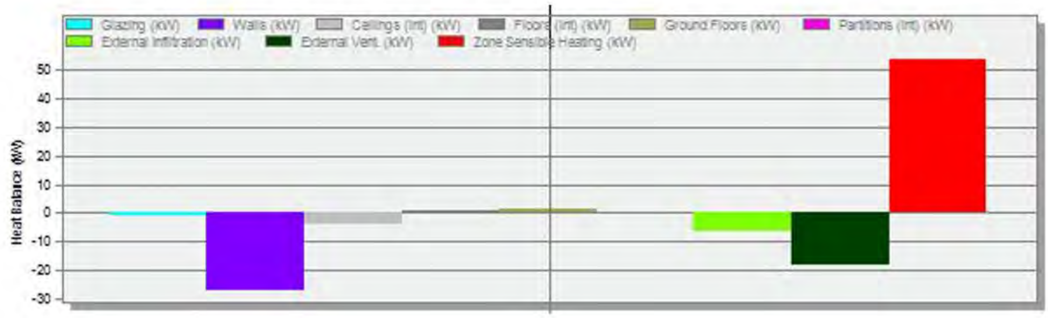


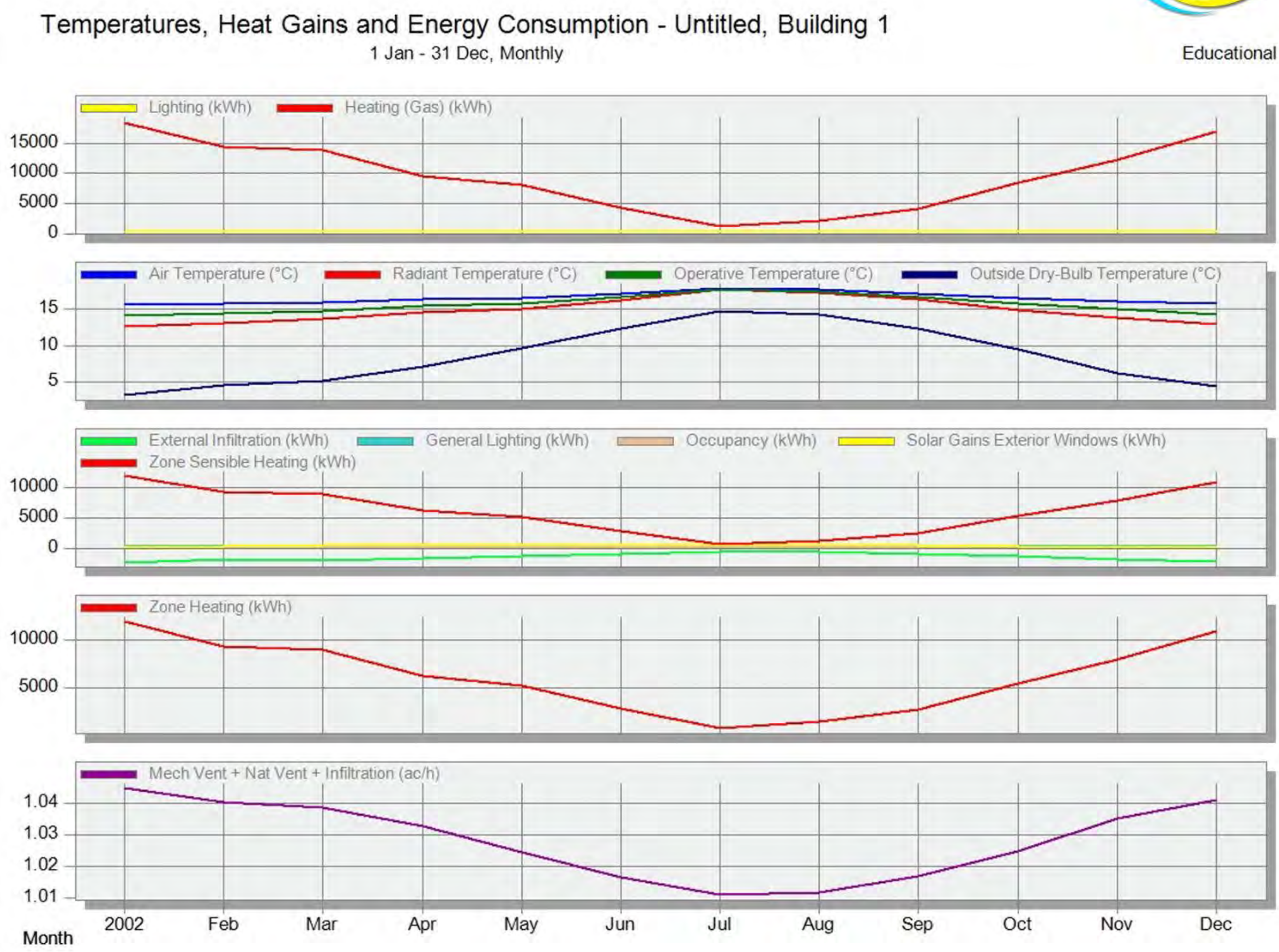
Figure A298. The Software visualization of the house.



Air Temperature (°C)	18.00
Radiant Temperature (°C)	11.80
Operative Temperature (°C)	14.90
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-0.98
Walls (kW)	-26.83
Ceilings (int) (kW)	-3.96
Floors (int) (kW)	0.77
Ground Floors (kW)	1.69
Partitions (int) (kW)	0.01
External Infiltration (kW)	-6.04
External Vent. (kW)	-18.11
Zone Sensible Heating (kW)	53.39

Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Design Capacity (kW)	Design Capacity (W/m2)
Building 1 Total Design Heating Capacity = 66.730 (kW)				
Ground Floor Total Design Heating Capacity = 22.050 (kW)				
Inner Hall	15.95	3.74	**4.67**	303.8647
Kitchen DiningRoom	14.89	8.65	**10.81**	279.5591
Landing	14.67	1.64	**2.05**	38534.6936
Utility	15.30	3.25	**4.06**	294.5980
Store	15.94	0.36	**0.46**	568.4076
Second Floor Total Design Heating Capacity = 22.050 (kW)				
Double BedRoom 1	14.74	3.41	**4.26**	420.9816
Hall	15.21	3.91	**4.89**	305.6232
Service 1	15.93	1.27	**1.59**	253.7947
Double BedRoom	15.87	1.30	**1.62**	258.9874
Wardrobe	15.31	0.85	**1.07**	477.3787
Service	14.49	1.02	**1.27**	884.5963
Bed Room	14.75	2.64	**3.30**	367.4018
Master BedRoom	14.85	3.24	**4.05**	308.9047
First Floor Total Design Heating Capacity = 22.630 (kW)				
Hall	14.83	3.09	**3.86**	328.5967
Store	15.10	0.41	**0.51**	1169.9542
Living Room	13.91	7.86	**9.83**	310.6710
Service	16.20	0.69	**0.87**	205.3668
Landing	14.00	1.68	**2.10**	92721.9116
FamilyRoom Library	14.40	4.37	**5.46**	273.9742
Roof 1 Total Design Heating Capacity = 0.000 (kW)				
Zone 1	-2.13	0.00	**0.00**	0.0000

Figure A299. The heating design simulation and data of the house.



Lighting (kWh)	327.80	297.63	331.82	317.74	327.80	321.77	327.80	329.81	319.75	327.80	319.75	329.81
Heating (Gas) (kWh)	18434.89	14363.98	13780.24	9572.15	8010.55	4317.04	1103.70	2044.37	3980.73	8427.73	12245.80	16843.95
Air Temperature (°C)	15.61	15.72	15.86	16.24	16.49	16.99	17.74	17.61	17.07	16.46	16.00	15.67
Radiant Temperature (°C)	12.59	13.09	13.59	14.59	15.01	16.10	17.60	17.23	16.24	14.90	13.85	12.87
Operative Temperature (°C)	14.10	14.41	14.73	15.41	15.75	16.54	17.67	17.42	16.66	15.68	14.93	14.27
Outside Dry-Bulb Temperature (°C)	3.31	4.60	5.18	7.12	9.63	12.35	14.61	14.29	12.31	9.51	6.27	4.38
External Infiltration (kWh)	-2253.34	-1838.74	-1958.48	-1627.63	-1240.90	-811.96	-565.60	-595.73	-838.57	-1257.09	-1732.30	-2075.25
General Lighting (kWh)	327.80	297.63	331.82	317.74	327.80	321.77	327.80	329.81	319.75	327.80	319.75	329.81
Occupancy (kWh)	102.88	94.71	107.49	100.16	102.88	104.76	102.08	104.24	102.45	102.88	102.46	105.19
Solar Gains Exterior Windows (kWh)	233.12	354.75	553.87	616.81	591.68	536.80	588.70	534.31	454.54	327.31	267.30	155.68
Zone Sensible Heating (kWh)	11953.91	9313.34	8934.24	6205.75	5194.52	2800.18	715.78	1326.04	2582.16	5465.40	7939.49	10921.68
Zone Heating (kWh)	11982.68	9336.59	8957.15	6221.90	5206.86	2806.08	717.40	1328.84	2587.48	5478.03	7959.77	10948.57
Mech Vent + Nat Vent + Infiltration (ac/h)	1.04	1.04	1.04	1.03	1.02	1.02	1.01	1.01	1.02	1.02	1.04	1.04

Figure A300. The simulation detailed results of the house.

Appendix B. Analyzing the required information to work by software

B.1 Energy Efficiency/Policy package in Spain and UK.

Table B1. The package of energy efficiency and policy in Spain and the UK.

Comprehensiveness of policy package	**Spain**	**The United Kingdom**
Long-term EE Strategy and targets.	Action plan until 2020 established.	• Differentiated targets for 2020; • Action plans for UK, Scotland, Northern Ireland, and Wales.
Involvement of non-governmental and market actors, and sub-national authorities.	The Autonomous Communities are involved.	Energy companies, Universities, local authorities and product Suppliers are included.
Climate Protection and Energy agencies	• A national agency (IDAE) exist. • Regional organizations contribute to the ESD target.	Energy companies exist at national, regional and local grades.
EE mechanisms for overall financing and coordination.	IDAE Strategic Grants program.	Financing is supplied through the national budget, the energy saving trust, the Green Deal and CERT.
Favourable framework conditions For energy services.	• The Energy Services companies supply funds. • Excellent documentation of investments.	Energy services are advanced through CERT.
Horizontal measures.	A national development plan and research as a planning instrument.	Voluntary agreements in transport, public, and house sector.
Reporting, monitoring, and verification.	Top-down and bottom-up schemes are used.	An advanced MRV programme has been applied; Savings differentiate among 2010/2016/2020.
Minimum Energy Performance Standards (MEPS).	• MEPS exist since the late 1970s. They are implemented and adjusted in new laws after probation. • Always not clear how compliance is ensured.	MEPS are planned and have been set to be enforced in future.
Other regulations.	• Regulations on the new electronically device. • Construction inspections are organized to be part of the future law.	No other regulations mentioned.
Economic incentives.	Economic incentives are available for new and old houses.	Several funding schemes have been managed; also support is available for low-income households.

Energy performance certificates (EPCs).	EPCs are established, but benefits and sanctions are not explicitly mentioned in the NEEAP.	A scheme for energy performance certificates has been managed.
Financing Instruments.	Financing aid available for different aims. Incentives through capital grants.	The Green Deal is expected to develop into operational in 2012 and to finance calculations through savings on the bills of energy.
Energy audits and advises.	Audits and advice are only slightly included as measures.	Indirectly will be promoted through the Green Deal.
Information programs.	Media campaigns on radio and TV to data about energy efficiency for households and end consumers.	Several information programs are available.
Demonstration projects.	Not mentioned.	Not mentioned in NEEAP.
Training and education or stakeholders.	Information, training and consciousness-raising plan exist.	Not mentioned in NEEAP.
Adequacy of the policy package.	The actual policy package is the first stage but needs to be enhanced to implement a change in the constructions energy-saving policies.	• The policy package considers different actors. • It comprises financing instruments and data tools. • Demonstration projects, as well as training and education measures, are not mentioned.

B 2. Energy Efficiency in Zaragoza and Edinburgh.

B 2.1 Zaragoza

In the case of Zaragoza (Spain), two primary actions have been the outcome of the application of the determined steps and are being developed in the city of Zaragoza within the year 2000:

• Build of over 2,000 new houses named “Goya Residence Park” with a high energy efficiency level based on an explicitly developed urban plan.

• Revision of the existing General Development Plan. There is a scope for the application of technical and financial aspects of MES-RES (Municipal measures to promote energy savings), involving the Public Planning Department of the Municipality.

These activities were planned for a more extensive time period (between 1996 and 2000) to face the energy efficiency features within an integrated and multidisciplinary planning path and are addressed to aspects as adequate street level, respect of minimum distances between buildings, percentages of glazing surface regard to the orientation of the facade, comprehensive implementation of passive cooling techniques and recommendations about minimum insulation levels. Financial and fiscal measures have also been a crucial point taken into account, complementing a practical application of all the plans, these were oriented to promote discounts on the real estate tax and reductions in the amount due to tax on construction work.

Depending on the type of buildings and technologies/techniques adopted, energy savings were estimated at up to 60%

The second phase of Residential Goya Park has incorporated energy saving principles from MES-RES as compulsory, but it has only contained the broader sustainable urban development criteria as voluntary suggestions. The reasons for the limitation include the impossibility of assuring reasonable extra costs for the implementation of specific technologies, the will to maintain coherency between phases 1 and 2, and the shortage of specialized professionals in techniques of environmental protection and recycling. Regarding the applications of long-term MES-RES criteria, it being implemented into the strategic urban plans, as the General Urban Plan of Zaragoza, and there are still further challenges to be overcome when entering the whole of these measures in the mentioned plan which is in the course of enhancement.

The municipality in Spain was stimulated to take initiatives for plans at two steps of the planning process that includes Local Development Plans and General or Structural Plans, at both levels, compulsory and voluntary measures, with or without financial incentives, can be introduced and MES-RES has tried to systematize them into a standard process scheme.

Technical measures and intervention should contain, the insulation grades and glazing standards, distribution of streets, typology of land plots, orientation, and minimum distances between maximum heights of houses, guaranteed minimum performance of solar thermal installations, the minimum area of south-oriented passive solar tools, incorporation of standard solar tools for the creation of Photovoltaic (PV) and Domestic Hot Water (DHW) panels for the management of electricity and the inclusion of environmental aspects in construction projects and urban planning. In contribute with financial measures, there are two principal aspects to be stated, the incorporation of this kind of incentive needs specific work from the interested municipality and local economic incentives, subsidies, and rebates provide an efficient support mechanism for achieving more widespread adoption of energy saving practice in building construction. They do not necessarily represent a significant cost of revenue to the municipality and implemented without budget provision, and thus target the primary aim of building developers, which is the extra cost using non-standard building solutions.

The initiative of the project was structured as a collaborative action between experienced consultants, architects, engineers and public administrations to explore the availability that the latter have in applying energy efficiency criteria to their plans within land planning and house development market regulation. The proposed work approach, based on information gathering and appropriate schemes development has been carried out by the project coordinator to develop a methodological framework describing the urban land development process.

This framework aims to define terms of reference, critical areas for investigation and, in this way, to enhance comparability throughout the project. Tasks set up were the following points:

1. Project administration and dissemination.

2. Description of the urban land development process.

3. Identification, analysis, and development of technical/architectural essential points.

4. Application in the towns of Zaragoza, Bologna, and Leicester.

5. Identification, analysis, and development of commercial/financial essential subjects.

6. Conclusions and recommendations.

7. Economic analysis of scenarios.

B 2.2 Edinburgh

The new and old towns of Edinburgh World Heritage Site boasts an outstanding different of dwellings with various materials, architectural styles, and unique characters. These traditional buildings already have specific benefits regarding environmental sustainability, including their longevity, locally-sourced materials, natural ventilation, and thermal mass. Contrary to widespread assumptions, it is possible to diminish energy inefficiency, even in traditional houses, without compromising the authenticity.

Adapting the existing houses is usually more energy efficient than building entirely new ones. It is therefore critical to concentrate our efforts on changing existing buildings, mainly because 80% of the buildings in which the people will be living in by 2050 have been constructed. When considering energy enhancements, it should be remembered that historic houses contain a great deal of embodied energy. Historical elements should be retained wherever possible, and new fabrics should be assessed not only regarding the compatibility with the home and U-value, but also for the whole life energy cost. Despite providing guidance on the application of energy efficiency improvements to historical and traditional houses, not all of the enhancement measures outlined will be suitable for all situations. Careful consideration is needed when applying energy efficiency measures to prevent long-term deterioration of the house's fabric or loss of the dwelling's significance.

Similar to every other place, Edinburgh depends on the consumption of energy for daily functions such as economic production, heating, lighting, communications, health care, education, and cleaning. To the extent that the energy consumption depends on the burning of fossil fuels, it not only depletes the limited properties of these resources but releases carbon into the atmosphere in the form of carbon dioxide. As the principal greenhouse gas, this is a significant contributor to global warming and complex processes of climate change. For future generations, it is essential that Edinburgh as a city use energy as efficiently and sparingly as possible, and relies as far as possible on renewable energy resources.

Energy consumption significantly is affected by built form, urban structure; land uses, economic characteristics, local climatic conditions, travel patterns and, as well as cultural factors. Therefore, it is an essential subject to the effect on carbon emissions through domestic policies and local energy consumption that shape the fabric of the city. Many initiatives of nature are necessarily long-term progress: they are constrained by the extent to that land and houses become available for enhancement or redevelopment, to enable to incorporate the latest best action for energy saving. Although, it is important to start putting these structural measures into action if only to ensure that present wasteful plans are not exacerbated.

Consumption in the building sector has been increasing, mirroring the raising the number of households and growing usage of a wide range of electrical appliances. Per capita consumption is higher than in England due to the reduced winter daylight and the colder climate. Also, house energy grades tend to be lower in Scotland. The other point is that a high concentration of flatted buildings especially in cities such as Edinburgh causes a positive contribution to energy efficiency. Dwelling energy consumption in Edinburgh is well below national grades when calculated per household. Although, it is affected by the city's household structure, with its preponderance of smaller owners. The energy consumption of Edinburgh is close to the British average. On the other hand, there are significant differences between the Scottish cities, with Edinburgh consuming 10% more than Glasgow but 30% less than Dundee and 9% (per person) less than Aberdeen.

The historic nature of much of the housing stock is an essential consideration affecting residential energy efficiency in Edinburgh. Many historic houses are sound in environmentally that they were constructed to last. Also, they tend to incorporate fewer toxic elements and to employ more locally sourced materials, compared with contemporary houses. Preservation rather than improvement should be an active presumption from an energy saving view. With financial products from the Edinburgh World Heritage Trust, Changeworks has piloted a goal, Energy Heritage that it hopes will perform in other historical zones throughout the UK. The effectiveness of developments is being calculated with the use of thermal technology, and by monitoring energy consumption and fuel bills carefully.

The energy efficiency of dwelling is calculated on a scale of 0 to 10 in the National Home Energy Rating (NHER), with ten being the most efficient. Researchers carried out in 2003 determined that the average NHER in Edinburgh be 6.2 for Council housing stock, excluding multi-story apartments, regeneration zones, and New Housing Partnership parts. The average NHER for the owner of occupied buildings in Edinburgh is around five that based on the Scottish House Condition Survey compares favorably with the Scottish average of 4.4. The Edinburgh regulations for a Sustainable house that came into force in May 2007 seeking to enhance best actions in all aspects of the home energy budget, including construction methods, choice of materials, the incorporation of on-site renewable, energy-efficient design and services and decentralized technologies. It helps Edinburgh to play its part in decreasing carbon pollution and tackling climate change, developing levels of welfare and comfort, and as well as decreasing fuel bills.

B 3. Energy Efficiency in Almeria and Avila.

B 3.1 Almeria

Almeria is a city in Andalusia (Spain). It is the capital of the province of the same name, located in the southeast of Spain on the Mediterranean Sea. Almeria was devastated by an earthquake and rebuilding and recovery did not get underway until the 19th century. It has rebuilt its economy around vegetable expanse, with 100,000 acres of greenhouses, supplying much of Europe. With a precipitation of just 200 mm yearly also, with only 26 days of rainfall and is the only place in Europe with a real hot desert climate; it borders a warm semi-arid climate. Almeria is the only European city with this kind of environment and is one of the driest parts of both the Mediterranean coast and shores. Also, it experiences the warmest winters of any city on the European continent. The Solar Platform in Almeria (PSA) is a centre for the exploration of the solar energy, a dependency of the CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Technológicas), is the most extensive concentrating solar technology research, test centre in Europe and, development. PSA activities are integrated into the CIEMAT organization as an R&D division of the Department of Energy.

The Platform Solar de Almeria is one of the outlying centres of the CIEMAT which is Public Research Centre of the Government of Spain, considered by the European Commission as a European Large Scientific Installation also, the largest and most complete R+D centre in the World devoted to solar thermal concentrating systems. PSA is integrated into the CIEMAT institute as an R&D division of the Department of Energy. In addition, a Singular Science and Technology Infrastructures (ICTS) of Government of Spain. The right solar conditions, its several solar facilities, and the highly-skilled staff supply a unique infrastructure for R+D, education, demonstration, evaluation, and technology transfer regarding solar energy applications.

PSA is located in southeastern Spain, in the Tabernas Desert. It receives annual insolation of more than 1900 kWh/ (m^2.year), and the annual temperature is around 17 ºC averagely. PSA counts with over 30 years of background in operation, evaluation, and maintenance of solar thermal concentrating systems, the components and different types of commercial applications.

The following goals inspire its activities:

- Assist industry in determining solar thermal market opportunities.
- Promote North-South technological cooperation, especially in the Mediterranean Area.
- Strengthen cost-reducing technological innovations contributing to the increased market acceptance of solar thermal technologies.
- Reinforce cooperation between business and scientific institutions in the field of research, development, demonstration, and marketing of solar thermal technologies.
- Contribute to the enhancement of a competitive Spanish solar thermal export company.
- Promote the market introduction of solar thermal technologies and those derived from solar chemical processes.

- Contribute to the production of European energy resources and conservation of the environment and climate.
- Contribute to establishing a sustainable clean world energy supply.

Another company Sunergy Almeria able to provide and design bespoke solar & wind power systems for remote dwelling and commercial constructions across Almeria, Granada, and Murcia. Providing combined solar and wind turbine power solutions for remote houses in Andalusia for over 12 years. Electricity supply is an expensive business to the building which is not on the local power grid or in more rural situations, the company professionally supply and install a combination of solar panels and wind turbines to satisfy the dwelling power supplies.

B 3.2 Avila

Avila is a province of central-western Spain, in the southern part of the autonomous community of Castilla y León, Its capital is Avila. The primary objective of the Energy Agency of the Province of Avila (APEA) is to enhance the energy efficiency (RUE) and promote the use of renewable energy sources (RES). Energy Agency of the province of Avila was created in 2001 and located in Avila (Spain). The contribution of the agency is the development and enhancement of the county council competitiveness, improve the quality of citizen lives, environmental conservation, and improvement.

Atlas of the Applications of the Biomass and the Forest Residues in the Atlantic Space is the title of Potentialities Evaluation of Renewable Resources project. The priorities are:

- The use of forest residues for its energetic exploitation in identified zones.
- The promotion of exchanges of forestry and agricultural respectful practices with the environment.
- The development of renewable energies of the Atlantic area.
- The promotion of environmental technologies.

There are three sectors with the greatest energy consumption which belongs to the rural zone as well as the city of Avila with the highest consumption of energy. They are:

-Rural Tourism Housing. The area around 300 Rural Tourism Housing in the province of Ávila. This province is one of the Spanish regions with a significant number of houses of this type. Tourism is a high point of the economy of Ávila. It is expected the growth of this sector in the next years.

-The province of Avila is a rural zone that the domestic and agriculture parts are the primary energy customers. The area of the target of a reduction of energy consumption and implementation of renewable energies are town halls, public buildings and street lighting in most of the villages.

-National Police Academy: it is located in the city of Ávila, the National Police Academy is the most prominent Police Academy in Europe. With more than 5.000 people, it is a huge energy consumer where there is no RES system installed in the buildings.

The primary objective of the Action Plan for the region of Avila is the reduction of energy consumption and greenhouses gases towards sustainable steps using divulgation activities and formation about RES and saving and energy efficiency to address province of Avila towards the sustainability and the fulfillment of Kyoto Protocol.

The objectives of the action plan are:

- New investment possibilities in the municipalities because of the bill diminution.
- The development of rural zones with new activities and jobs that avoids the movement of the population.
- Competitiveness improvement of rural tourism companies.
- Energy use of native resources which allows a reduced in the fossil fuels dependence.
- An improvement in the energy situation in the area.

Proper management of the agricultural lands and the forests which diminish the propagation of plagues and fires and stop erosion. In 2008, with the contribution of the Morana Service Station, the number of service stations that sell biodiesel stood at eight. In the last two years, the outcome of biodiesel has been increased over 50% in the province of Avila. Still, this number of sale is meager compared to the total of fuel sold.

Photovoltaic solar energy is still promoted in the province of Avila. The agency from the area put in contact agencies of renewable energies with Avila towns which solar orchards able to be applied in the municipalities. Some Avila localities have found an alternative to maintain and attract the population. For example, already the council of Gotarrendura put into implementing a solar PV orchard with a nominal power of 1.4 MW. In December 2009 another farm with 2 MW was finalized and connected to the grid.

B 4. Energy Efficiency in Leeds and Pembrokeshire.

B 4.1 Leeds

Leeds City Council delivered major energy efficiency enhancements to 2,050 buildings and installed gas main connections to a further 570. Moreover, it protected 640 vulnerable buildings to boilers repaired/replaced or have new heating tools installed, and have supplied energy efficiency and fuel switching guidance and small-scale developments to further 1,500 vulnerable buildings. Also, it continued to work with over 45 community partners to supply winter warmth protect to tens of thousands of vulnerable houses. In addition, it completed the 1,200 house solar PV project and proceed White Rose Energy, an energy provider company for Yorkshire, operated in partnership with Robin Hood Energy.

Setting aims for future are challenging due to changes in the policy, priority that government has imposed on energy efficiency, and shortage of investment. The Leeds City Council are continuing the scheme for district heating for 2,200 council houses, and start connecting flats to the system in 2018, and target to attract 11,000 customers to White Rose Energy and continue to supply advice and small-scale enhancements to vulnerable buildings and trial projects which explore various funding mechanisms; for example, looking at potential for social prescription; piloting smart energy management and new tariff structures to decrease fuel bills; working with the University of Leeds on a revolving fund; and piloting ECO projects to maximise the energy company funds which can be brought to the city to decrease reliance on European funding and government.

Table B2. The action plan for energy efficiency in Leeds.

Action	2017-19 Commitments
Energy efficiency priorities and ambitions	The aims and strategies within Leeds have been upgraded to a longer-term view and recent advice: a) Leeds Climate Change program is 40% CO_2 diminishes from all parts of 2005-2020, 60% from 2005 - 2030 and finally 100% from 2005-2050. b) Affordable Warmth Strategy 2017: development of the average SAP rating of buildings in Leeds to band C by 2020, also to ensure that no buildings are below band E by 2030.
Green deal eco	The Leeds City Council intends to enhance a city region-wide approach to performance the forthcoming Eligibility policy initiative through the regulations of 2017/18 Energy Company Obligation, via the Better House Yorkshire scheme, the council of Leeds City Statement of Intent coordinates within the mentioned framework. The policy approach is stood on the following points. - Focus on ECO funding to protect council funded progress and Local Growth Fund. - Criteria are to be as simple and, streamlined, as possible - Engagement with partners, energy suppliers, and local members. - Eligibility through two ways; first, Geographical zones based on deprived communities; and next, Eligibility for funding because of individual circumstances.
Reducing energy costs	Leeds City Council continues to protect occupants decrease their energy costs by: a) White Rose Energy that will obtain 11,000 customers by the August 2018 and will continue to expand it. The primary target is to acquire customers from across the area. Part of the acquisition program is to bring regional, local authority and housing association partners onboard through a formal service level agreement. This will bring much better reciprocal opportunities for promotion that should equate to improved sign-ups. By the end of the 12 months, it begins to create funding for fuel poverty alleviation plans through the surplus. b) Warmth for Wellbeing continues to provide independent face to face guidance on assistance with fuel bills and switching energy suppliers.

B 4.2 Pembrokeshire

The Nest program is the Welsh Assembly Government's New Fuel Poverty Scheme, and British Gas is the delivery partner for this program. The program is designed to make private sector buildings healthier and warmer places to live. The program suggests residences a range of free home enhancements to help them heat the house more efficiently, warmer, and healthier without facing huge energy bills. The Nest program takes a whole building approach to identify what energy enhancement work would be most suitable, some examples contain:

- Boiler replacement.
- Solid wall insulation.

- Loft and cavity wall insulation.
- Draught proofing.

One of the first Wale solar villages launched in Pembrokeshire in 2003. It is expected the six timber houses at Pentre Solar, near Cardigan, they will save occupants hundreds of pounds in annual living costs thanks to their A++ energy ratings. They also have solar roof panels capable of developing 6000kWh/year. The Welsh Government granted the start-up £140,000 to support create its production base for the houses that have 11in (28cm) of insulation. With access to a shared electric car and low energy use, the company claimed occupants could avoid up to £2,000 a year in living costs.

Community Energy in Pembrokeshire is applying for a single wind turbine of up to 77m in height. A Swansea based consultancy, Seren Energy, are performance as agents and prepared the planning application and have carried out technical services for this proposal. The Managing Director of Seren Energy, Steve Hack, is a Director of Carmarthenshire Energy, a social enterprise protecting community renewable energy and tackling fuel poverty in Carmarthenshire.

Electricity generated from wind turbine power has the lowest carbon footprints compared with other kinds of electricity generation. Nearly all the emissions occur during the manufacturing and construction phases, arising from the production of steel for the tower, concrete for the foundations and epoxy/ fiberglass for the rotor blades. These account for 97% of the total lifecycle CO_2 emissions. This means onshore wind turbine power has a relatively small carbon footprint range of between 10 and 20g CO_2eq/kWh, considering not only emissions from the generation of electricity but those incurred during the construction, manufacture, and decommissioning phases. By comparing, averagely the emissions from power generation of fossil-fuelled in the UK was around 550gCO_2/kWh. As a conclusion, onshore wind turbine power can contribute to carbon diminish targets. The Department of Energy & Climate Change, in 2011, estimated that 6.4 million tonnes of CO_2 were avoided in the UK (more than the carbon footprint of a city the size of Leeds), where onshore wind turbine power displaces electricity generated from power generation of fossil-fuelled.

B 5. The energy simulation software tools.

Along with construction techniques and materials, energy simulation software tools for buildings have had developments over the years. There are several energy simulation programs with different levels of complexity and response to different variables. Among a complete simulation program are the DesignBuilder, Energy Plus, the ESP-r (Energy Simulation Software tool), IES-VE (Integrated Environmental Solutions - Virtual Environment) and TRNSYS. Being a complete software tool, these are also the most complex and therefore require higher expertise.

DesignBuilder calculations are based on the standards set out in the document BR 443 Conventions for U-value calculations which underpin house regulation energy conservation legislation and are also the base of different energy assessment methods. DesignBuilder is a thermal simulation program that allows the analysis of energy throughout the construction and the thermal load used by architects, engineers and researchers to model the energy use. The software program simulates models for heating, cooling, heating, ventilation, lighting, and other flows of energy.

Energy Plus is one of the famous energy simulation software program. Its development began in 1996, sponsored by the Department of Energy (DOE) from the United States of America. It has the capabilities and features of DOE-2 and BLAST, however, is an entirely new software program combines the heat balance of BLAST with a generic HVAC system. The Energy Plus aims to organize and develop software tools in modules that can efficiently work separately or together. It is essential to outline that Energy Plus does not exist a visual interface that allows the customer to concept the building. In this case third-party program, i.g., DesignBuilder need to be used.

The ESP-r (Energy Simulation program) is intended to support the building project about environmental performance and energy, accurately and realistically. A plan is a mathematical tool for a project manager coordinates the data, CAD applications, simulation, different tools for evaluating performance, report generators, and display. The ESP-r uses several complex equations to deal with all aspects at the same time (construction, geometry, distribution, operation, heat dissipation). The comparisons are integrated into successive time steps in response to the influences of the occupants and climate control systems. The geometry of the construction can be set in CAD programs or other similar software to allow the specification of the geometry of houses. The models created in this program can be exported to Energy Plus.

TRNSYS is a transient system simulation program with a modular structure that especially has designed to develop complex devices related to energy, outlining the problem in some smaller components. The components may range from a simple heat pump to a multi-zone of a construction complex. They are configured through the graphical customer interface known as TRNSYS Simulation Studio. In TRNSYS, the construction of the house can be achieved by the introduction of information on the dedicated visual interface, known for TRNBuild.

The program includes the possibility of adding HTML views through a program called TRNSED, that enable non-customer to view and do parametric studies of TRNSYS files, in a simplified representation of a web page.

The IES-VE (Integrated Environmental Solutions-Virtual Environment) software tool provides the design professionals with a variety of variables in simulation analysis of houses. The subject works on the geometric representation that shows the house. The program allows interaction with other energy simulation program. The simulation program incorporates a tool for dynamic thermal simulation of heat transfer processes of houses that are the ApacheSim. The simulation program tested using the IES ASHRAE 140 which qualified as a dynamic model in the CIBSE system of classification. The program provides an environment for the detailing of the construction systems, allowing their optimization is taking into account criteria such as energy and comfort. The dynamic tool ApacheSim able to be dynamically linked to the Macro FLO dynamic program for natural ventilation and HVAC Apache powerful software to perform analysis of air leaks and for analysis of shading and natural lighting. The results can be automatically exported.

As a comparison, each program of the mentioned energy simulation software has specific applications and characteristics, most of the programs fundamentally have the capability for HVAC system simulation, and the differences in the simulation results are within a small range. From the analyzed energy simulation program, TRNSYS is the most complete, but depending on the customer perspective and final purpose the DesignBuilder could be more appropriated. The primary limitation of TRNSYS is to not being able to connect with the AutoCAD program for importation and exportation of files. In this aspect, DesignBuilder is more appropriate

B 6. The weather of Zaragoza, Edinburgh, Almeria, and Avila.

Table B3. The condition of the weather of Edinburgh and Zaragoza.

	Edinburgh	**Zaragoza**
Climate	Cold and moist, cloudy and rainy, being influenced by the ocean.	The Mediterranean, with warm, bright, continental summers, harsh winters, mild autumns and mild spring daylight.
Temperature	Regularly varies from 1 °C to 19 °C.	Regularly varies from 3 °C to 33 °C.
Summer	Cold.	Hot and mostly clear.
Winter	Cold but not freezing.	Cold, windy, and partly cloudy.
Hot season / the hottest day	From June 14 to September 14, with a daily average high temperature of 16 °C / August 2.	From June 10 to September 10, with a daily average high temperature of 28 °C / July 31.
Cool Season / the coldest day	From November 19 to March 17, with a daily average high temperature below 9 °C. / January 1.	November 15 to March 3, with a daily average high temperature below 15 °C. / January 6.
The cloudier part/day	Begins on October 10 and lasts for 6.4 months, ending on April 23. / January 26.	Begins on September 5 and lasts for 9.4 months, ending on June 16. / October 30.
The clearer part/day	Begins on April 23 and lasts for 5.6 months, ending on October 10. / July 29.	Begins on June 16 and lasts for 2.6 months, ending around September 5. / July 21.
The wetter season/day	From July 7 to February 2, with a higher than 32% chance. / peaks at 38% on November 3.	From October 5 to June 22, with a higher than 15% chance. / peaks at 22% on May 12.
The drier season/day	From February 2 to July 7. / The smallest chance of a wet day is 25% on April 19.	From June 22 to October 5. / The smallest chance of a wet day is 9% on July 23
The most rain part	Falls during the 31 days centered on October 22, with an average total accumulation of 66 mm.	Falls during the 31 days centered on May 10, with an average total accumulation of 33 mm.
The least rain part	Falls on May 2, with a total average accumulation of 38 mm.	Falls around January 26, with an average total accumulation of 12.7 mm.

The longest day / The earliest sunrise	Is June 21, with 18 hours, 37 minutes of daylight. / at 4:25 AM on June 18	Is June 21, with 16 hours, 12 minutes of the day. / at 6:28 AM on June 14
The shortest day / The earliest sunset	Is December 21, with 6 hours, 56 minutes of daylight. / At 3:38 PM on December 14.	Is December 21, with 9 hours, 10 minutes of daylight. / at 5:33 PM on December 7.
The humidity level	Muggy, oppressive, or miserable. Remaining a virtually constant 0% throughout.	Muggy, oppressive, or miserable. Staying within 4% of 4% throughout
The windier part of the year / the most blustery day	Lasts for 5.3 months, from October 23 to April 2, with average wind speeds of more than 7.0 miles per hour. / January 24.	Lasts for 6.1 months, from November 6 to May 12, with average wind speeds of more than 4.9 miles per hour. / February 2,
The calmer time of year / the calmest day	Lasts for 6.7 months, from April 2 to October 23. / July 24.	Lasts for 5.9 months, from May 13 to November 7. / August 27
The brighter period of the year / the brightest day	Lasts for 3.5 months, from April 29 to August 14, with a daily average incident shortwave energy per square meter above 4.6 kWh. / June 22.	Lasts for 3.2 months, from May 12 to August 19, with a daily average incident shortwave energy per square meter above 6.8 kWh. / July 5.
The darker period of the year / the darkest day	Lasts for four months, from October 22 to February 22, with a daily average incident shortwave energy per square meter below 1.4 kWh./ December 25.	Lasts for 3.5 months, from October 27 to February 13, with a daily average incident shortwave energy per square meter below 3.2 kWh. / December 18.

Table B4. The condition of the weather of Almeria and Avila.

	Almeria	**Avila**
Temperature	Regularly varies from 8 °C to 31 °C.	Regularly varies from -1 °C to 28 °C.
Summer	Hot, humid, arid, and mostly clear.	Short, warm, and mostly clear.
Winter	Long, cold, dry, windy, and partly cloudy.	Long, very cold, and partly cloudy.
Hot season / the Hottest day	From June 19 to September 17, with a daily average high temperature of 28 °C. / July 29.	From June 14 to September 11, with a daily average high temperature of 24 °C. / July 30.
Cool Season / the Coldest day	Lasts for four months, from November 20 to March 21, with a daily average high temperature below 18 °C. / January 15.	From November 14 to March 5, with a daily average high temperature below 11 °C. / January 22.
The cloudier part/day	Begins on September 6 and lasts for 9.1 months, ending on June 10. / October 30.	Begins on September 15 and lasts for 8.8 months, ending on June 8. / December 16.

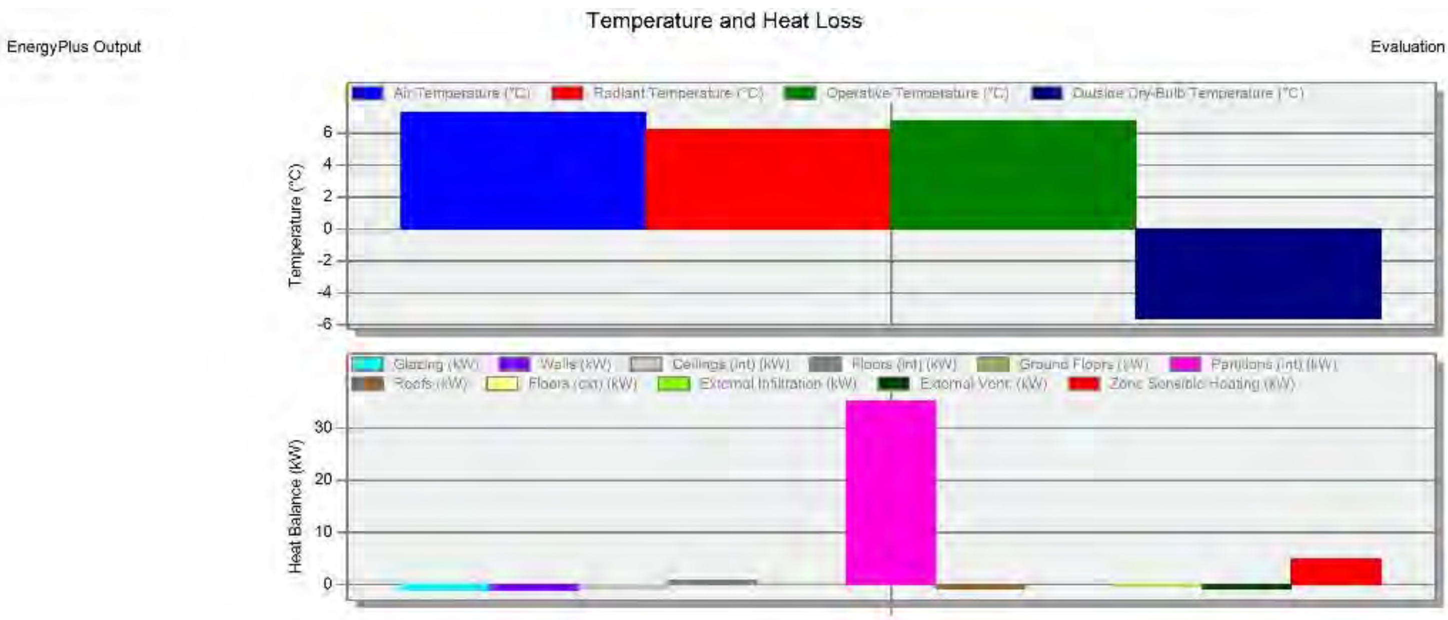
The clearer part/day	Begins on June 10 and lasts for three months, ending on September 7. / July 17.	Begins on June 8 and lasts for 3.2 months, ending September 15. / July 21.
The wetter season / Day	Begins on June 10 and lasts for three months, ending on September 7. / peaks at 13% on November 17.	From September 27 to June 16, with a higher than 13% chance. / peaks at 22% on October 31.
The drier season / Day	From May 16 to September 28. The smallest possibility of a wet day is 0% on July 28.	From June 16 to September 28. / The smallest possibility of a wet day is 5% on July 30.
The most rain part / Day	From September 22 to May 6, with a sliding 31-day rainfall of at least 15.2 mm. / November 11	From September 1 to July 3, with a sliding 31-day rainfall of at least 12.7 mm. / October 24.
The least rain pat / Day	From May 6 to September 22. / The least rain falls on August 1.	From July 3 to September 1. / The least rain falls on July 27.
the longest day / The earliest sunrise	June 21, with 15 hours, 41 minutes of daylight. / is at 6:50 AM on June 13.	June 21, with 16 hours, 5 minutes of daylight. / at 6:47 AM on June 14.
the shortest day / The earliest sunset	December 21, with 8 hours, 38 minutes of daylight. / is at 5:53 PM on December 6.	December 21, with 8 hours, 16 minutes of daylight. / at 5:51 PM on December 8.
The humidity level	From June 14 to October 8, the comfort level is muggy, oppressive, or miserable at least 15% of the time.	Is muggy, oppressive, or miserable, does not significantly vary over the course of the year, remaining a virtually constant 0% throughout.
The windier part of the year / the windiest day	From December 7 to May 21, with average wind speeds of more than 5.1 miles per hour. / February 21.	From October 19 to May 12, with average wind speeds of more than 4.2 miles per hour. / April 7.
The calmer time of year / the calmest day	From May 21 to December 7. / The calmest day of the year is August 5.	From May 12 to October 19. / The calmest day of the year is August 25.
The brighter period of the year / The brightest day	From May 4 to August 19, with a daily average incident shortwave energy per square meter above 7.0 kWh. / June 30.	From May 14 to August 22, with a daily average incident shortwave energy per square meter above 7.0 kWh. / July 6.
The darker period of the year / The darkest day	From October 28 to February 10, with a daily average incident shortwave energy per square meter below 3.7 kWh. / December 16.	From October 26 to February 14, with a daily average incident shortwave energy per square meter below 3.2 kWh. / December 20.

Appendix C. Results of Design Builder Software

C. 1 Brick Construction

The below figures and tables show the results of heating, cooling, simulation, cost of construction, site and source energy, embodied and equivalent carbon of materials for brick construction in Edinburgh and Zaragoza using DesignBuilder program.

C.1.1 Heating Results



Air Temperature (°C)	7.32
Radiant Temperature (°C)	6.20
Operative Temperature (°C)	6.76
Outside Dry-Bulb Temperature (°C)	-5.60
Glazing (kW)	-1.05
Walls (kW)	-1.15
Ceilings (int) (kW)	-0.78
Floors (int) (kW)	0.78
Ground Floors (kW)	0.05
Partitions (int) (kW)	35.04
Roofs (kW)	-0.84
Floors (ext) (kW)	-0.00
External Infiltration (kW)	-0.17
External Vent. (kW)	-0.80
Zone Sensible Heating (kW)	4.82

Figure C1. The heating results of Edinburgh

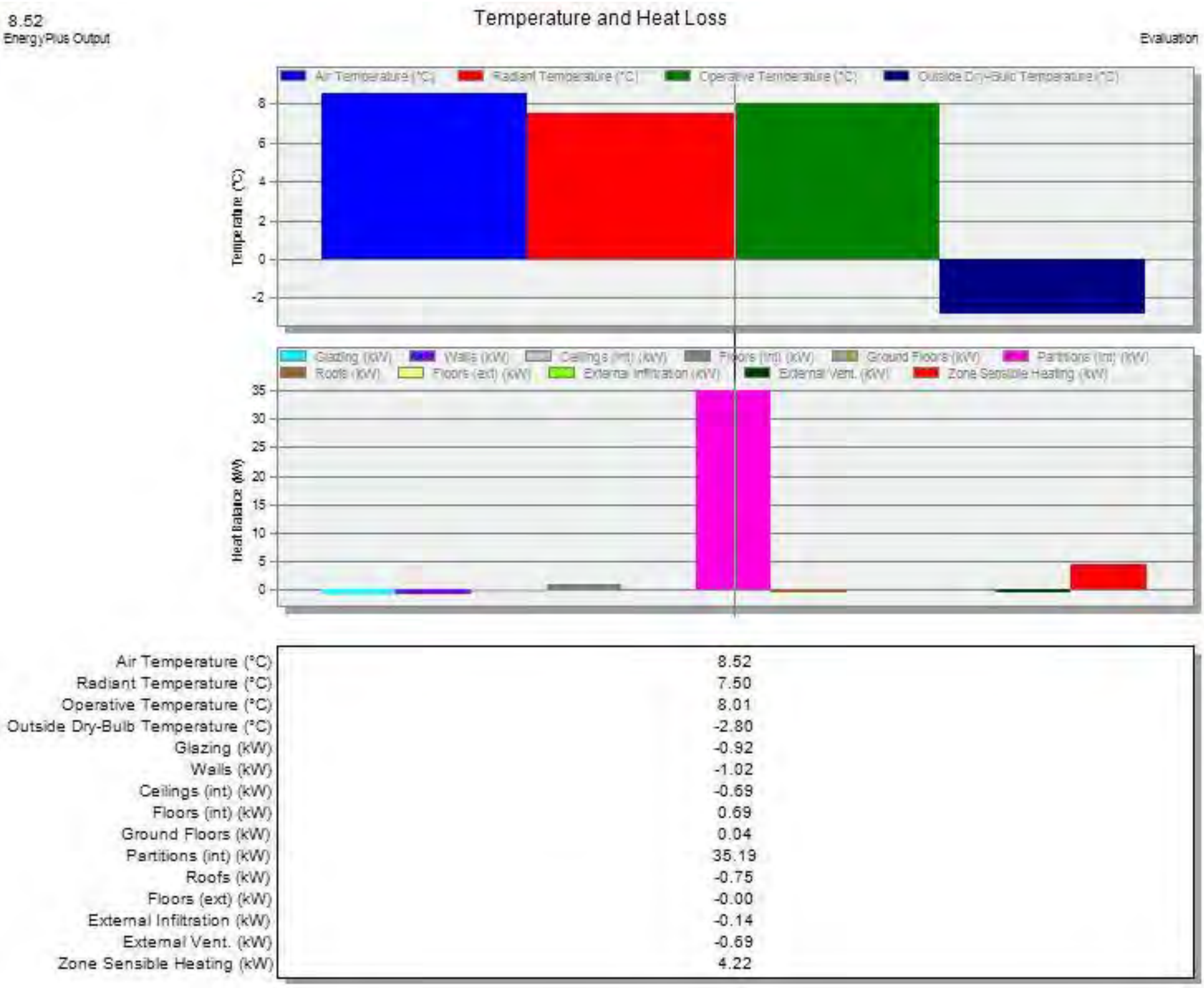


Figure C2. The heating results of Zaragoza.

Table C1. The heating results of Edinburgh and Zaragoza in different zones.

Block	**Zone**	**Edinburgh**		**Zaragoza**	
		Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Comfort Temperature (°C)	Steady-State Heat Loss (kW)
House	Service 1	17.32	0.19	17.38	0.16
House	Bedroom (Western)	16.77	0.6	16.88	0.53
House	Dining Room, Hall	17.25	0.75	17.32	0.66
House	Bedroom (Central)	17.01	0.48	17.09	0.42
House	Bedroom (Eastern)	16.9	0.53	17	0.46
House	Kitchen	16.72	0.72	16.83	0.63
House	Service	17.31	0.19	17.37	0.17
House	Entrance Area	15.76	0.4	15.96	0.35
Garage	Garage Area	16.56	0.96	16.69	0.85

C.1.2 Cooling Results

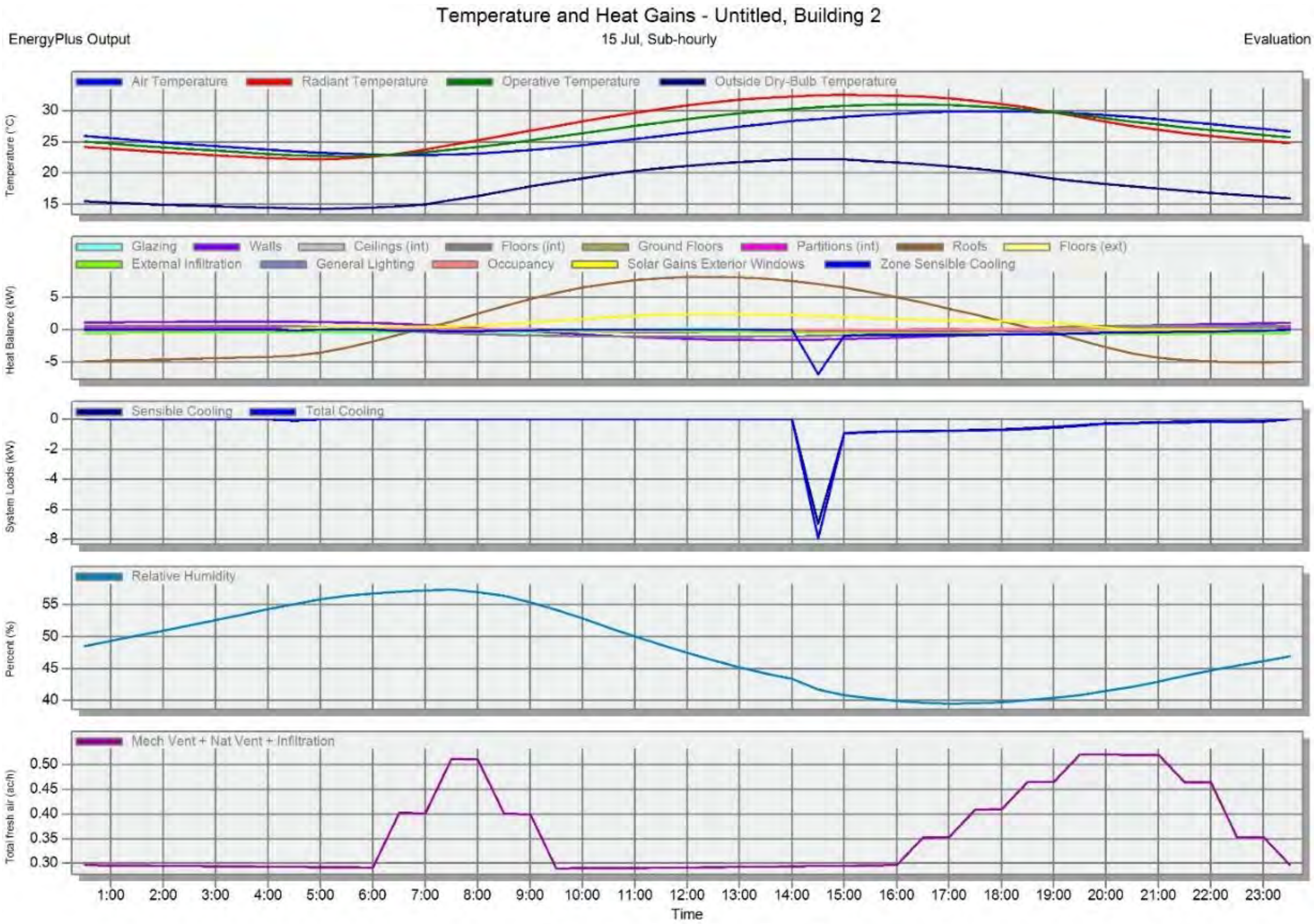


Figure C3. The cooling results of Edinburgh.

Table C2. The cooling results of Edinburgh in different zones.

Block	Design Flow Rate (m^3/s)	Total Cooling Load (kW)	Sensible (kW)	Humidity (%)	Max Op Temp in Day (°C)	Floor Area (m^2)	Flow/Floor Area ($l/s\text{-}m^2$)
House	0.017	0.27	0.23	46.9	25.7	5.1	3.3
House	0.006614	0.09	0.09	57	24.8	36.3	0.18
House	0.024537	0.41	0.4	45.6	26.5	13.2	0.8
House	0.007342	0.12	0.12	45.6	26.4	11.2	0.2
House	0.002646	0.03	0.03	55.7	25.6	11.8	0.22
House	0.008627	0.12	0.12	45.2	25.8	5.1	1.68
House	0.000466	0	0	63.2	22.6	1.6	0.29
Garage	0.003506	0.04	0.04	59.6	24	16.5	0.21

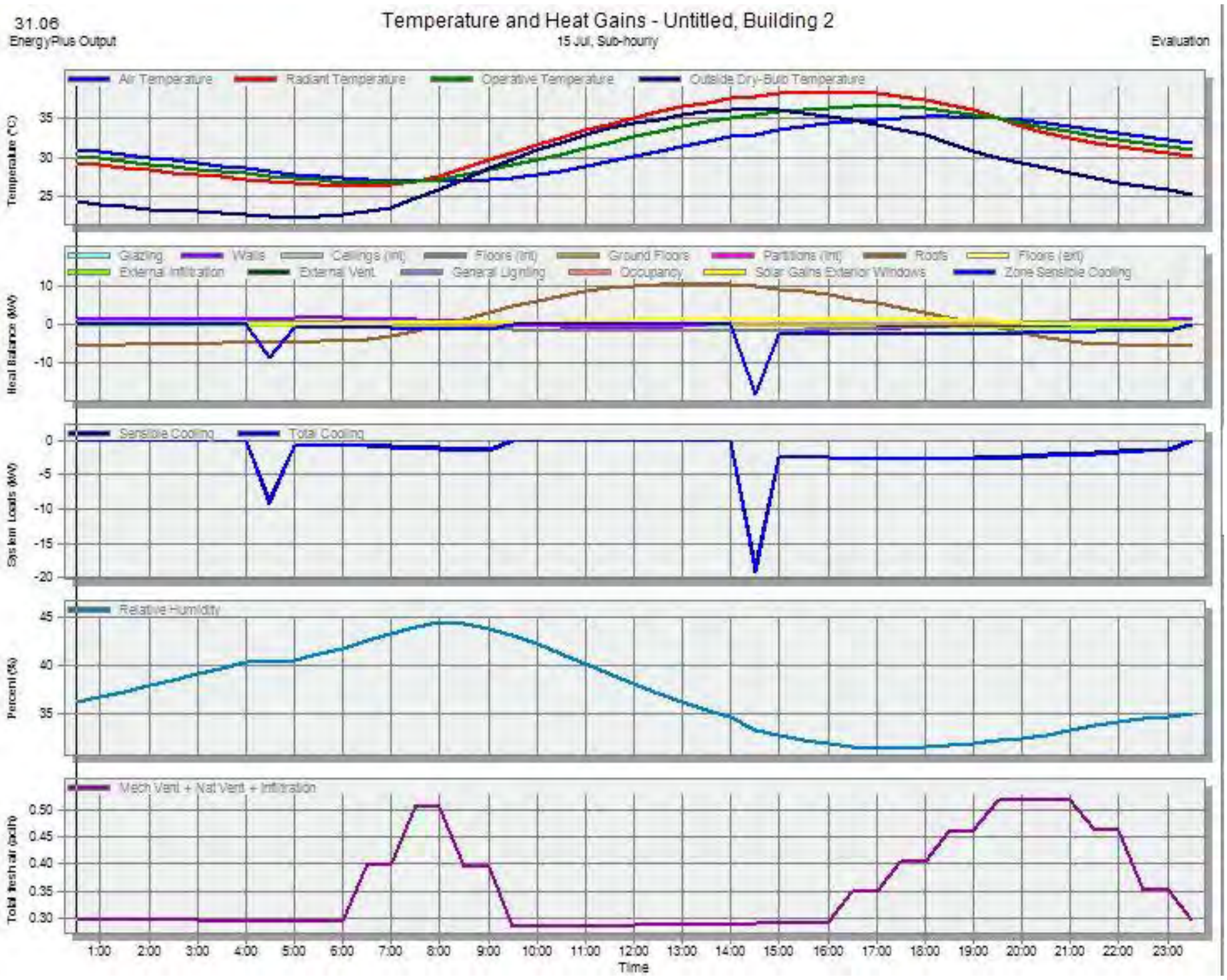


Figure C4. The cooling results of Zaragoza.

Table C3. The cooling results of Edinburgh in different Zaragoza.

Block	Design Flow Rate (m^3/s)	Total Cooling Load (kW)	Sensible (kW)	Humidity (%)	Max Op Temp in Day (°C)	Floor Area (m^2)	Flow/Floor Area (l/s-m^2)
House	0.0582	0.81	0.77	44.8	26	5.1	11.3
House	0.1375	2.03	1.83	46.3	25.9	36.3	3.79
House	0.1546	2.17	2.05	44.9	26.2	13.2	11.67
House	0.1787	2.48	2.37	44.7	26.2	11.2	15.93
House	0.2329	3.21	3.09	44.5	26.3	11.8	19.8
House	0.0551	0.77	0.73	44.9	26.1	5.1	10.71
House	0.0796	1.11	1.06	44.3	26.2	1.6	49.12
Garage	0.2402	3.35	3.19	44.7	26	16.5	14.53

C.1.3 Simulation Results

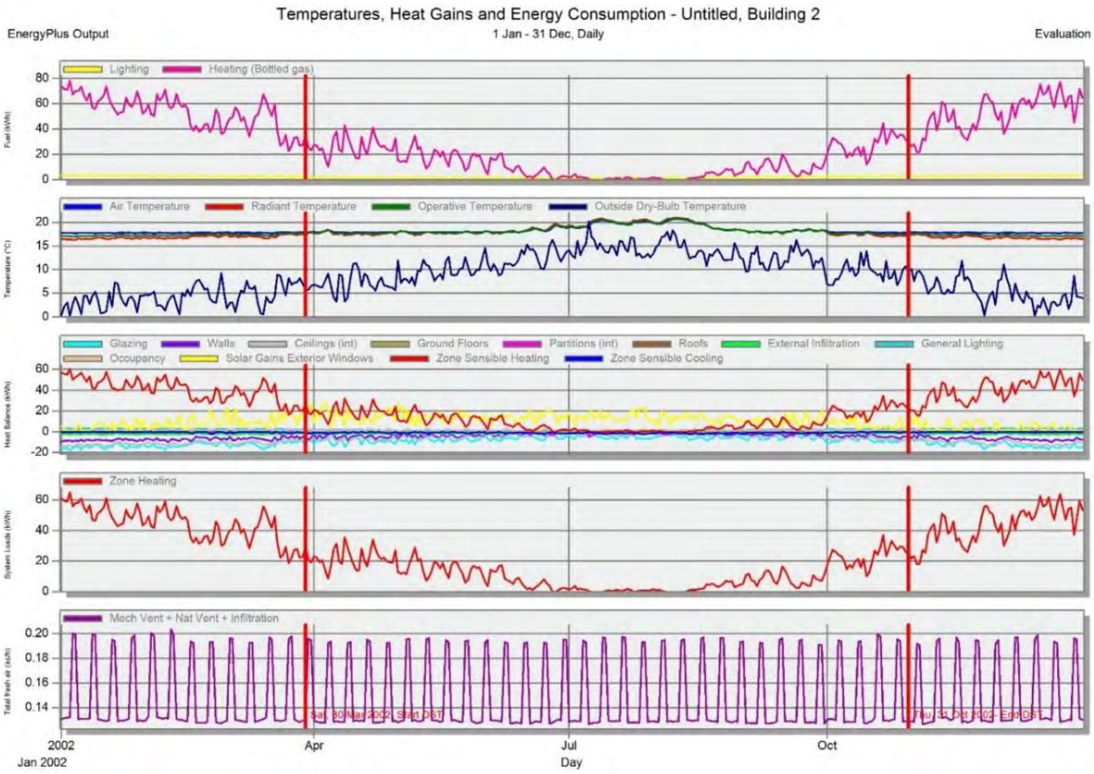


Figure C5. The simulation results of Edinburgh.

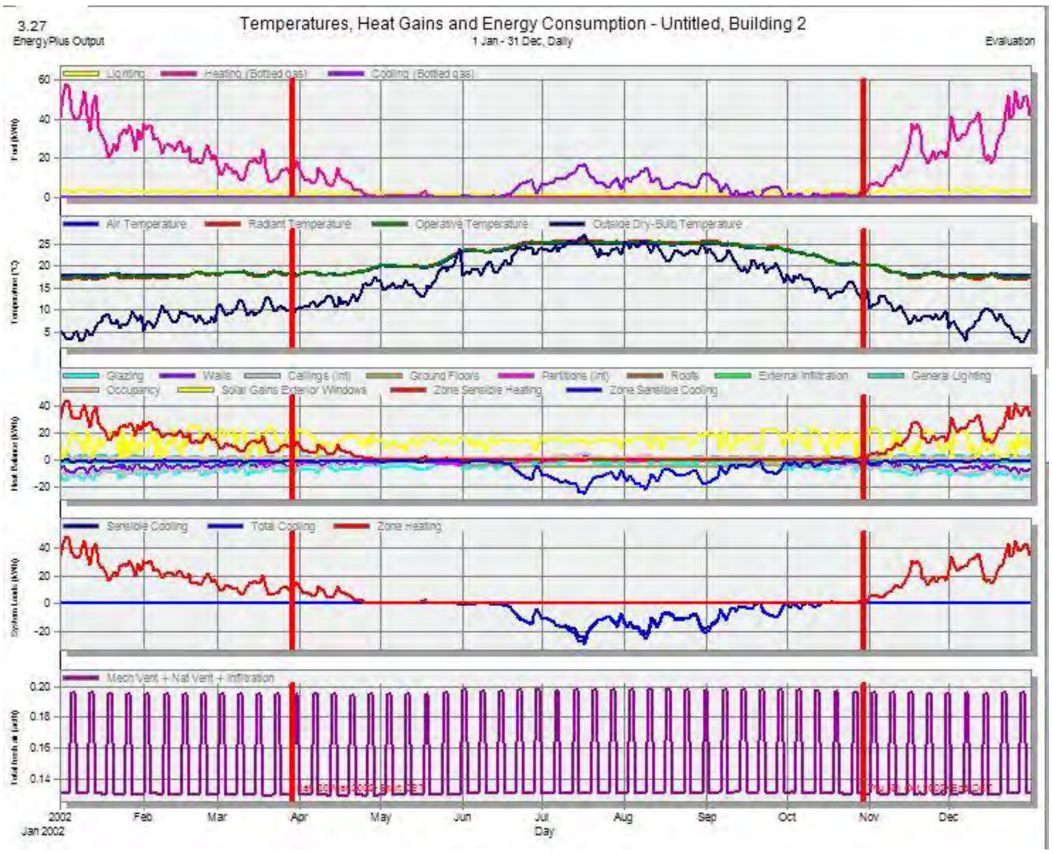


Figure C6. The simulation results of Zaragoza.

C.1.4 Site and Source Energy

Table C4. The total site and source energy of Edinburgh.

	Total Energy [kWh]	Energy Per Total Building Area [kWh/ m^2]	Energy Per Conditioned Building Area [kWh/ m^2]
Total Site Energy	9772.03	47.24	87.37
Total Source Energy	34954.88	168.98	312.54

Table C5. The total site and source energy of Zaragoza.

	Total Energy [kWh]	Energy Per Total Building Area [kWh/ m^2]	Energy Per Conditioned Building Area [kWh/ m^2]
Total Site Energy	5481.76	26.50	49.01
Total Source Energy	16301.70	78.80	145.76

C.1.5 Construction Costs for Brick Construction.

The estimated building construction cost data shown below is based on 'per gross internal floor area' costs of services, sub-structure and frame construction. The cost of construction and glazing relies on the per size cost data from the construction and glazing database. Surface finish costs are also calculated from actual building surface areas and entered surface finish per area costing data.

Table C6. The estimated construction cost in Edinburgh and Zaragoza.

Structure Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	206.9	43441.2
HVAC Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	206.9	16776.4
Lighting Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	206.9	10065.9
Sub-Structure Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	142.5	15675.0

Surface Finish Costs	Surface Area (m^2)	Cost (GBP)
Walls	382.9	4798.6
Floors	142.5	6412.5
Ceiling	142.5	675.0
Sub Total		11886
Building Total Cost (GBP)		**294197**

C.1.6 Embodied and Equivalent Carbon for Brick Construction.

The estimated embodied and comparable carbon data are shown below is based on bulk carbon data obtained from the Bath ICE and other data sources. The embodied carbon associated with building services such as lighting and HVAC equipment is not covered in these results.

Equivalent carbon is similar to embodied carbon but also includes the effects of other greenhouse gases to provide an equivalent amount of CO_2 that causes the same amount of global warming as the real greenhouse gases emitted by the processes involved in the production of the material.

Table C7. The estimated embodied and equivalent carbon data in Edinburgh and Zaragoza.

Materials Embodied Carbon and Inventory	Area (m^2)	Embodied Carbon ($kgCO_2$)	Equivalent CO_2 ($kgCO_2$)	Mass (kg)
Cement/plaster/mortar - gypsum plaster sand aggregate	142.5	574.6	622.4	4788.0
Carpet/underlay - polystyrene expanded (EPS)	142.5	409.7	534.2	163.9
Mineral fibre/wool - fibre textile organic bonded at 10C degrees	142.5	0.0	0.0	213.7
Painted Oak	57.6	0.0	0.0	1411.5
Plywood (Heavyweight)	240.0	1360.8	1411.2	1680.0
Clay Tile (roofing)	146.9	3378.2	3525.1	7343.9
External Rendering	7.2	23.4	23.4	234.0
Floor/Roof Screed	142.5	2736.0	2736.0	17100.0
Plasterboard	240.0	3319.7	3494.4	8736.0
Gypsum Plastering	152.4	1158.3	1219.2	3048.0

Gypsum Plasterboard	505.0	1090.9	1181.8	9090.6
MW Stone Wool (rolls)	7.2	55.6	59.3	53.0
MW Glass Wool (standard board)	252.5	772.7	848.5	505.0
MW Glass Wool (rolls)	240.0	440.6	483.8	288.0
XPS Extruded Polystyrene - CO_2 Blowing	174.9	2712.5	9023.0	941.9
Concrete Reinforced (with 2% steel)	142.5	19083.6	20314.8	61559.9
Concrete Block (Medium)	152.4	1962.9	1962.9	24536.6
Cast Concrete (Lightweight)	262.5	2692.8	2692.8	33660.0
Cast Concrete (Dense)	10.4	175.4	175.4	2192.5
Brickwork Inner Leaf	252.5	11805.2	12341.8	53659.9
Brickwork Outer Leaf	152.4	6554.8	6852.7	29794.5
Fibreboard	22.5	62.0	64.4	121.5
Roofing Felt	146.9	676.8	0.0	705.0
Asphalt	22.5	47.3	47.3	945.0
Sub Total		**61093.6**	**69614.4**	**262772.4**

Table C8. The estimated glazing embodied and equivalent carbon data in Edinburgh and Zaragoza.

Glazing Embodied Carbon and Inventory	**Area (m^2)**	**Embodied Carbon ($kgCO_2$)**	**Equivalent CO_2 ($kgCO_2$)**
Glazing-Part L 2013 Notional Building	28.1	716.8	759.0
Local shading		0.0	0.0
Window Shading		0.0	0.0
Sub Total	28.1	716.8	759.0
Building Total	1060.2	61810.5	71050.2

C.2 Metal construction

The below figures and tables show the results of Heating, Cooling, Simulation, Cost of construction, site and source energy, Embodied and Equivalent Carbon of materials for Metal construction in Edinburgh and Zaragoza by DesignBuilder program.

C.2.1 Heating Results

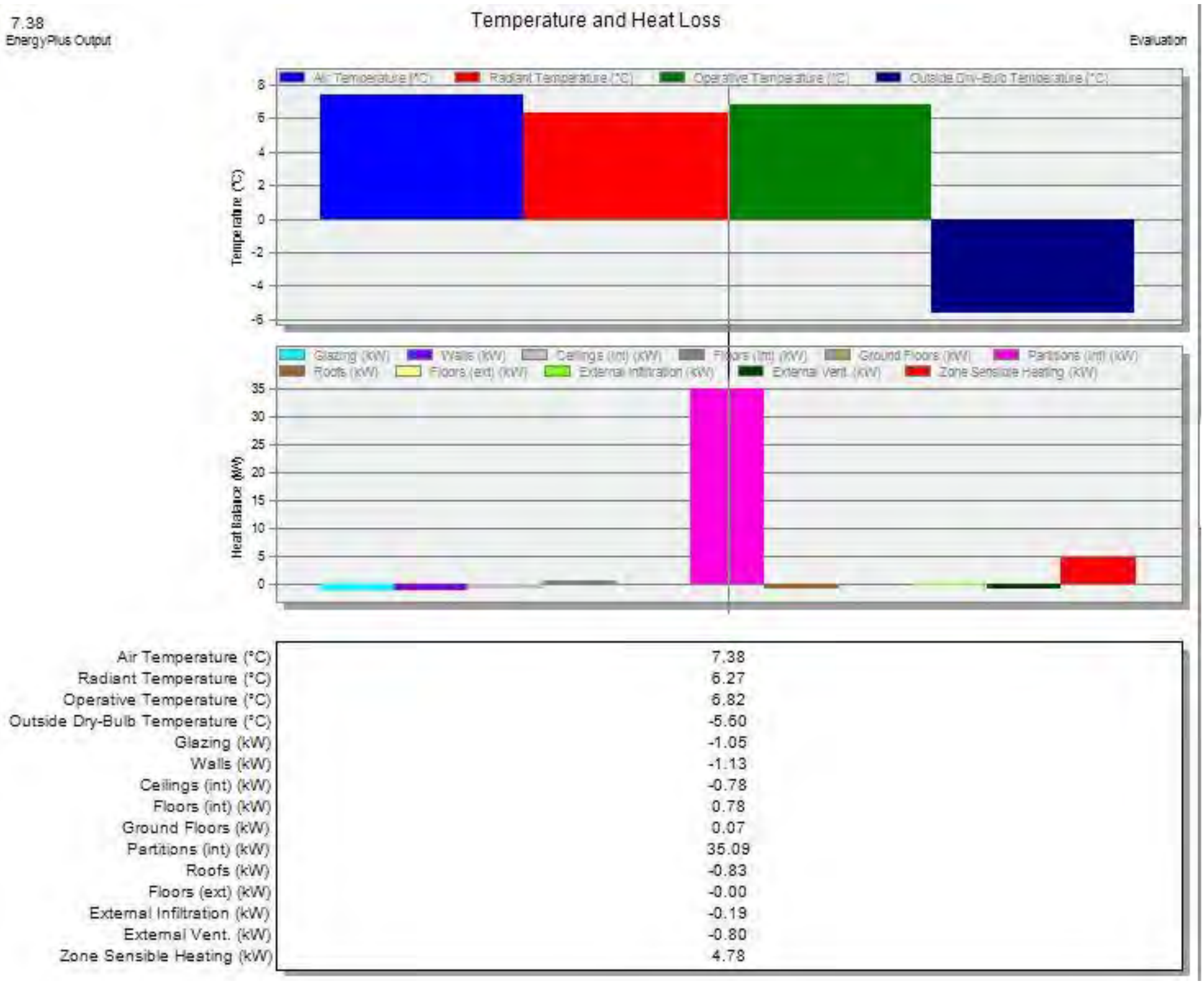


Figure C7. The heating results of Edinburgh

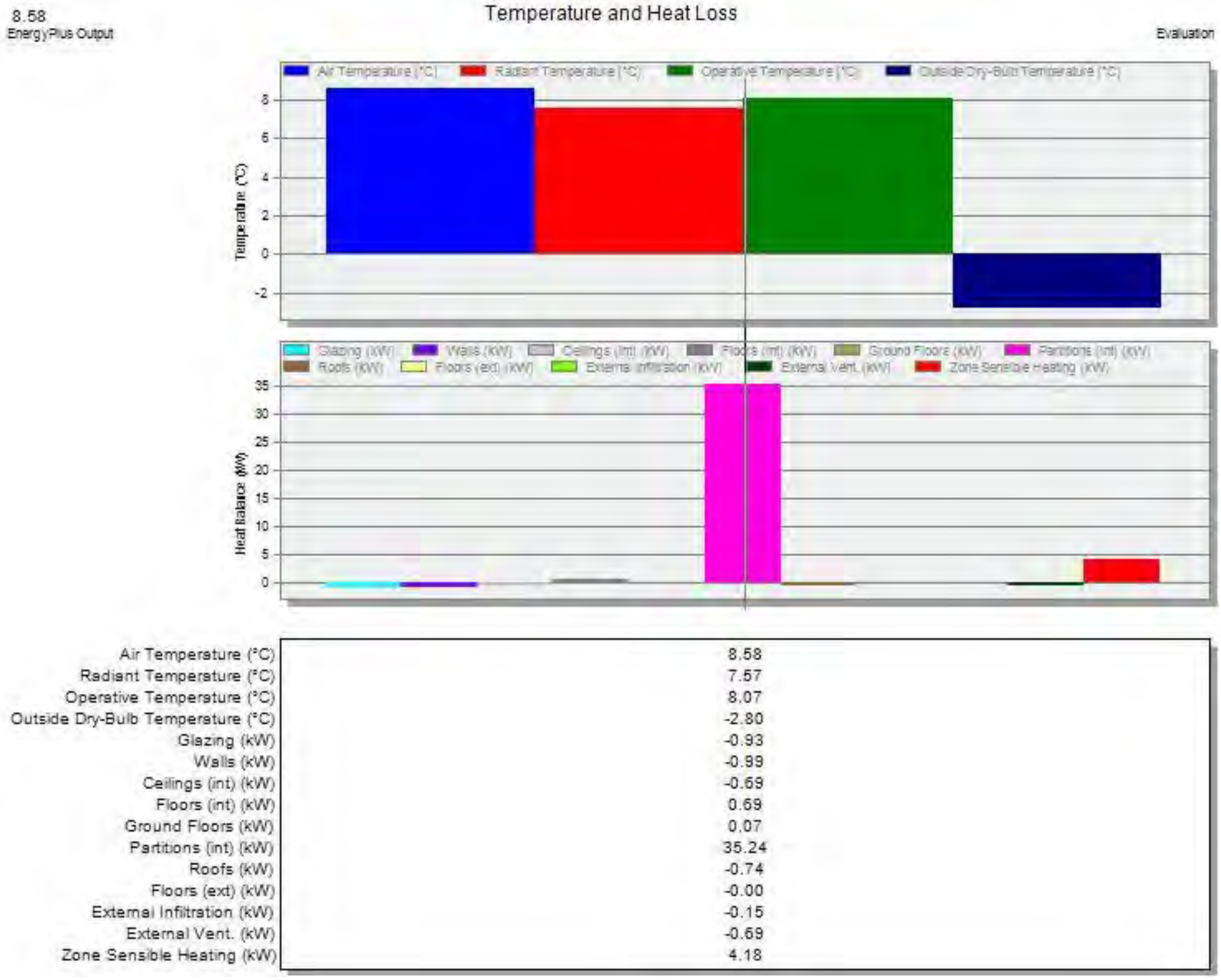


Figure C8. The heating results of Zaragoza.

Table C9. The heating results of Edinburgh and Zaragoza in different zones.

		Edinburgh		Zaragoza	
Block	Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Comfort Temperatu re (°C)	Steady-State Heat Loss (kW)
House	Service 1	17.33	0.19	17.39	0.16
House	Bedroom (Western)	16.78	0.59	16.9	0.52
House	DinningRoom, Hall	17.28	0.74	17.34	0.64
House	Bedroom (Central)	17.02	0.48	17.11	0.42
House	Bedroom (Estern)	16.92	0.52	17.02	0.46
House	Kitchen	16.73	0.71	16.85	0.63
House	Service	17.33	0.19	17.39	0.16
House	Entrance Area	15.76	0.4	15.97	0.35
Garage	Garage Area	16.58	0.96	16.71	0.84
Pitched roof	Zone 1	-5.17	0	-2.55	0

C.2.2 Cooling Results

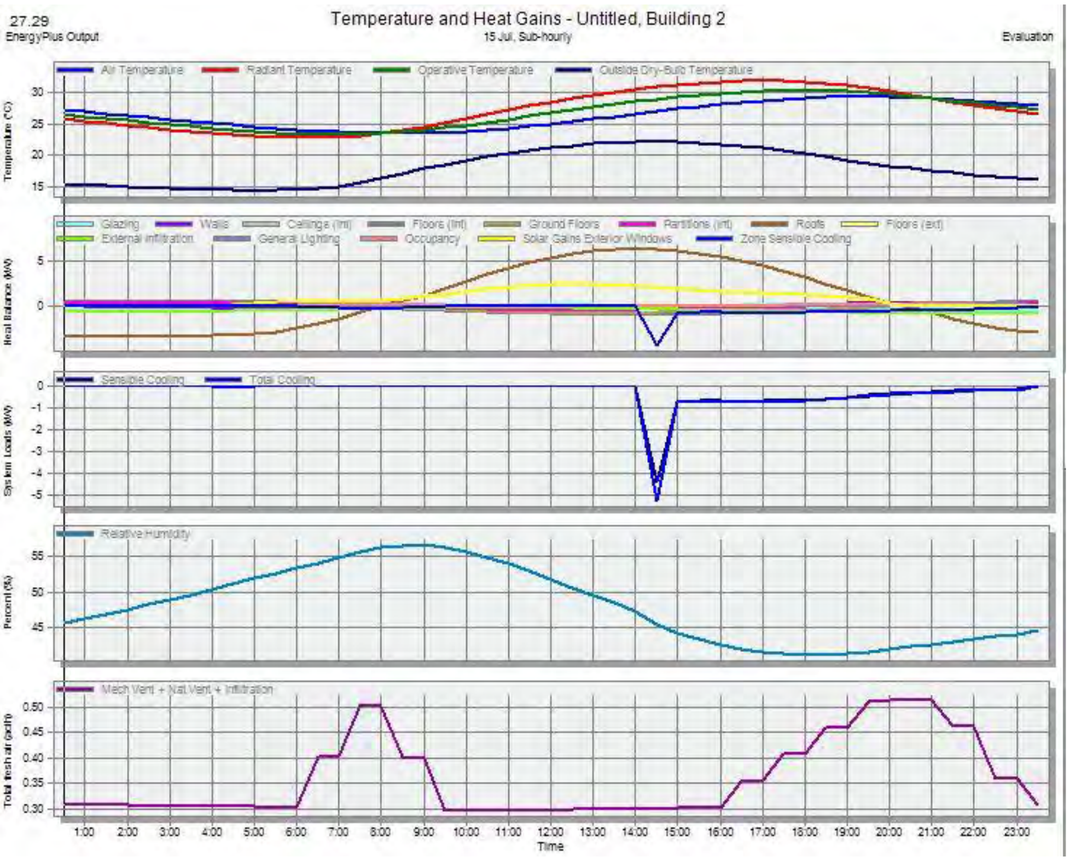


Figure C9. The cooling results of Edinburgh.

Table C10. The cooling results of Edinburgh in different zones.

Block	Design Flow Rate (m^3/s)	Total Cooling Load (kW)	Sensible (kW)	Humidity (%)	Max Op Temp in Day (°C)	Flow/Floor Area ($l/s\text{-}m^2$)
House	0.00764	0.11	0.1	45.6	25.7	1.34
House	0.006583	0.08	0.08	57.8	24.6	0.17
House	0.0045	0.05	0.05	46.5	26.1	0.6
House	0.00483	0.06	0.06	47.1	26	0.04
House	0.002628	0.03	0.03	56.9	25.3	0.2
House	0.005114	0.07	0.07	46.4	25.5	0.9
House	0.000463	0	0	64.5	22.4	0.23
Garage	0.003396	0.04	0.04	62.5	23.4	0.19
Pitched roof	0	0	0	-	36.8	0

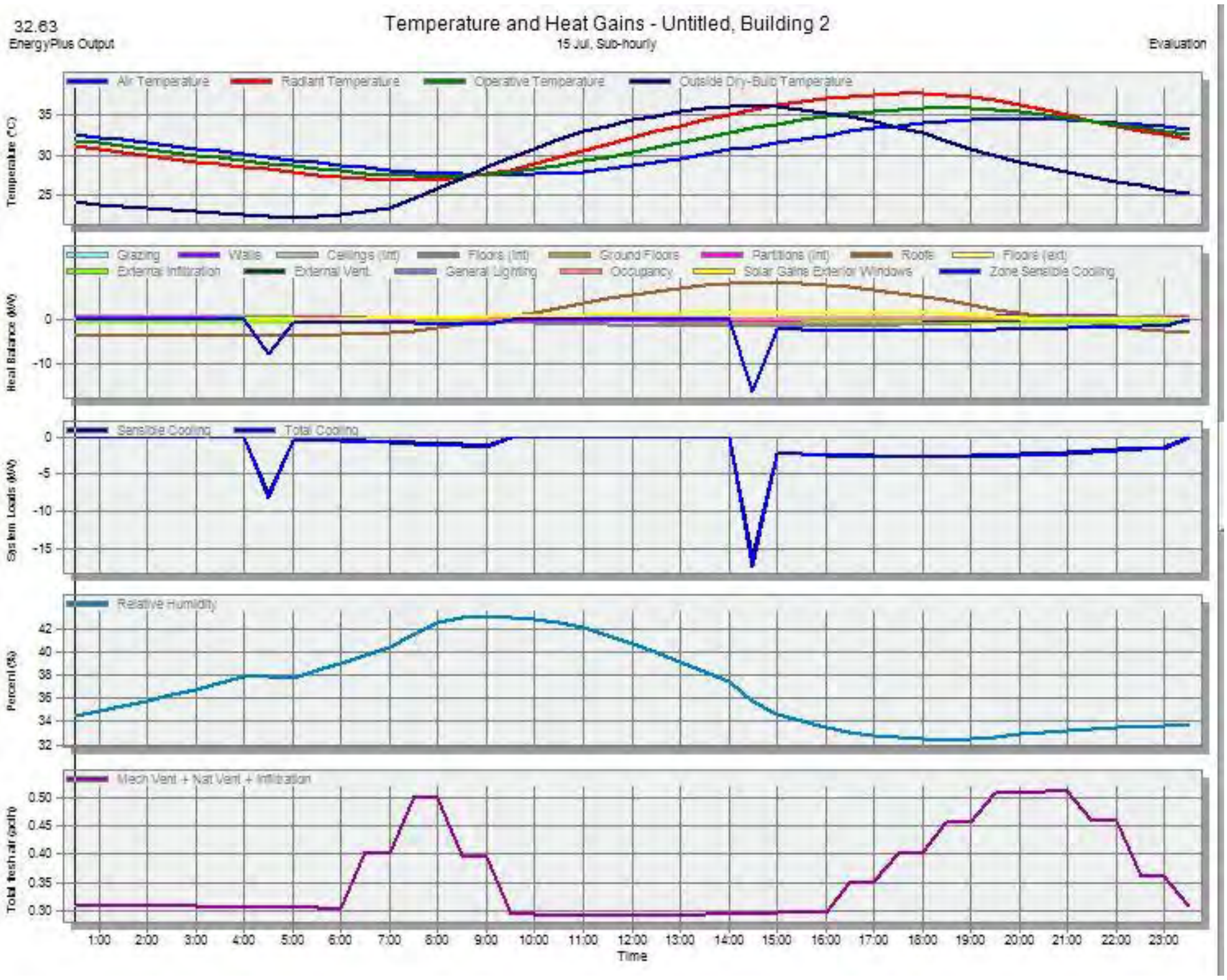


Figure C10. The cooling results of Zaragoza.

Table C11. The cooling results of Edinburgh in different Zaragoza.

Block	Design Flow Rate (m^3/s)	Total Cooling Load (kW)	Sensible (kW)	Humidity (%)	Max Op Temp in Day (°C)	Flow/Floor Area ($l/s\text{-}m^2$)
House	0.0523	0.74	0.69	45	26	9.2
House	0.1336	2	1.78	46.5	25.9	3.55
House	0.1316	1.87	1.75	45.1	26	9.32
House	0.1546	2.17	2.05	44.8	26	12.76
House	0.2205	3.06	2.93	44.6	26.3	17.12
House	0.0513	0.72	0.68	45	25.9	9.02
House	0.069	0.94	0.92	44.3	26.1	33.91
Garage	0.205	3.02	2.72	45.3	26	11.42
Pitched roof	0	0	0	-	47.8	0

C.2.3 Simulation Results

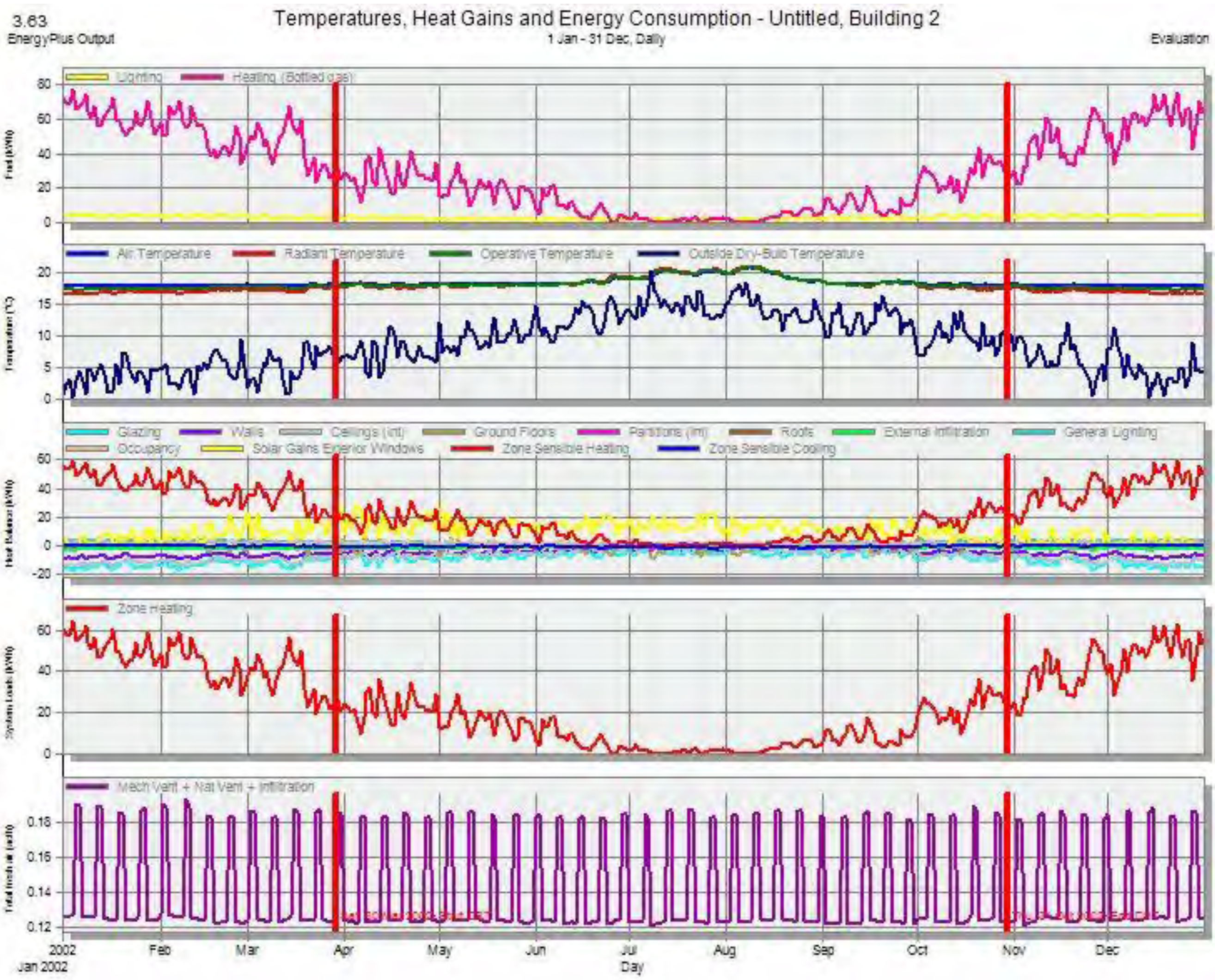


Figure C11. The simulation results of Edinburgh.

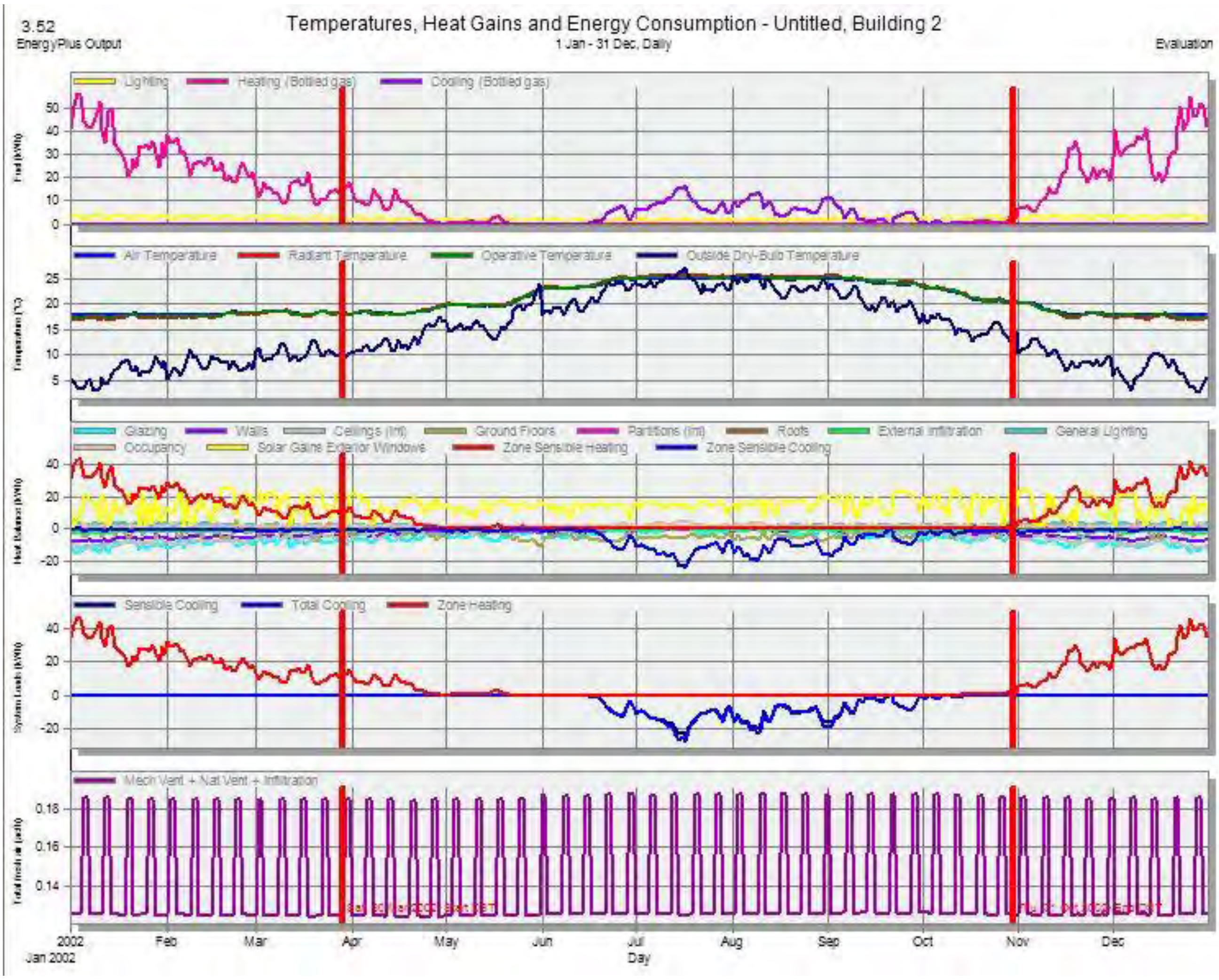


Figure C12. The simulation results of Edinburgh.

C.2.4 Site and Source Energy

Table C12. The total site and source energy of Edinburgh.

Edinburgh	Total Energy [kWh]	Energy Per Total Building Area [kWh/m^2]	Energy Per Conditioned Building Area [kWh/m^2]
Total Site Energy	9830.09	44.36	81.93
Total Source Energy	35135.05	158.56	292.83

Table C13. The total site and source energy of Zaragoza.

Zaragoza	Total Energy [kWh]	Energy Per Total Building Area [kWh/m^2]	Energy Per Conditioned Building Area [kWh/m^2]
Total Site Energy	5455.39	24.62	45.47

Total Source Energy	16393.46	73.98	136.63

C.2.5 Construction Costs for Metal Construction.

The estimated building construction cost data shown below is based on 'per gross internal floor area' costs of services, sub-structure and frame construction. Surface finish costs are also calculated from actual building surface areas and entered surface finish per area costing data.

Table C14. The estimated construction cost in Edinburgh and Zaragoza.

Structure Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	221.6	46535.2
HVAC Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	221.6	17998.2
Lighting Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	221.6	10798.9
Sub-Structure Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	142.5	15675.0
Surface Finish Costs	**Surface Area (m^2)**	**Cost (GBP)**
Walls	382.9	4798.6
Floors	142.5	6412.5
Ceiling	142.5	675.0
Sub Total		11886
Building Total Cost (GBP)		**314210**

C.2.6 Embodied and Equivalent Carbon for Metal Construction.

The estimated embodied and comparable carbon data are shown below is based on bulk carbon data obtained from the Bath ICE and other data sources. The embodied carbon associated with building services such as lighting and HVAC equipment is not covered in these results.

Equivalent carbon is similar to embodied carbon but also includes the effects of other greenhouse gases to provide an equivalent amount of CO^2 that would cause the same amount of global warming as the real greenhouse gases (which may include sulfur dioxide, methane, etc.) emitted by the processes involved in the production of the material.

Table C15. The estimated embodied and equivalent carbon data in Edinburgh and Zaragoza.

Materials Embodied Carbon and Inventory	**Area (m^2)**	**Embodied Carbon ($kgCO_2$)**	**Equivalent CO_2 ($kgCO_2$)**	**Mass (kg)**
Copy of 2010 NCM insulation for metal cladding lambda 0.0432	152.4	0.0	0.0	274.3
Metal surface	169.4	12351.3	13328.3	6978.1
Cement/plaster/mortar - gypsum plaster sand aggregate	142.5	574.6	622.4	4788.0
Glass fibre/wool - wool resin bonded at 50C degrees	142.5	941.9	1034.2	615.6
Painted Oak	57.6	0.0	0.0	1411.5
Plywood (Heavyweight)	240.0	1360.8	1411.2	1680.0
PVC/Asbestos Tiles	146.9	21238.6	22824.8	8812.7
External Rendering	7.2	23.4	23.4	234.0
Floor/Roof Screed	142.5	1368.0	1368.0	8550.0
Plasterboard	240.0	3319.7	3494.4	8736.0
White-painted steel	252.5	69725.1	75240.1	39392.7
MW Stone Wool (rolls)	7.2	55.6	59.3	53.0
MW Glass Wool (rolls)	240.0	440.6	483.8	288.0
Concrete Reinforced (with 2% steel)	142.5	19083.6	20314.8	61559.9
Cast Concrete (Lightweight)	382.5	2988.0	2988.0	37349.9
Cast Concrete (Dense)	10.4	175.4	175.4	2192.5
Lightweight Metallic Cladding	152.4	81439.5	87630.8	9525.1
R-12 batt Insulation Glas fiber for roof and floor insulation installed between metal framing	22.5	0.0	0.0	33.8
Board insulation (Glass fiber board)	252.5	0.0	0.0	4848.3
Glass-fiber batt insulation (compressed)	22.5	0.0	0.0	33.8
Metal deck	169.4	0.0	0.0	14484.4
0.625 in. gypsum board	809.8	0.0	0.0	8240.9
Sub Total		215086.0	230998.9	220082.5

Table C16. The estimated glazing embodied and equivalent carbon data in Edinburgh and Zaragoza.

Glazing Embodied Carbon and Inventory	Area (m^2)	Embodied Carbon ($kgCO_2$)	Equivalent CO_2 ($kgCO_2$)
Glazing - Part L 2013 Notional Building	28.1	716.8	759.0
Local shading		0.0	0.0
Window Shading		0.0	0.0
Sub Total	28.1	716.8	759.0
Building Total	**1060.2**	**215802.8**	**231757.9**

C.3 Timber construction

The below figures and tables show the results of Heating, Cooling, Simulation, Cost of construction, site, and source energy Embodied and Equivalent Carbon of materials for Timber construction in Edinburgh and Zaragoza by DesignBuilder program.

C.3.1 Heating Results

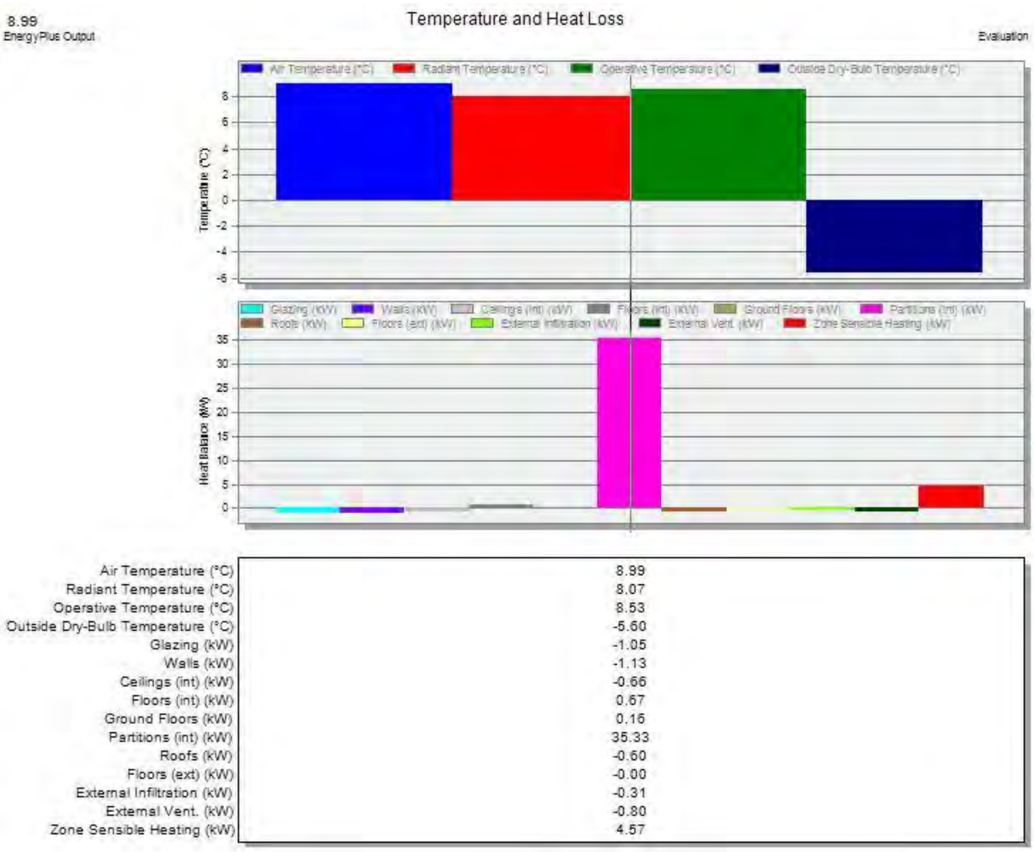


Figure C13. The heating results of Edinburgh.

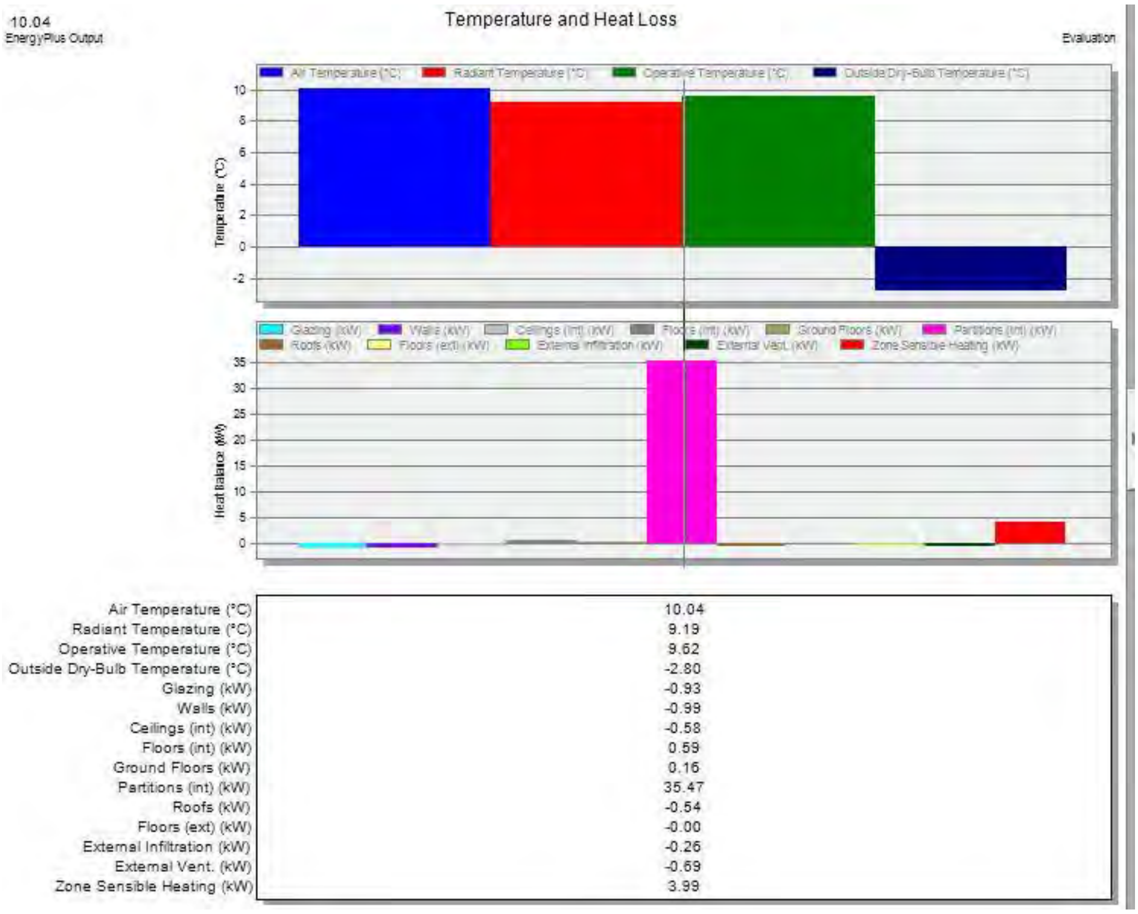


Figure C14. The heating results of Zaragoza.

Table C17. The heating results of Edinburgh and Zaragoza in different zones.

		Edinburgh		Zaragoza	
Block	Zone	Comfort Temperature (°C)	Steady-State Heat Loss (kW)	Comfort Temperature (°C)	Steady-State Heat Loss (kW)
House	Service 1	17.4	0.17	17.46	0.15
House	Bedroom (Western)	16.86	0.57	16.97	0.5
House	Dining Room, Hall	17.37	0.68	17.43	0.59
House	Bedroom (Central)	17.11	0.45	17.19	0.39
House	Bedroom (Eastern)	17	0.5	17.1	0.43
House	Kitchen	16.81	0.69	16.92	0.6
House	Service	17.4	0.17	17.46	0.15
House	Entrance Area	15.8	0.39	16	0.34
Garage	Garage Area	16.59	0.96	16.72	0.84

C.3.2 Cooling Results

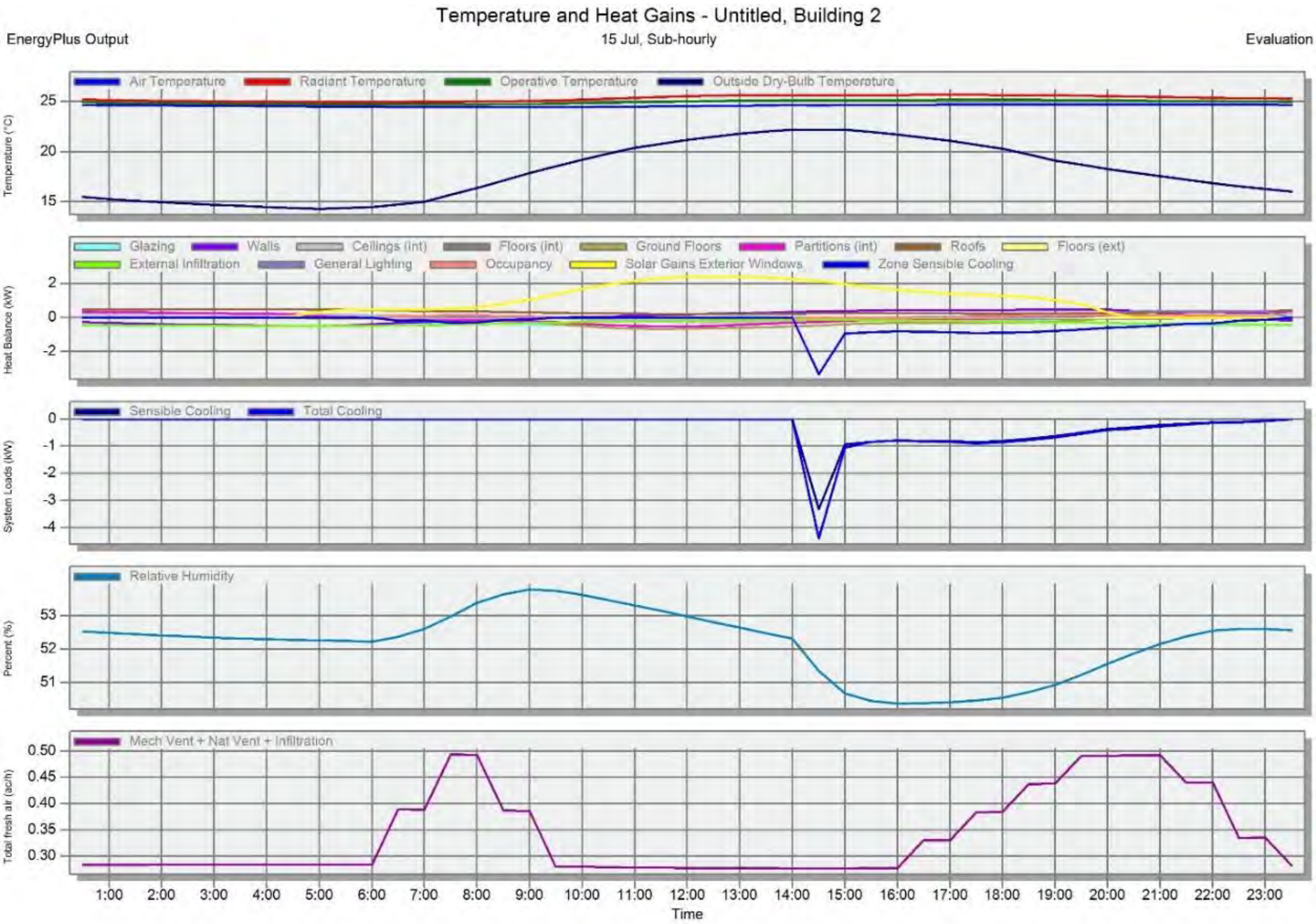


Figure C15. The cooling results of Edinburgh.

Table C18. The cooling results of Edinburgh in different zones.

Block	Design Flow Rate (m^3/s)	Total Cooling Load (kW)	Sensible (kW)	Humidity (%)	Max Op Temp in Day (°C)	Flow/Floor Area ($l/s\text{-}m^2$)
House	0.008502	0.12	0.12	45.9	25.8	1.5
House	0.006461	0.08	0.08	59.2	24.2	0.17
House	0.0067	0.09	0.09	47.7	26.2	0.68
House	0.00894	1.11	0.87	48	26.3	0.52
House	0.002624	0.03	0.03	56.9	25.5	0.21
House	0.007562	0.11	0.1	47	25.7	1.34
House	0.000457	0	0	65	22.3	0.23
Garage	0.00352	0.04	0.04	59.8	24.5	0.2
Pitched roof	0	0	0	-	25.5	0

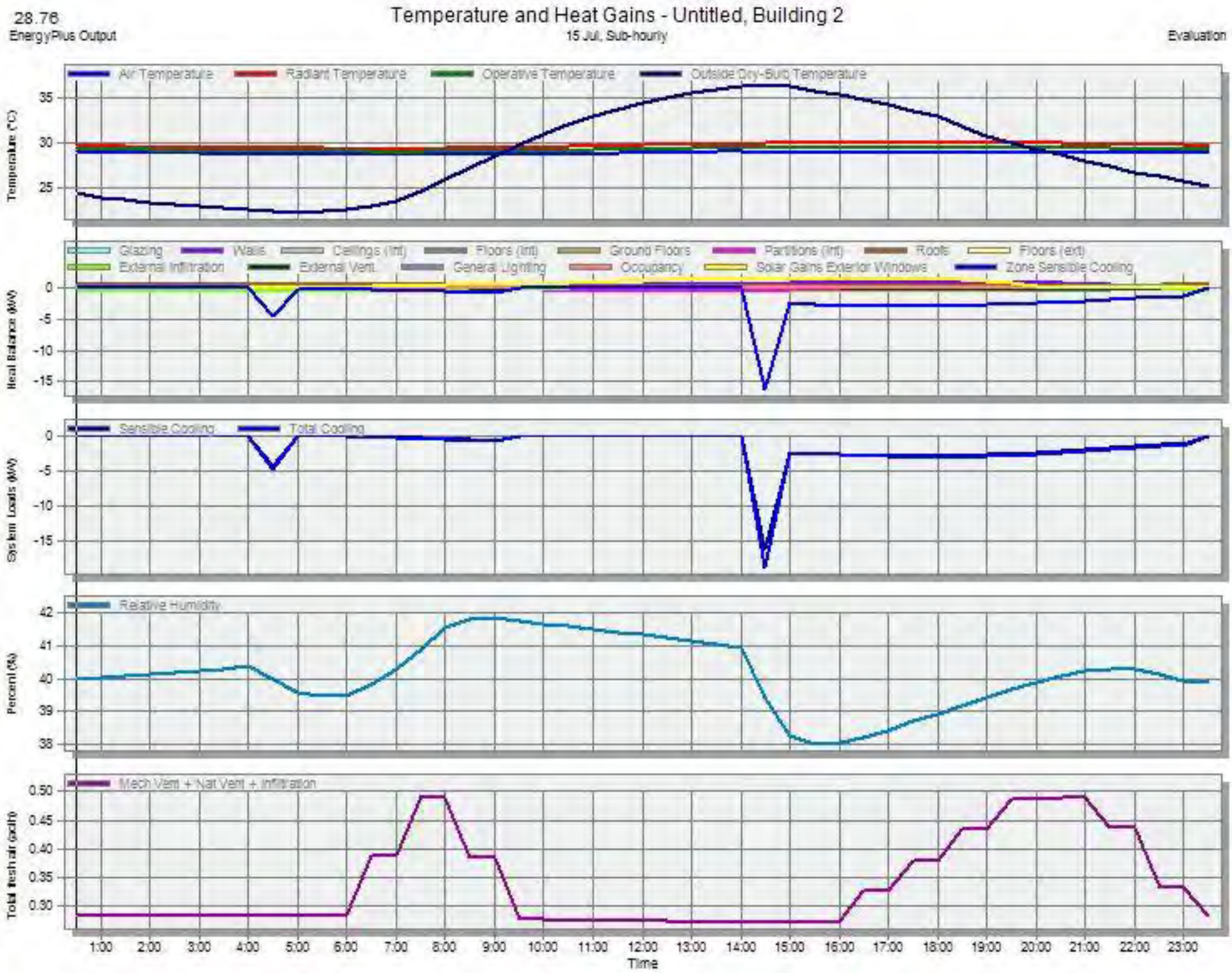


Figure C16. The cooling results of Zaragoza.

Table C19. The cooling results of Edinburgh in different Zaragoza.

Block	Design Flow Rate (m^3/s)	Total Cooling Load (kW)	Sensible (kW)	Humidity (%)	Max Op Temp in Day (°C)	Flow/Floor Area ($l/s\text{-}m^2$)
House	0.0418	0.63	0.56	45.6	26	7.4
House	0.1008	1.61	1.34	47.7	25.7	2.68
House	0.1307	1.98	1.74	45.5	26.1	9.32
House	0.1703	2.54	2.26	45	26.2	14.23
House	0.2129	3.12	2.83	44.8	26.5	16.81
House	0.0413	0.62	0.55	45.6	26	7.32
House	0.071	1.12	0.94	44.7	26.2	36.03
Garage	0.2528	4.12	3.36	45.6	26.3	14.34
Pitched roof	0	0	0	-	33.8	0

C.3.3 Simulation Results

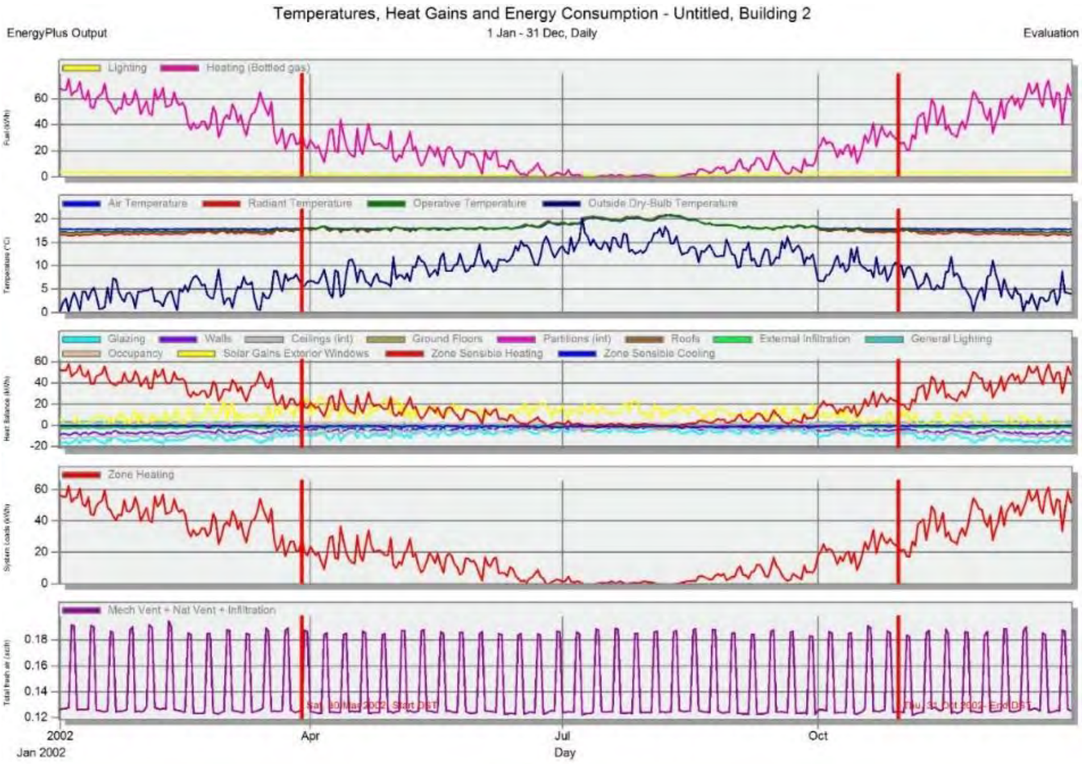


Figure C17. The simulation results of Edinburgh.

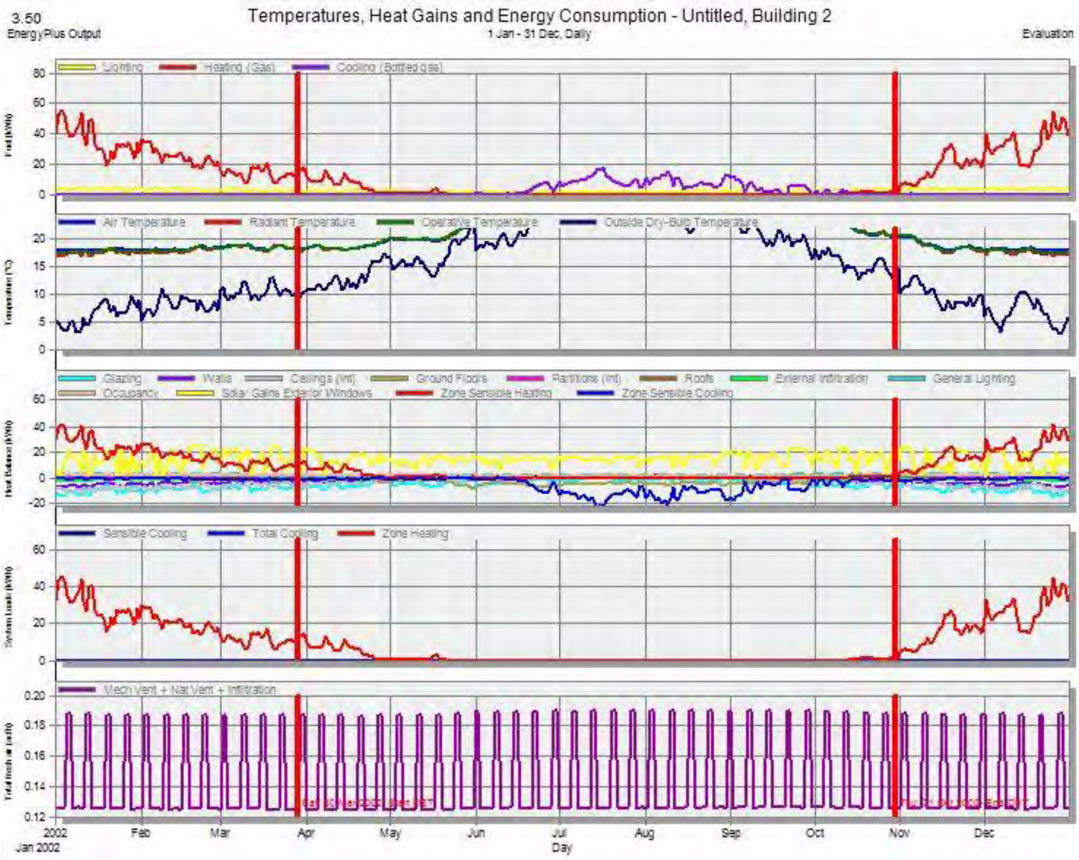


Figure C18. The simulation results of Zaragoza.

C.3.4 Site and Source Energy

Table C20. The total site and source energy of Edinburgh.

Edinburgh	Total Energy [kWh]	Energy Per Total Building Area [kWh/m^2]	Energy Per Conditioned Building Area [kWh/m^2]
Total Site Energy	9442.16	44.03	79.45
Total Source Energy	33733.74	157.31	283.85

Table C21. The total site and source energy of Zaragoza.

Zaragoza	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	5353.77	24.97	45.05
Total Source Energy	15807.12	73.71	133.01

C.3.5 Construction Costs for Timber Construction.

Construction Costs The estimated building construction cost data shown below is based on 'per gross internal floor area' costs of services, sub-structure and frame construction. The cost of construction and glazing is based on the 'per size' cost data from the construction and glazing database. Surface finish costs are also calculated from actual building surface areas and entered surface finish per area costing data.

Table C22. The estimated construction cost in Edinburgh and Zaragoza.

Structure Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	214.4	45032.2
HVAC Costs	**Floor Area (m2)**	**Cost (GBP)**
Sub Total	214.4	17826.4
Lighting Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	214.4	10695.9
Sub-Structure Costs	**Floor Area (m^2)**	**Cost (GBP)**
Sub Total	142.5	15675.0
Surface Finish Costs	**Surface Area (m^2)**	**Cost (GBP)**
Walls	382.9	4798.6
Floors	142.5	6412.5
Ceiling	142.5	675.0
Sub Total		11886
Building Total Cost (GBP)		**298681**

C.3.6 Embodied and Equivalent Carbon for Timber Construction.

The estimated embodied and comparable carbon data shown below is based on bulk carbon data obtained from the Bath ICE and other data sources. The embodied carbon associated with building services such as lighting and HVAC equipment is not covered in these results.

Equivalent carbon is similar to embodied carbon but also includes the effects of other greenhouse gases to provide an equivalent amount of CO^2 that would cause the same amount of global warming as the real greenhouse gases (which may include sulfur dioxide, methane, etc.) emitted by the processes involved in the production of the material.

Table C23. The estimated embodied and equivalent carbon data in Edinburgh and Zaragoza.

Materials Embodied Carbon and Inventory	**Area (m^2)**	**Embodied Carbon ($kgCO_2$)**	**Equivalent CO_2 ($kgCO_2$)**	**Mass (kg)**
Ceramic/clay tiles - clay tile burnt	146.9	3378.2	3525.1	7343.9
Wooden battons	146.9	25127.9	25127.9	53463.6
Painted Oak	57.6	0.0	0.0	1411.5
Plywood (Heavyweight)	745.0	8519.7	8835.2	10518.1
Timber Flooring	142.5	1704.3	1741.3	3705.0
External Rendering	7.2	23.4	23.4	234.0
Floor/Roof Screed	142.5	2188.8	2188.8	13680.0
Plasterboard	262.5	3798.5	3998.4	9996.0
Urea Formaldehyde Foam	142.5	507.3	547.2	285.0
MW Stone Wool (rolls)	7.2	55.6	59.3	53.0
MW Glass Wool (rolls)	262.5	515.0	565.5	336.6
XPS Extruded Polystyrene - CO2 Blowing	252.5	3054.5	10160.3	1060.6
Concrete Reinforced (with 2% steel)	142.5	18023.4	19186.2	58139.9
Cast Concrete (Lightweight)	240.0	2304.0	2304.0	28800.0
Cast Concrete (Dense)	10.4	175.4	175.4	2192.5
Asphalt	22.5	52.0	52.0	1039.5
R-21Fiberglass batt 2*6 in.(5.5 in. cavity)(Weighting Factor is 75% Insulated cavity)	152.4	0.0	0.0	329.2
Hardboard(high density)	152.4	0.0	0.0	2682.3
0.625 in. gypsum board	451.7	0.0	0.0	4962.2
Sub Total		69427.8	78490.0	200232.7

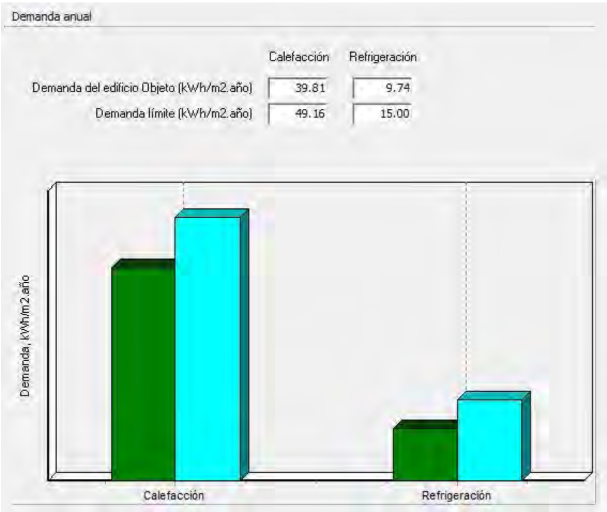
Table C24. The estimated glazing embodied and equivalent carbon data in Edinburgh and Zaragoza.

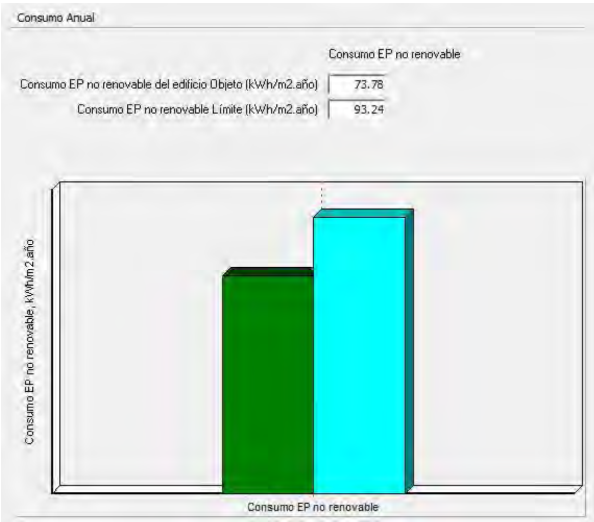
Glazing Embodied Carbon and Inventory	Area (m^2)	Embodied Carbon ($kgCO_2$)	Equivalent CO_2 ($kgCO_2$)
Glazing - Part L 2013 Notional Building	28.1	716.8	759.0
Local shading		0.0	0.0
Window Shading		0.0	0.0
Sub Total	28.1	716.8	759.0
Building Total	**1060.2**	**70144.7**	**79248.9**

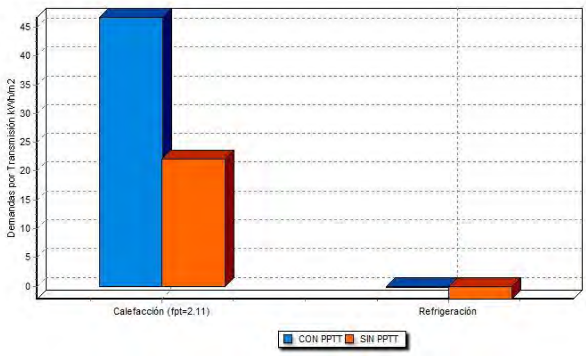
Appendix D. Results of HULC software

D1. Brick/Block Construction

D.1.1. Brick/Block Construction for Zaragoza with Uninsulated Pitched Roof.







	Clase	kWh/m²	kWh/año
Demanda calefacción	B	39.8	3592.7
Demanda refrigeración	A	9.7	879.2
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	55.7	5022.2
Consumo energía primaria no renovable refrigeración	A	9.5	859.0
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	B	73.8	6658.6
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	11.8	1063.5
Emisiones CO2 refrigeración	A	1.6	145.5
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	B	15.2	1373.7

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	39.8	3592.7
Refrigeración	9.7	879.2

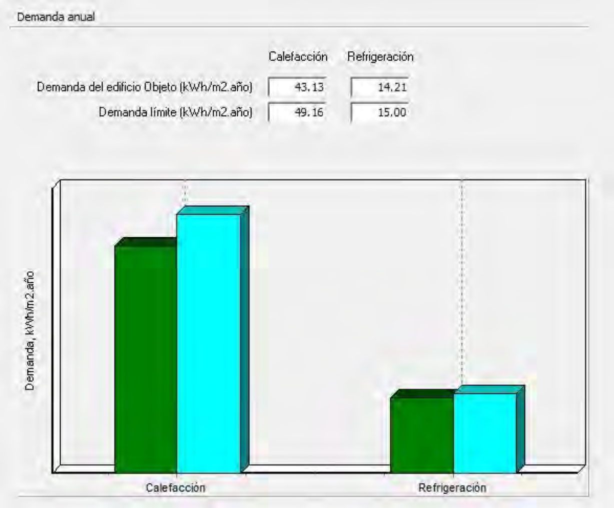
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	46.8	4220.4
Refrigeración	4.9	439.6
ACS	7.2	653.2
Global	58.9	5313.2

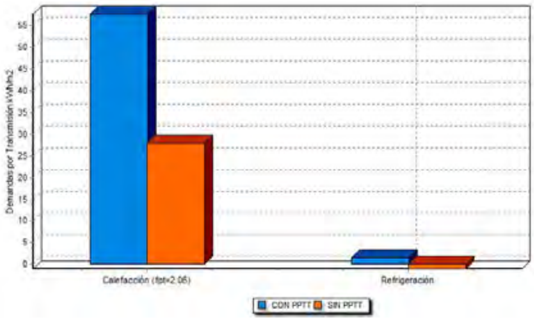
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	55.7	5022.2
Refrigeración	9.5	859.0
ACS	8.6	777.4
Global	73.8	6658.6

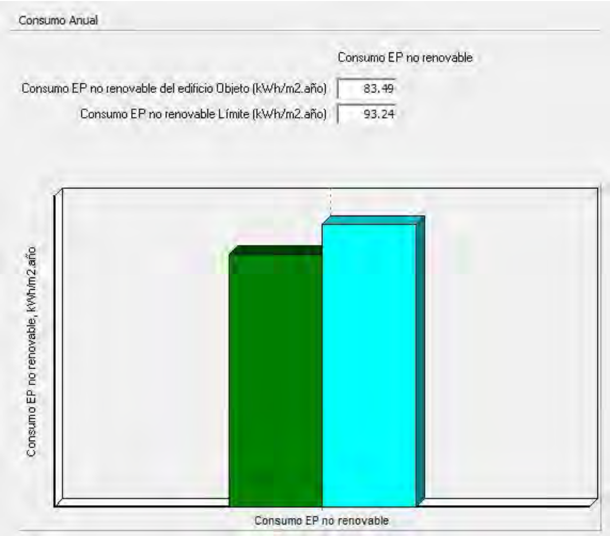
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	11.8	1063.5
Refrigeración	1.6	145.5
ACS	1.8	164.6
Global	15.2	1373.7

Figures D1. The results of HULC software for Brick/Block Construction in Zaragoza with Insulated Pitched Roof.

D.1.2. Brick/Block Construction for Zaragoza with Uninsulated Pitched Roof.



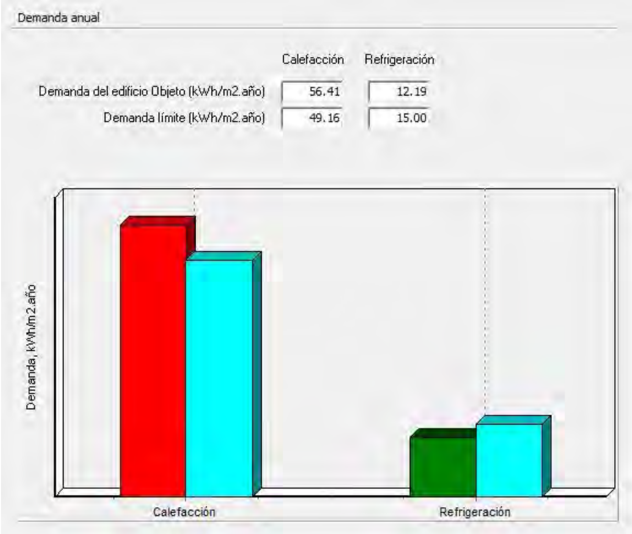


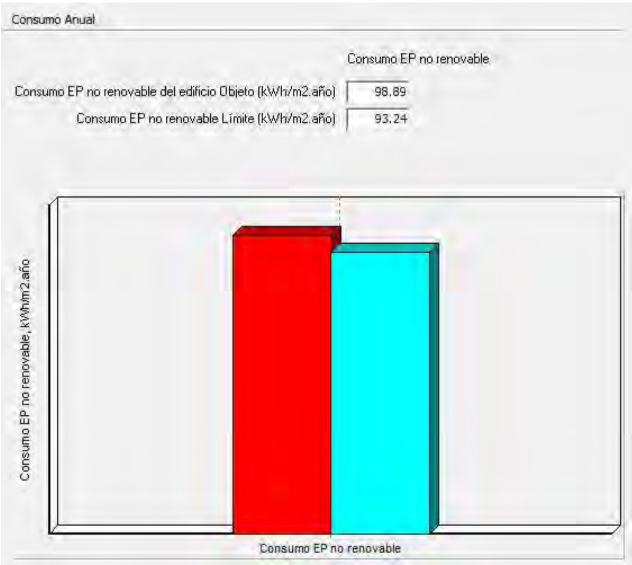


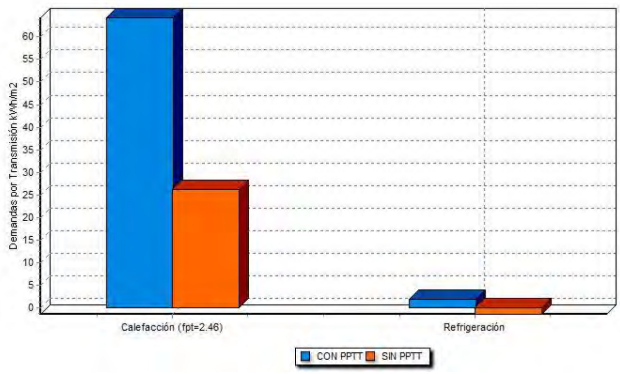
	Clase	kWh/m²	kWh/año
Demanda calefacción	B	43.1	3892.6
Demanda refrigeración	B	14.2	1282.0
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	61.0	5504.6
Consumo energía primaria no renovable refrigeración	B	13.9	1252.7
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	B	83.5	7534.7
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	12.9	1165.7
Emisiones CO2 refrigeración	A	2.4	212.2
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	B	17.1	1542.5

Figures D2. The results of HULC software for Brick/Block Construction in Zaragoza with Uninsulated Pitched Roof.

D.1.3. Brick/Block Construction for Zaragoza with Flat Roof







	Clase	kWh/m²	kWh/año
Demanda calefacción	C	56.4	5090.8
Demanda refrigeración	B	12.2	1099.9
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	C	78.4	7073.2
Consumo energía primaria no renovable refrigeración	B	11.9	1074.6
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	C	98.9	8925.2
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	C	16.6	1497.9
Emisiones CO2 refrigeración	A	2.0	182.0
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	C	20.4	1844.5

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	56.4	5090.8
Refrigeración	12.2	1099.9

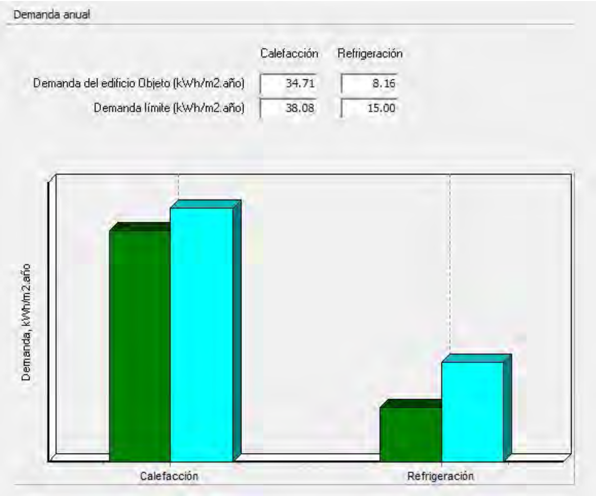
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	65.9	5943.9
Refrigeración	6.1	550.0
ACS	7.2	653.2
Global	79.2	7147.1

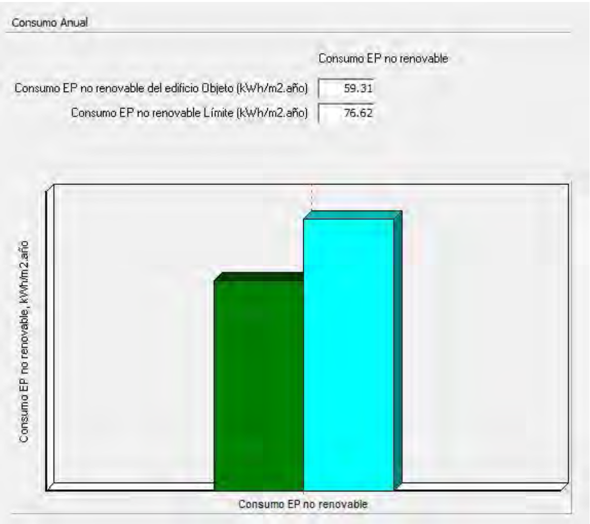
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	78.4	7073.2
Refrigeración	11.9	1074.6
ACS	8.6	777.4
Global	98.9	8925.2

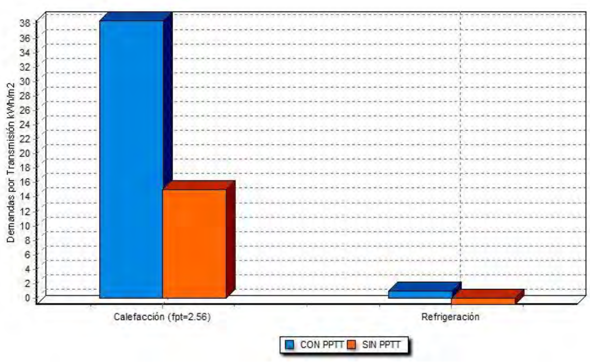
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	16.6	1497.9
Refrigeración	2.0	182.0
ACS	1.8	164.6
Global	20.4	1844.5

Figures D3. The results of HULC software for Brick/Block Construction in Zaragoza with flat Roof.

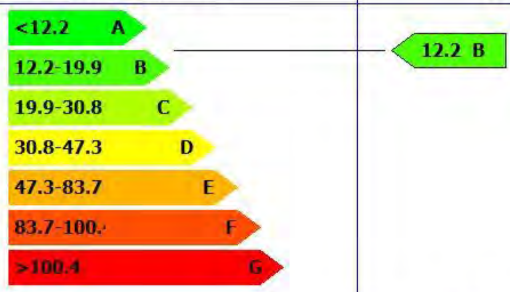
D.1.4. Brick/Block Construction for Zaragoza with Triple Glazed windows, (insulated Pitched Roof)







Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto		



	Clase	kWh/m²	kWh/año
Demanda calefacción	B	34.7	6264.9
Demanda refrigeración	A	8.2	1472.7
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	47.0	8489.1
Consumo energía primaria no renovable refrigeración	A	8.0	1438.9
Consumo energía primaria no renovable ACS	A	4.3	777.4
Consumo energía primariano renovable totales	B	59.3	10705.3
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	10.0	1797.7
Emisiones CO2 refrigeración	A	1.4	243.7
Emisiones CO2 ACS	A	0.9	164.6
Emisiones CO2 totales	B	12.2	2206.0

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	34.7	6264.9
Refrigeración	8.2	1472.7

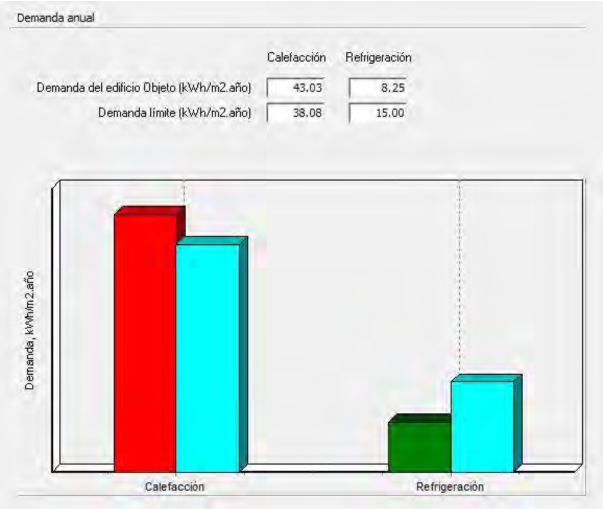
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	39.5	7133.7
Refrigeración	4.1	736.4
ACS	3.6	653.2
Global	47.2	8523.3

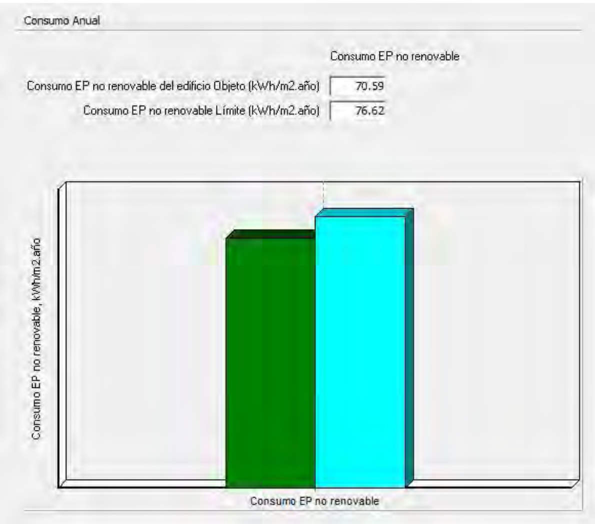
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	47.0	8489.1
Refrigeración	8.0	1438.9
ACS	4.3	777.4
Global	59.3	10705.3

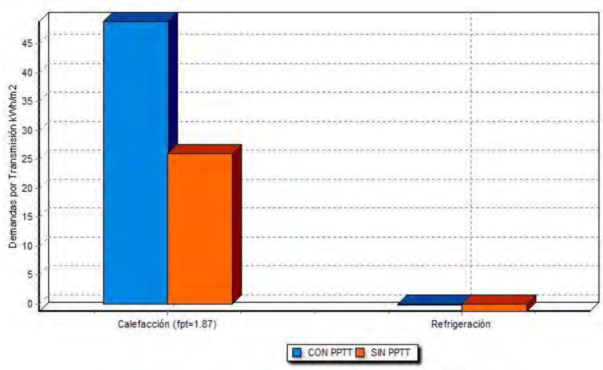
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	10.0	1797.7
Refrigeración	1.4	243.7
ACS	0.9	164.6
Global	12.2	2206.0

Figures D4. The results of HULC software for Brick/Block Construction in Zaragoza with Triple Glazed windows, (insulated Pitched Roof).

D.1.5. Brick/Block Construction for Zaragoza with Simple Glazed windows, (insulated Pitched Roof)







	Clase	kWh/m²	kWh/año
Demanda calefacción	B	43.0	7766.6
Demanda refrigeración	A	8.3	1489.2
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	58.2	10508.7
Consumo energía primaria no renovable refrigeración	A	8.1	1455.0
Consumo energía primaria no renovable ACS	A	4.3	777.4
Consumo energía primariano renovable totales	B	70.6	12741.0
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	12.3	2225.4
Emisiones CO2 refrigeración	A	1.4	246.5
Emisiones CO2 ACS	A	0.9	164.6
Emisiones CO2 totales	B	14.6	2636.5

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	43.0	7766.6
Refrigeración	8.3	1489.2

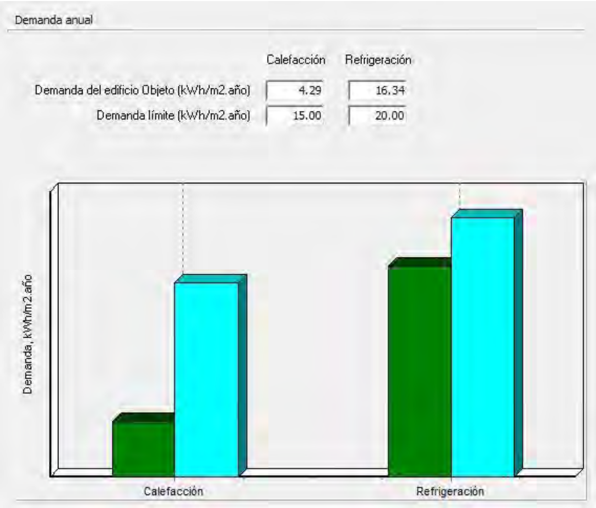
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	48.9	8830.8
Refrigeración	4.1	744.6
ACS	3.6	653.2
Global	56.7	10228.7

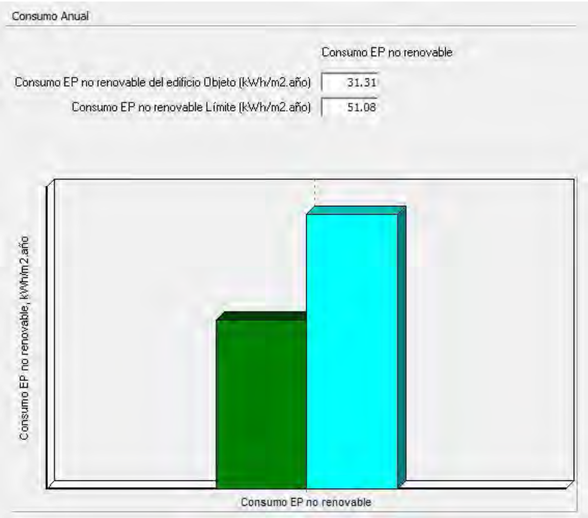
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	58.2	10508.7
Refrigeración	8.1	1455.0
ACS	4.3	777.4
Global	70.6	12741.0

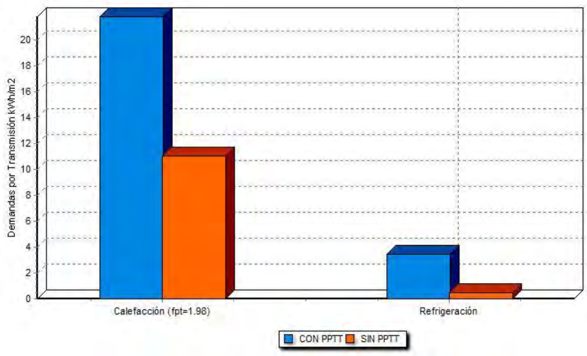
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	12.3	2225.4
Refrigeración	1.4	246.5
ACS	0.9	164.6
Global	14.6	2636.5

Figures D5. The results of HULC software for Brick/Block Construction in Zaragoza with Simple Glazed windows, (insulated Pitched Roof).

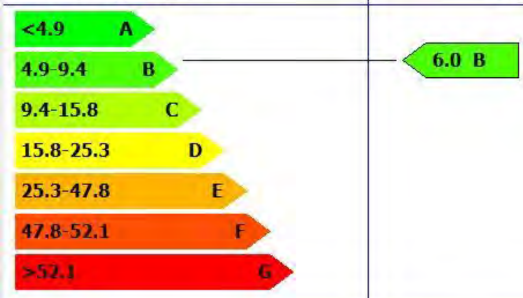
D.1.6. Brick/Block Construction for Almeria with insulated Pitched Roof.







Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto		



	Clase	kWh/m²	kWh/año
Demanda calefacción	A	4.3	387.3
Demanda refrigeración	B	16.3	1474.4
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	A	6.7	608.0
Consumo energía primaria no renovable refrigeración	B	16.0	1440.5
Consumo energía primaria no renovable ACS	D	8.6	777.4
Consumo energía primariano renovable totales	B	31.3	2825.8
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	A	1.4	128.7
Emisiones CO2 refrigeración	A	2.7	244.0
Emisiones CO2 ACS	D	1.8	164.6
Emisiones CO2 totales	B	6.0	537.4

	Edificio Objeto	
Demandas	**kWh/m2 año**	**kWh/año**
Calefacción	4.3	387.3
Refrigeración	16.3	1474.4

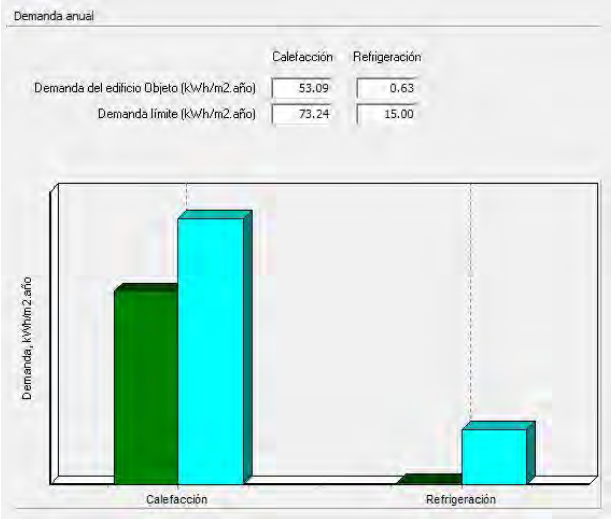
	Edificio Objeto	
Consumos Energía Final	**kWh/m² año**	**kWh/año**
Calefacción	5.7	510.9
Refrigeración	8.2	737.2
ACS	7.2	653.2
Global	21.1	1901.3

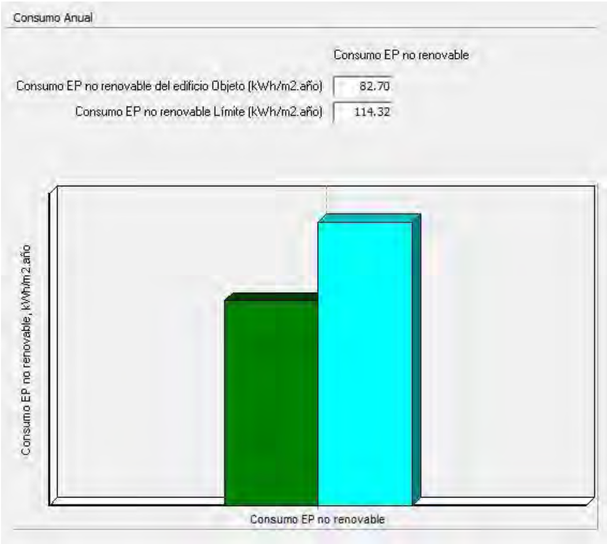
	Edificio Objeto	
Consumos Energía Primaria No Renovable	**kWh/m² año**	**kWh/año**
Calefacción	6.7	608.0
Refrigeración	16.0	1440.5
ACS	8.6	777.4
Global	31.3	2825.8

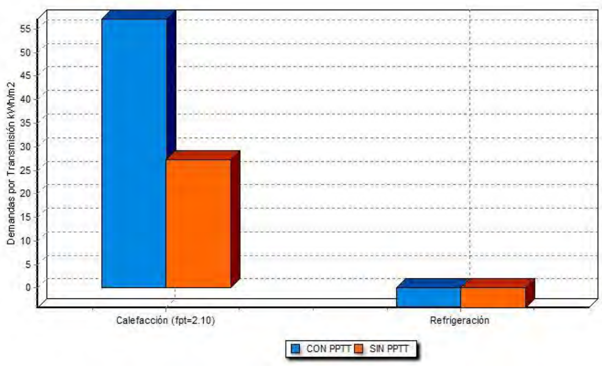
	Edificio Objeto	
Emisiones	**kgCO2/m² año**	**kgCO2/año**
Calefacción	1.4	128.7
Refrigeración	2.7	244.0
ACS	1.8	164.6
Global	6.0	537.4

Figures D6. The results of HULC software for Brick/Block Construction in Almeria with insulated Pitched Roof.

D.1.7. Brick/Block Construction in Avila with insulated Pitched Roof.







	Clase	kWh/m²	kWh/año
Demanda calefacción	B	53.1	4791.4
Demanda refrigeración	G	0.6	57.1
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	73.5	6630.3
Consumo energía primaria no renovable refrigeración	G	0.6	55.8
Consumo energía primaria no renovable ACS	A	8.6	777.4
Consumo energía primariano renovable totales	B	82.7	7463.5
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	15.6	1404.1
Emisiones CO2 refrigeración	G	0.1	9.5
Emisiones CO2 ACS	A	1.8	164.6
Emisiones CO2 totales	B	17.5	1578.1

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	53.1	4791.4
Refrigeración	0.6	57.1

	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	61.7	5571.7
Refrigeración	0.3	28.6
ACS	7.2	653.2
Global	69.3	6253.5

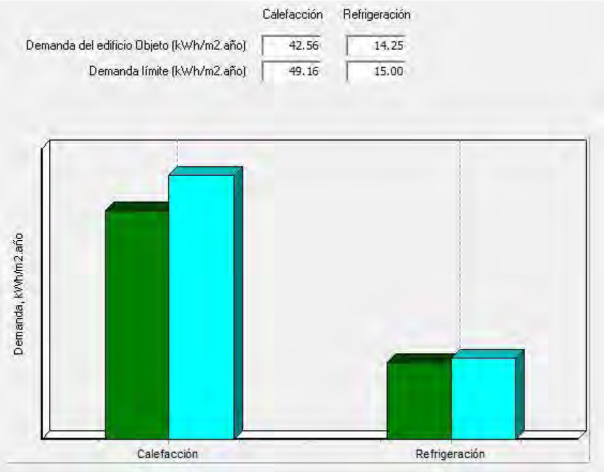
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	73.5	6630.3
Refrigeración	0.6	55.8
ACS	8.6	777.4
Global	82.7	7463.5

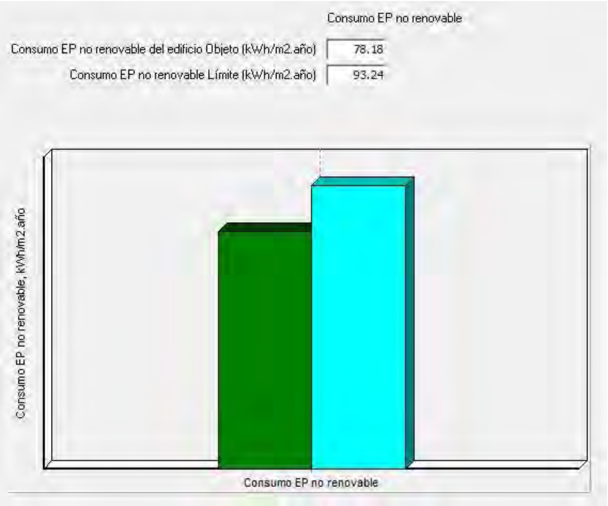
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	15.6	1404.1
Refrigeración	0.1	9.5
ACS	1.8	164.6
Global	17.5	1578.1

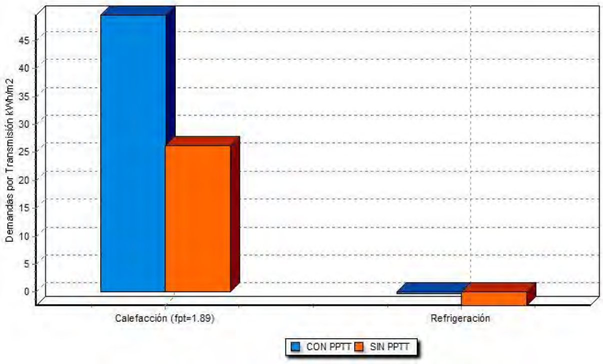
Figures D7. The results of HULC software for Brick/Block Construction in Avila with insulated Pitched Roof.

D.2. Metal Construction

D.2.1. Metal Construction for Zaragoza with Insulated Pitched Roof







	Clase	kWh/m²	kWh/año
Demanda calefacción	B	42.6	3841.0
Demanda refrigeración	B	14.2	1286.0
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	55.7	5022.0
Consumo energía primaria no renovable refrigeración	B	13.9	1256.7
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	B	78.2	7056.1
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	11.8	1063.5
Emisiones CO2 refrigeración	A	2.4	212.9
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	B	16.0	1441.0

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	42.6	3841.0
Refrigeración	14.3	1286.0

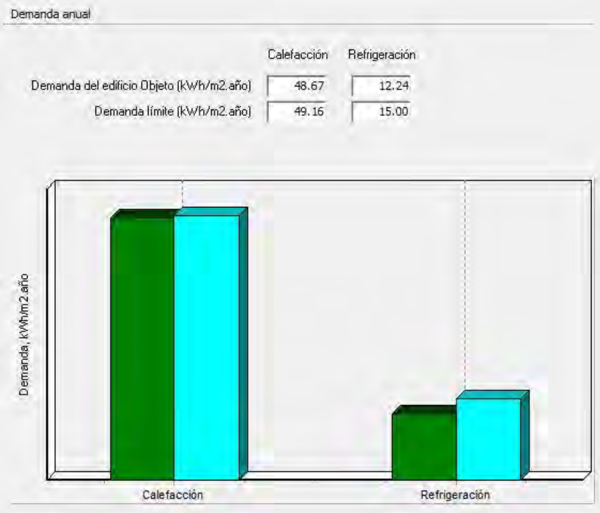
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	46.8	4220.2
Refrigeración	7.1	643.1
ACS	7.2	653.2
Global	61.1	5516.6

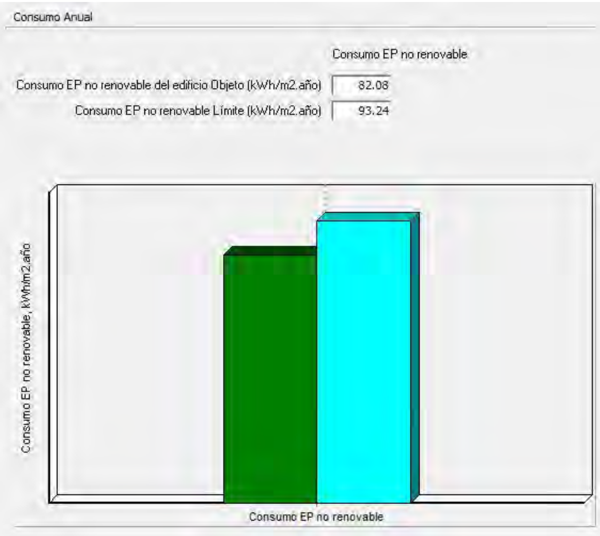
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	55.7	5022.0
Refrigeración	13.9	1256.7
ACS	8.6	777.4
Global	78.2	7056.1

	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	11.8	1063.5
Refrigeración	2.4	212.9
ACS	1.8	164.6
Global	16.0	1441.0

Figures D8. The results of HULC software for Metal Construction in Zaragoza with Insulated Pitched Roof.

D.2.2. Metal Construction for Zaragoza with fewer windows and insulated Pitched Roof.

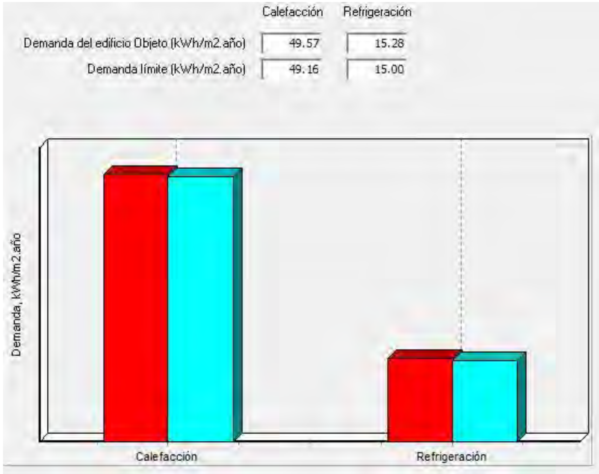


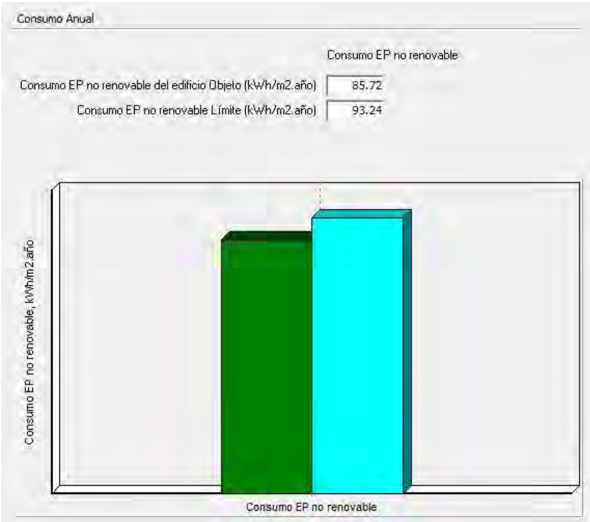


	Clase	kWh/m²	kWh/año
Demanda calefacción	C	48.7	4392.4
Demanda refrigeración	B	12.2	1104.3
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	61.5	5551.2
Consumo energía primaria no renovable refrigeración	B	12.0	1078.9
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	B	82.1	7407.5
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	13.0	1175.6
Emisiones CO2 refrigeración	A	2.0	182.8
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	B	16.9	1522.9

Figures D9. The results of HULC software for Metal Construction in Zaragoza with fewer windows and insulated Pitched Roof.

D.2.3. Metal Construction for Zaragoza with Uninsulated Pitched Roof

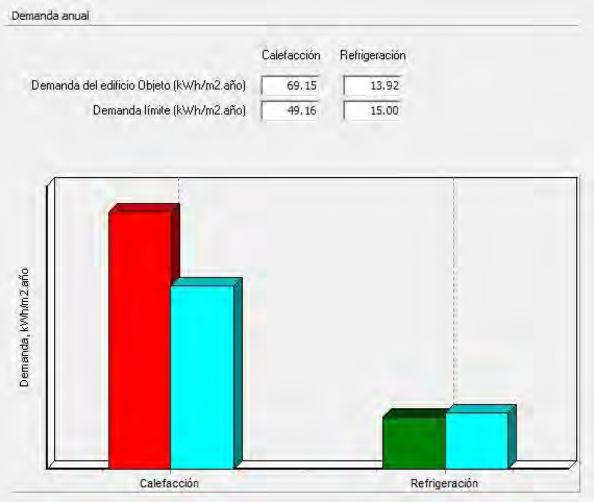


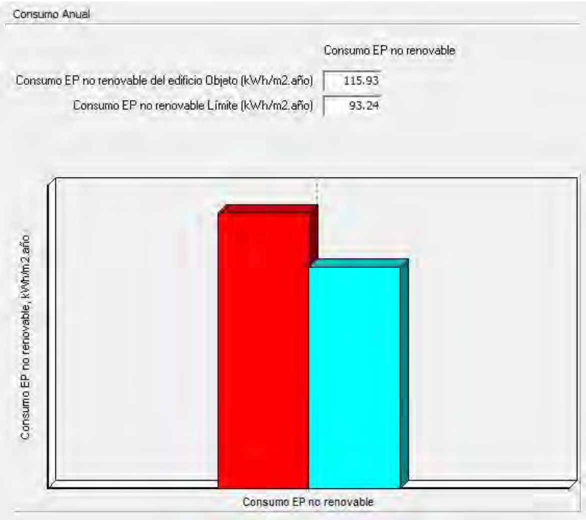


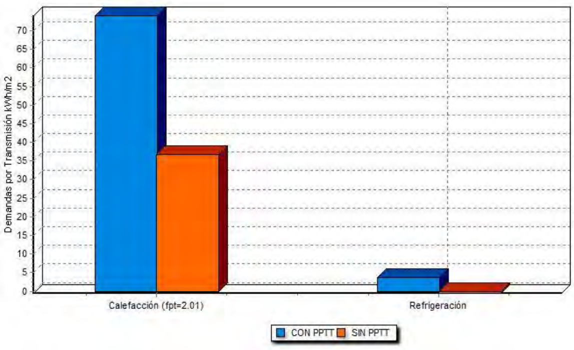
	Clase	kWh/m²	kWh/año
Demanda calefacción	C	49.6	4473.7
Demanda refrigeración	C	15.3	1379.5
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	62.2	5610.7
Consumo energía primaria no renovable refrigeración	C	14.9	1347.7
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	B	85.7	7735.8
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	13.2	1188.2
Emisiones CO2 refrigeración	B	2.5	228.3
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	B	17.5	1581.1

Figures D10. The results of HULC software for Metal Construction in Zaragoza with Uninsulated Pitched Roof.

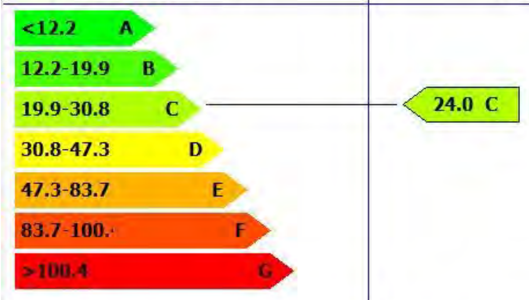
D.2.4. Metal Construction for Zaragoza with Flat Roof







Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto



	Clase	kWh/m²	kWh/año
Demanda calefacción	C	69.1	6240.4
Demanda refrigeración	B	13.9	1256.4
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	C	93.7	8457.8
Consumo energía primaria no renovable refrigeración	B	13.6	1227.5
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	C	115.9	10462.7
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	C	19.8	1791.1
Emisiones CO2 refrigeración	A	2.3	207.9
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	C	24.0	2163.6

	Edificio Objeto	
Demandas	**kWh/m2 año**	**kWh/año**
Calefacción	69.2	6240.4
Refrigeración	13.9	1256.4

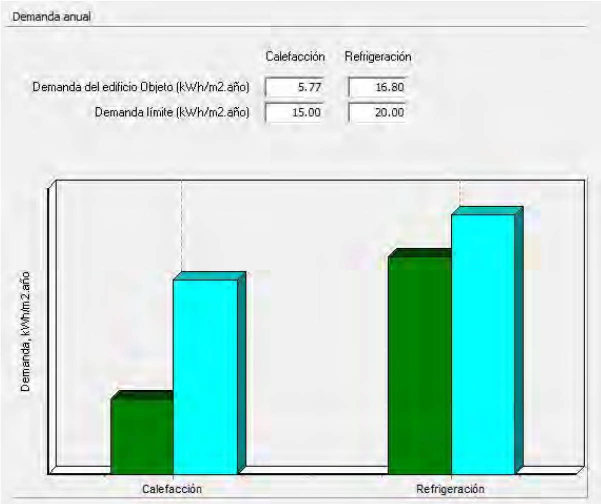
	Edificio Objeto	
Consumos Energía Final	**kWh/m² año**	**kWh/año**
Calefacción	78.8	7107.4
Refrigeración	7.0	628.2
ACS	7.2	653.2
Global	93.0	8388.9

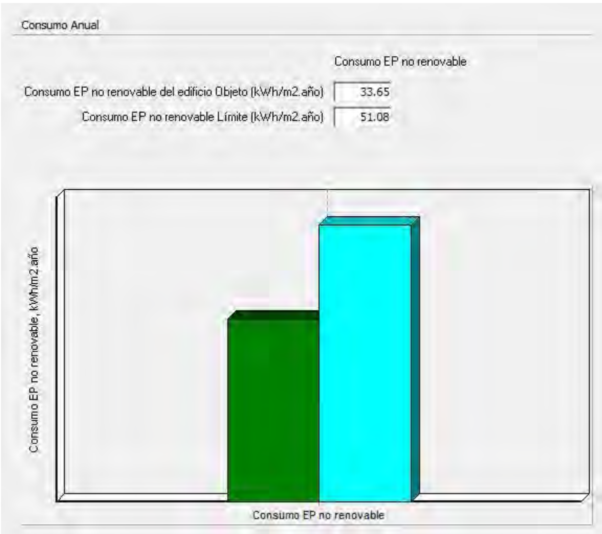
	Edificio Objeto	
Consumos Energía Primaria No Renovable	**kWh/m² año**	**kWh/año**
Calefacción	93.7	8457.8
Refrigeración	13.6	1227.5
ACS	8.6	777.4
Global	115.9	10462.7

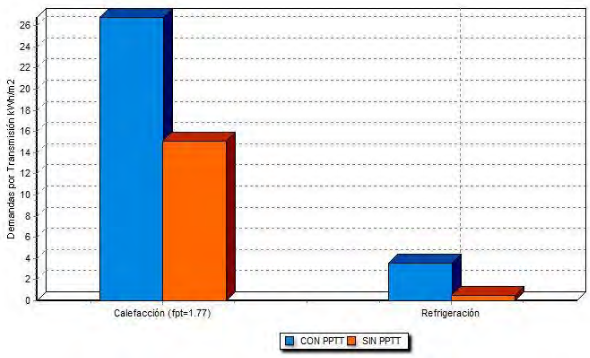
	Edificio Objeto	
Emisiones	**kgCO2/m² año**	**kgCO2/año**
Calefacción	19.9	1791.1
Refrigeración	2.3	207.9
ACS	1.8	164.6
Global	24.0	2163.6

Figures D11. The results of HULC software Metal Construction in Zaragoza with Flat Roof.

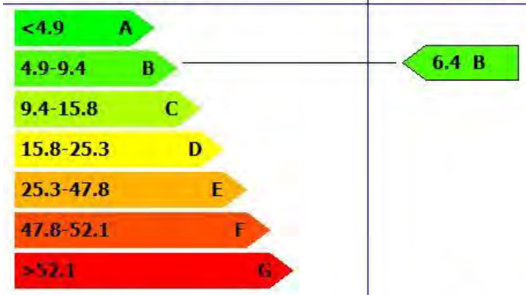
D.2.5. Metal Construction for Almeria with insulated Pitched Roof.







Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto



	Clase	kWh/m²	kWh/año
Demanda calefacción	B	5.8	520.8
Demanda refrigeración	B	16.8	1516.3
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	8.6	777.8
Consumo energía primaria no renovable refrigeración	B	16.4	1481.5
Consumo energía primaria no renovable ACS	D	8.6	777.4
Consumo energía primariano renovable totales	B	33.7	3036.7
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	1.8	164.7
Emisiones CO2 refrigeración	A	2.8	251.0
Emisiones CO2 ACS	D	1.8	164.6
Emisiones CO2 totales	B	6.4	580.3

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	5.8	520.8
Refrigeración	16.8	1516.3

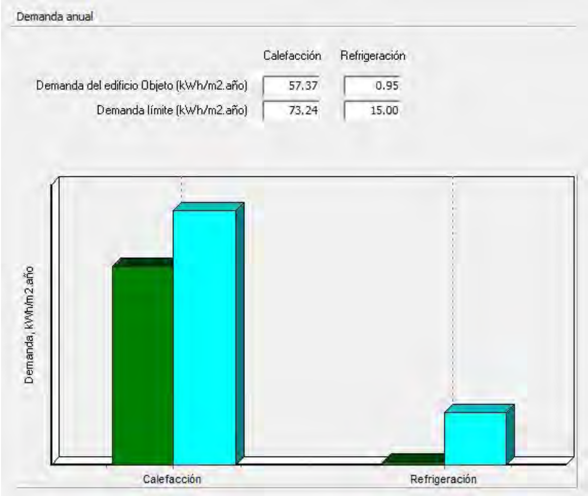
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	7.2	653.7
Refrigeración	8.4	758.2
ACS	7.2	653.2
Global	22.9	2065.1

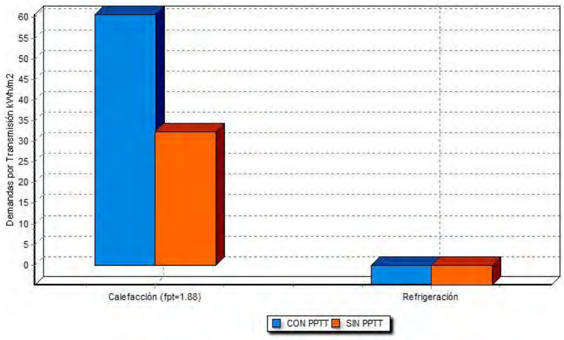
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	8.6	777.8
Refrigeración	16.4	1481.5
ACS	8.6	777.4
Global	33.7	3036.7

	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	1.8	164.7
Refrigeración	2.8	251.0
ACS	1.8	164.6
Global	6.4	580.3

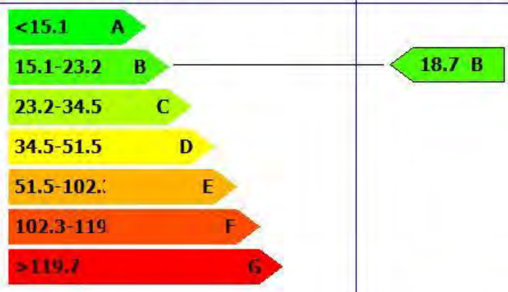
Figures D12. The results of HULC software Metal Construction in Almeria with insulated Pitched Roof.

D.2.6. Metal Construction for Avila with insulated Pitched Roof.





Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto		



	Clase	kWh/m²	kWh/año
Demanda calefacción	B	57.4	5177.7
Demanda refrigeración	G	0.9	85.5
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	78.8	7111.4
Consumo energía primaria no renovable refrigeración	G	0.9	83.5
Consumo energía primaria no renovable ACS	A	8.6	777.4
Consumo energía primariano renovable totales	B	88.3	7972.3
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	16.7	1505.9
Emisiones CO2 refrigeración	G	0.2	14.2
Emisiones CO2 ACS	A	1.8	164.6
Emisiones CO2 totales	B	18.7	1684.7

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	57.4	5177.7
Refrigeración	1.0	85.5

	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	66.2	5976.0
Refrigeración	0.5	42.7
ACS	7.2	653.2
Global	73.9	6671.9

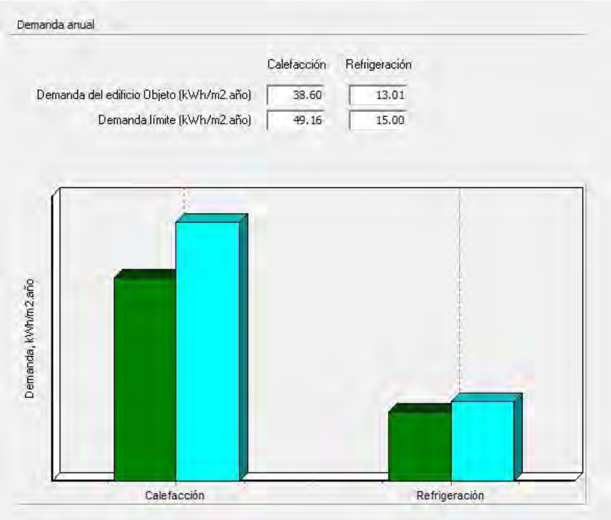
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	78.8	7111.4
Refrigeración	0.9	83.5
ACS	8.6	777.4
Global	88.3	7972.3

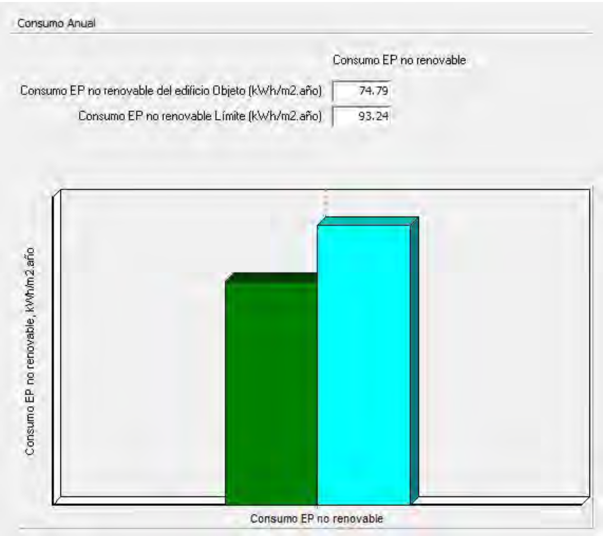
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	16.7	1505.9
Refrigeración	0.2	14.2
ACS	1.8	164.6
Global	18.7	1684.7

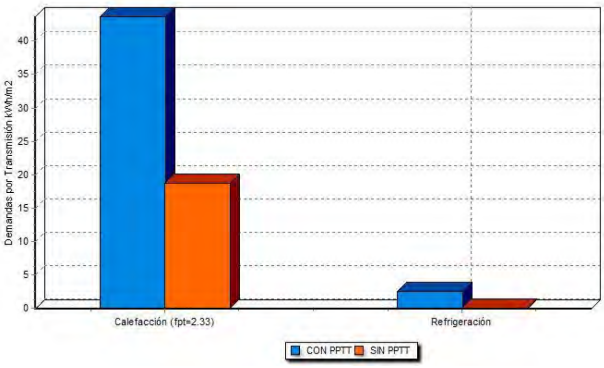
Figures D13. The results of HULC software Metal Construction in Avila with insulated Pitched Roof.

D.3. Timber Construction

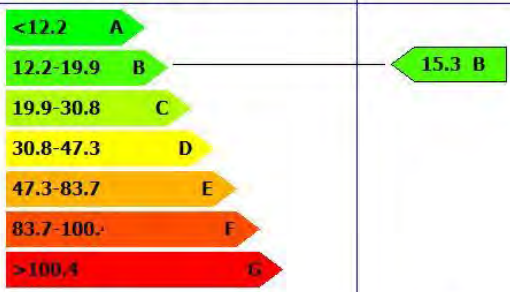
D.3.1. Timber Construction for Zaragoza with Insulated Pitched Roof.







Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto		



	Clase	kWh/m²	kWh/año
Demanda calefacción	B	38.6	3484.0
Demanda refrigeración	B	13.0	1174.2
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	53.5	4825.5
Consumo energía primaria no renovable refrigeración	B	12.7	1147.2
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	B	74.8	6750.0
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	11.3	1021.9
Emisiones CO2 refrigeración	A	2.2	194.3
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	B	15.3	1380.8

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	38.6	3484.0
Refrigeración	13.0	1174.2

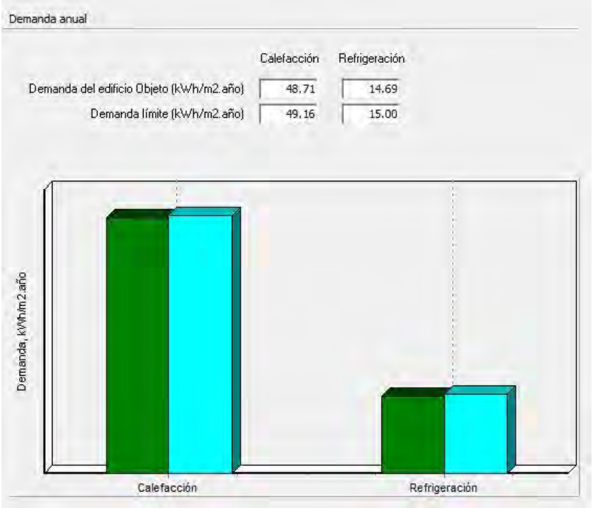
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	44.9	4055.1
Refrigeración	6.5	587.1
ACS	7.2	653.2
Global	58.7	5295.4

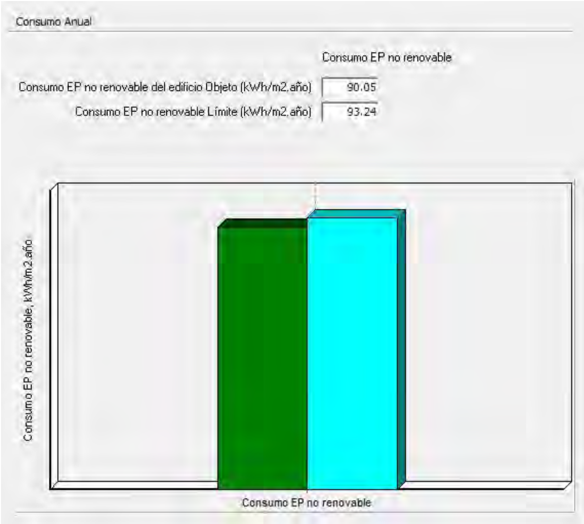
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	53.5	4825.5
Refrigeración	12.7	1147.2
ACS	8.6	777.4
Global	74.8	6750.0

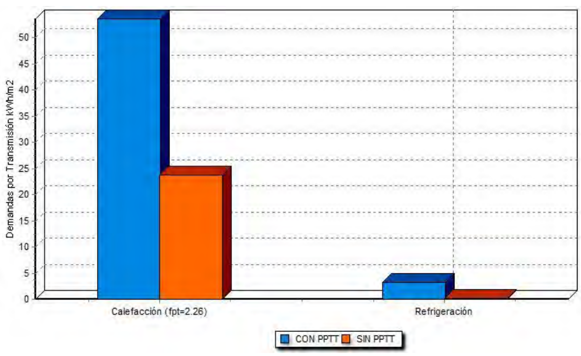
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	11.3	1021.9
Refrigeración	2.2	194.3
ACS	1.8	164.6
Global	15.3	1380.8

Figures D14. The results of HULC software for Timber Construction in Zaragoza with Insulated Pitched Roof.

D.3.2. Timber Construction for Zaragoza with Uninsulated Pitched Roof.







	Clase	kWh/m²	kWh/año
Demanda calefacción	C	48.7	4396.2
Demanda refrigeración	C	14.7	1325.6
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	67.1	6054.9
Consumo energía primaria no renovable refrigeración	B	14.4	1295.1
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	C	90.1	8127.3
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	14.2	1282.2
Emisiones CO2 refrigeración	A	2.4	219.4
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	B	18.5	1666.2

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	48.7	4396.2
Refrigeración	14.7	1325.6

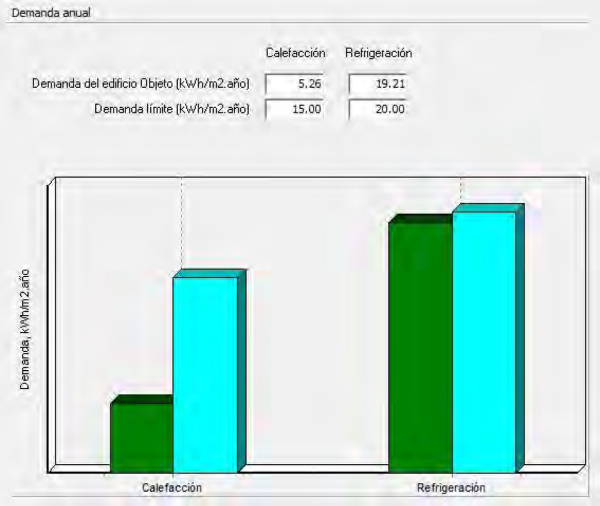
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	56.4	5088.1
Refrigeración	7.3	662.8
ACS	7.2	653.2
Global	71.0	6404.2

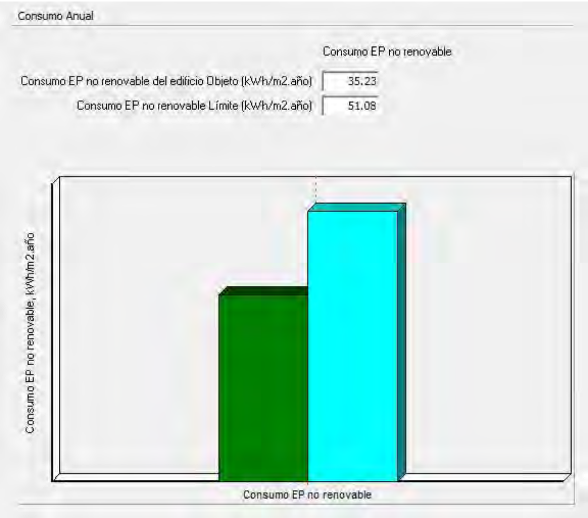
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	67.1	6054.9
Refrigeración	14.4	1295.1
ACS	8.6	777.4
Global	90.1	8127.3

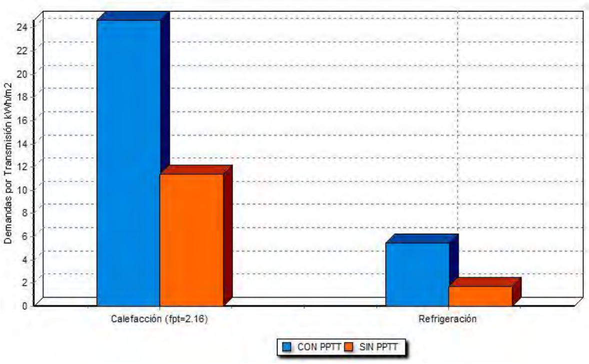
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	14.2	1282.2
Refrigeración	2.4	219.4
ACS	1.8	164.6
Global	18.5	1666.2

Figures D15. The results of HULC software for Timber Construction in Zaragoza with Uninsulated Pitched Roof.

D.3.3. Timber Construction for Almeria with Insulated Pitched Roof.







	Clase	kWh/m²	kWh/año
Demanda calefacción	B	5.3	475.1
Demanda refrigeración	B	19.2	1733.4
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	7.9	708.7
Consumo energía primaria no renovable refrigeración	B	18.8	1693.5
Consumo energía primaria no renovable ACS	D	8.6	777.4
Consumo energía primariano renovable totales	B	35.2	3179.5
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	A	1.7	150.1
Emisiones CO2 refrigeración	A	3.2	286.9
Emisiones CO2 ACS	D	1.8	164.6
Emisiones CO2 totales	B	6.7	601.6

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	5.3	475.1
Refrigeración	19.2	1733.4

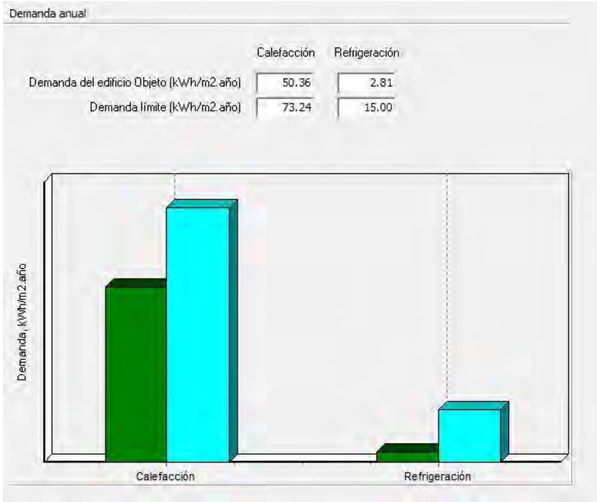
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	6.6	595.5
Refrigeración	9.6	866.7
ACS	7.2	653.2
Global	23.4	2115.4

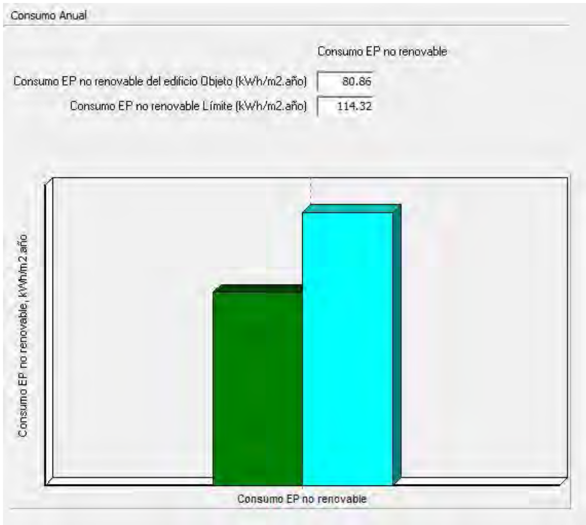
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	7.9	708.7
Refrigeración	18.8	1693.5
ACS	8.6	777.4
Global	35.2	3179.5

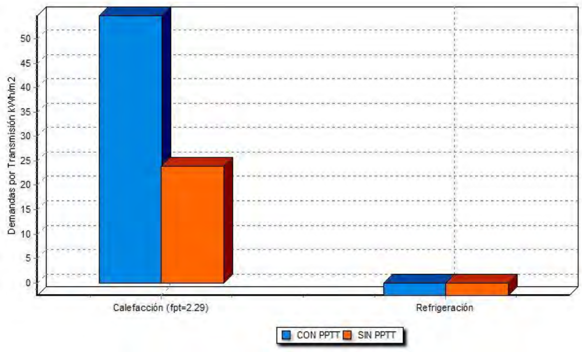
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	1.7	150.1
Refrigeración	3.2	286.9
ACS	1.8	164.6
Global	6.7	601.6

Figures D16. The results of HULC software for Timber Construction in Almeria with Insulated Pitched Roof.

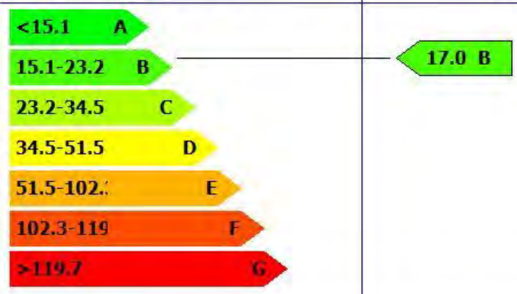
D.3.4. Timber Construction for Avila with insulated Pitched Roof.







Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto		



	Clase	kWh/m²	kWh/año
Demanda calefacción	B	50.4	4545.2
Demanda refrigeración	G	2.8	254.0
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	69.5	6272.5
Consumo energía primaria no renovable refrigeración	G	2.8	248.2
Consumo energía primaria no renovable ACS	A	8.6	777.4
Consumo energía primariano renovable totales	B	80.9	7298.0
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	A	14.7	1328.3
Emisiones CO2 refrigeración	G	0.5	42.0
Emisiones CO2 ACS	A	1.8	164.6
Emisiones CO2 totales	B	17.0	1534.9

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	50.4	4545.2
Refrigeración	2.8	254.0

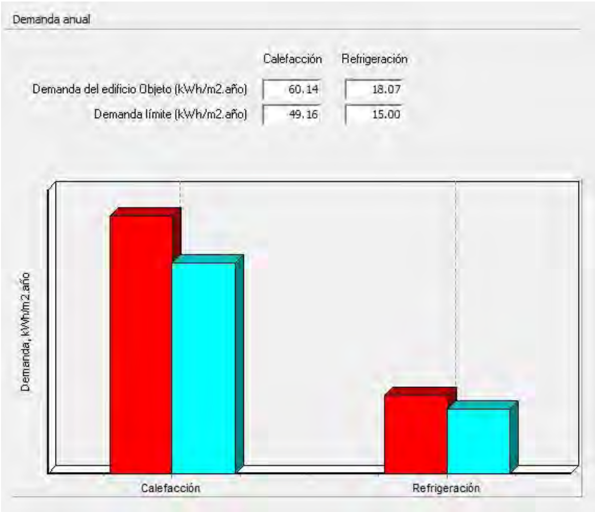
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	58.4	5271.0
Refrigeración	1.4	127.0
ACS	7.2	653.2
Global	67.1	6051.2

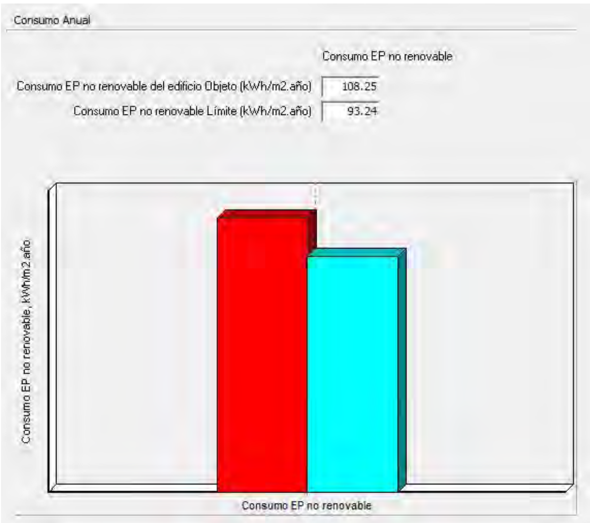
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	69.5	6272.5
Refrigeración	2.8	248.2
ACS	8.6	777.4
Global	80.9	7298.0

	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	14.7	1328.3
Refrigeración	0.5	42.0
ACS	1.8	164.6
Global	17.0	1534.9

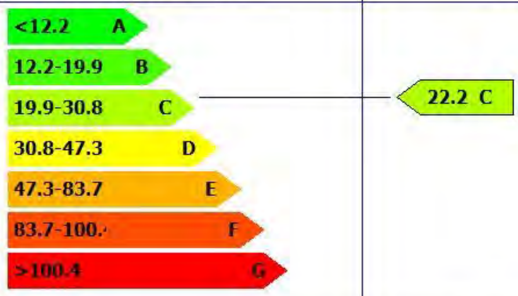
Figures D17. The results of HULC software for Timber Construction in Avila with insulated Pitched Roof.

D.3.5. Timber Construction in Zaragoza with Flat Roof.





Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto



	Clase	kWh/m²	kWh/año
Demanda calefacción	C	60.1	5427.8
Demanda refrigeración	C	18.1	1631.1
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	C	82.0	7398.4
Consumo energía primaria no renovable refrigeración	C	17.7	1593.5
Consumo energía primaria no renovable ACS	B	8.6	777.4
Consumo energía primariano renovable totales	C	108.3	9769.3
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	C	17.4	1566.7
Emisiones CO2 refrigeración	B	3.0	269.9
Emisiones CO2 ACS	B	1.8	164.6
Emisiones CO2 totales	C	22.2	2001.3

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	60.1	5427.8
Refrigeración	18.1	1631.1

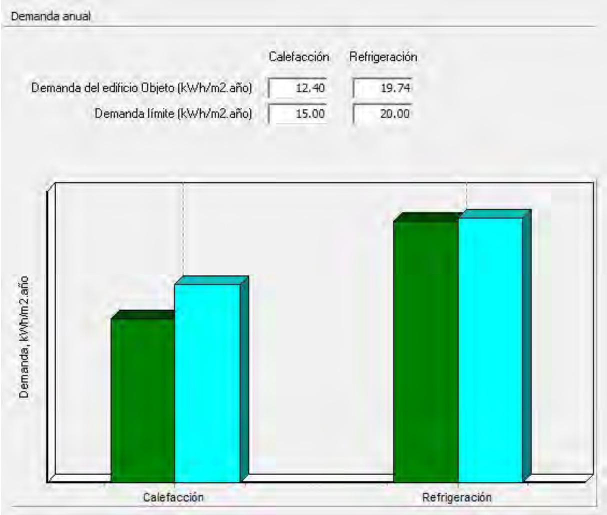
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	68.9	6217.1
Refrigeración	9.0	815.5
ACS	7.2	653.2
Global	85.2	7685.9

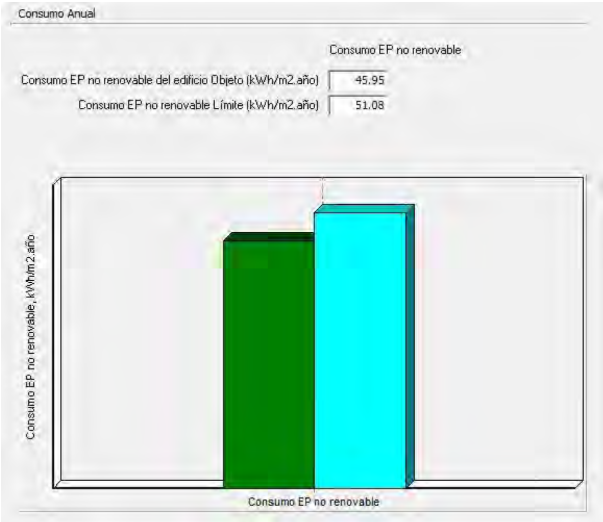
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	82.0	7398.4
Refrigeración	17.7	1593.5
ACS	8.6	777.4
Global	108.3	9769.3

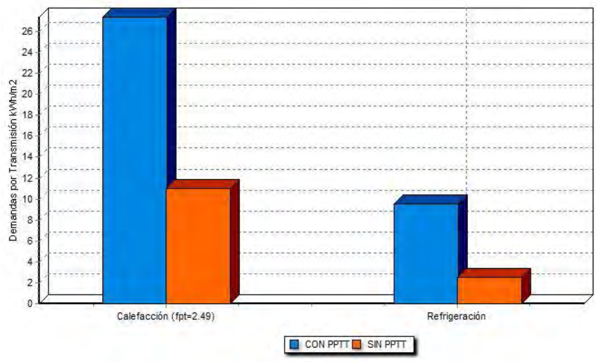
	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	17.4	1566.7
Refrigeración	3.0	269.9
ACS	1.8	164.6
Global	22.2	2001.3

Figures D18. The results of HULC software for Timber Construction in Zaragoza with Flat Roof.

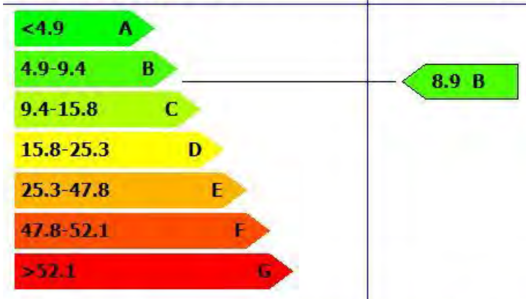
D.3.6. Timber Construction for Almeria with Flat roof.







Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto



	Clase	kWh/m²	kWh/año
Demanda calefacción	C	12.4	1118.7
Demanda refrigeración	B	19.7	1782.0
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	C	18.1	1628.8
Consumo energía primaria no renovable refrigeración	B	19.3	1741.0
Consumo energía primaria no renovable ACS	D	8.6	777.4
Consumo energía primariano renovable totales	C	46.0	4147.2
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	C	3.8	344.9
Emisiones CO2 refrigeración	A	3.3	294.9
Emisiones CO2 ACS	D	1.8	164.6
Emisiones CO2 totales	B	8.9	804.5

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	12.4	1118.7
Refrigeración	19.8	1782.0

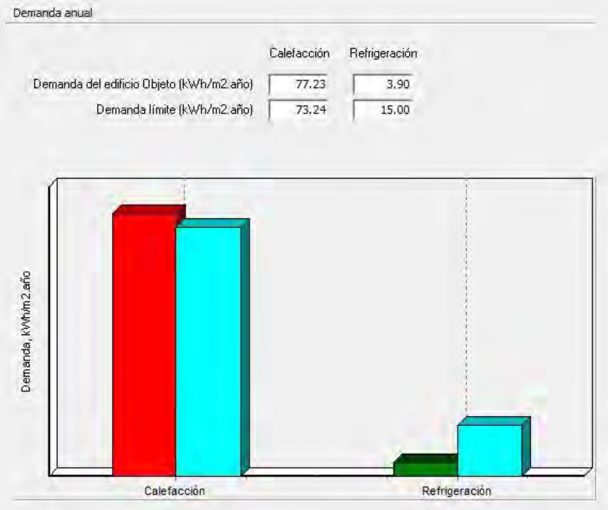
	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	15.2	1368.8
Refrigeración	9.9	891.0
ACS	7.2	653.2
Global	32.3	2913.0

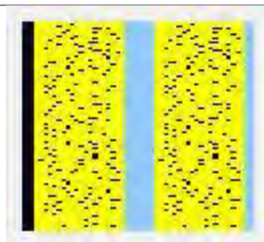
	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	18.1	1628.8
Refrigeración	19.3	1741.0
ACS	8.6	777.4
Global	46.0	4147.2

	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	3.8	344.9
Refrigeración	3.3	294.9
ACS	1.8	164.6
Global	8.9	804.5

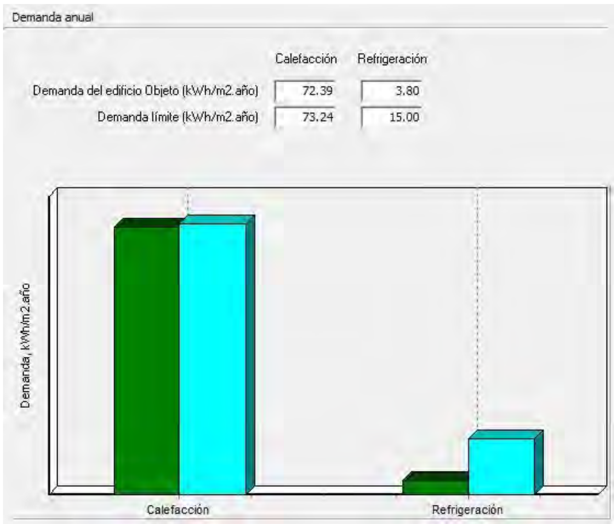
Figures D19. The results of HULC software for Timber Construction in Almeria with Flat roof.

D.3.7. Timber Construction for Avila with Flat Roof.

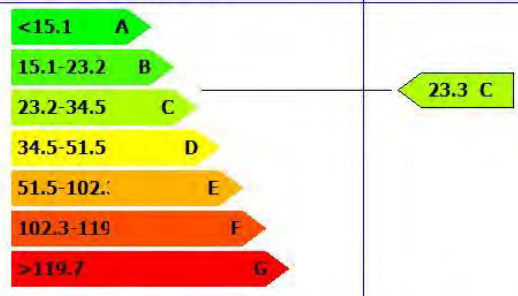


Material	Espesor [m]	Conductividad [W/Mk]	Densidad [kg/m³]	C_p [J/Kg·K]	U-value [W/m²K]
Asfalto arenoso	0.022	0.150	2100	1000	0.08
XPS expandido con HFC [0,025 W/mK]	0.150	0.025	38	1000	
Cámara e aire ligeramente ventilada horizontal	0.02	Resistencia térmica [m²K/W]			
		0.080			
XPS expandido con HFC [0,025 W/mK]	0.150	0.025	38	1000	
Cámara e aire ligeramente ventilada horizontal	0.01	Resistencia térmica [m²K/W]			
		0.075			
Enlucido de yeso aislante	0.020	0.180	550	1000	

Regards to the previous kinds of flat roof materials, the limitation of heating demand have exceeded; the problem will solve with increasing the amount of the insulation layer according to the above figure. It demonstrates the influence of the insulation materials on heating.



Certificación Energética de Edificios Indicador kgCO2/m² año	Edificio Objeto



	Clase	kWh/m²	kWh/año
Demanda calefacción	C	72.4	6533.0
Demanda refrigeración	G	3.8	342.6
	Clase	kWh/m²	kWh/año
Consumo energía primaria no renovable calefacción	B	98.4	8878.9
Consumo energía primaria no renovable refrigeración	G	3.7	334.7
Consumo energía primaria no renovable ACS	A	8.6	777.4
Consumo energía primariano renovable totales	C	110.7	9990.9
	Clase	kgCO2/m² año	kgCO2/año
Emisiones CO2 calefacción	B	20.8	1880.2
Emisiones CO2 refrigeración	G	0.6	56.7
Emisiones CO2 ACS	A	1.8	164.6
Emisiones CO2 totales	C	23.3	2101.5

	Edificio Objeto	
Demandas	kWh/m2 año	kWh/año
Calefacción	72.4	6533.0
Refrigeración	3.8	342.6

	Edificio Objeto	
Consumos Energía Final	kWh/m² año	kWh/año
Calefacción	82.7	7461.2
Refrigeración	1.9	171.3
ACS	7.2	653.2
Global	91.8	8285.8

	Edificio Objeto	
Consumos Energía Primaria No Renovable	kWh/m² año	kWh/año
Calefacción	98.4	8878.9
Refrigeración	3.7	334.7
ACS	8.6	777.4
Global	110.7	9990.9

	Edificio Objeto	
Emisiones	kgCO2/m² año	kgCO2/año
Calefacción	20.8	1880.2
Refrigeración	0.6	56.7
ACS	1.8	164.6
Global	23.3	2101.5

Figures D20. The results of HULC software for Timber Construction in Avila with Flat Roof.

Appendix E. The characteristics and full details of 12 case studies of activities 4, 5 and 6

The overall data regarding this appendix have been offered by assessors accredited by Elmhurst, an Approved Organization Appointed by Scottish Ministers. The information has been produced under the Energy Performance of Buildings (Scotland) Regulations 2008 from data lodged to the Scottish EPC register.

E.1. Case 1. Traditional house (age = 102)

Two stories detached villa with surrounding garden grounds and double garage. The property is located in the Barnton area of Edinburgh approximately four miles North West of Edinburgh City Centre and a first class residential area. In the house, one insulated wall and roof have been measured.

Figure E.1 The location, picture, DesignBuilder visualisation image and plan of case 1.

E.1.1 Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.1 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Cavity wall with insulation	★★★☆☆	0.79*
Roof	Pitched, 50 mm loft insulation	★★★★☆	0.43
Floor	Suspended, no insulation	-	0.64
Windows	Fully double glazed	★★★☆☆	
Main heating	Boiler and radiators, mains gas	★★★★☆	
Main heating controls	Programmer, room thermostat and TRVs	★★★★☆	
Secondary heating	None	-	
Hot water	From main system	★★★★☆	
Lighting	Low energy lighting in 91% of fixed outlets	★★★★★	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.1.2 Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.2 The recommended measures and their results on energy and environmental performance.

Recommended Measure	Indicative cost	Typical savings per year	Rating after improvement		Green Deal[2]
			Energy	Environment	
Cavity wall insulation	£500 - £1,500	£212	C 73	D 67	✔
Floor insulation (suspended floor)	£800 - £1,200	£120	C 76	C 70	✔
Replace boiler with new condensing boiler	£2,200 - £3,000	£200	C 79	C 75	✔
Replacement glazing units	£1,000 - £1,400	£79	C 80	C 78	✔
5 Solar photovoltaic panels, 2.5 kWp.	£5,000 - £8,000	£255	B 86	B 82	✔

Table E.3 The current and potential energy efficiency and environmental rating.

	Current[3]	Potential[4]
Energy Efficiency Rating*	C 69	B 86
Environmental Impact CO_2 Rating**	D 62	B 82

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.1.3 Alternative measures

There are alternative improvement measures which residences could also consider for the home. It would be advisable to seek further advice and illustration of the benefits and costs of such measures.

External insulation with cavity wall insulation.

Biomass boiler (Exempted Appliance if in Smoke Control Area).

Air or ground source heat pump.

Micro Combined Heat and Power (CHP).

E.1.4. Estimated energy costs for the house

The following table shows how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.4 The current and potential energy cost.

	Current energy costs	Potential energy costs
Heating	£4,107 over three years	£2,412 over three years
Hot water	£522 over three years	£387 over three years
Lighting	£312 over three years	£312 over three years
Totals	£4,941	£3,111
Potential future savings over three years	£1,830	

E.1.5 Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating tool with one which generates renewable heat and, where appropriate, cavity walls filled and having the loft insulated. The estimated energy need for water heating and space will form the basis of the costs.

Table E.5 The estimated heat demand for space and water heating.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	21,650	N/A	(3,695)	N/A
Water hating (kWh per year)	2,879			

Table E.6 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 1

House elements				Installations	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiator
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Shading internal/ external	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Upgraded existing window (glass, fitting, etc.)	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			Biomass boiler
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.2. Case 2. Traditional house (age = 107)

The property comprises a detached villa with attic accommodation. The residential area is involving similar style properties lying to the north of Edinburgh city.

Edinburgh
EH4 2AR

Gross internal floor area:

184 m²

Age:

107 (1910)

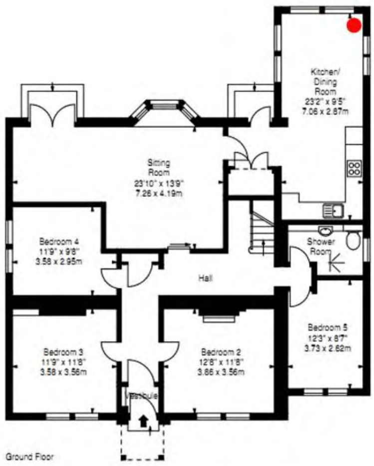


Figure E.2 The location, picture, DesignBuilder visualisation image and plan of case 2.

E.2.1 Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.7 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Cavity wall with little insulation	★★☆☆☆	0.89*
Roof	Pitched, 400 mm loft insulation	★★★★★	0.84
	Roof rooms, insulated	★★★★☆	0.68
Floor	Suspended, insulated	-	1.1
Windows	Partial double glazed	★★★☆☆	
Main heating	Boiler and radiators, mains gas	★★★★☆	
Main heating controls	Programmer, TRVs and bypass	★★★☆☆	
Secondary heating	None	-	
Hot water	From the main system, no cylinder thermostat	★★★☆☆	
Lighting	Low energy lighting in all fixed outlets	★★★★★	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.2.2 Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.8 The recommended measures and their results on energy and environmental performance.

Recommended Measure	Indicative cost	Typical savings per year	Rating after improvement		Green Deal[2]
			Energy	Environment	
Cavity wall insulation	£500 - £1,500	£420	C 70	D 63	
Solar water heating	£4,000 - £6,000	£140	C 73	C 67	
5 Solar photovoltaic panels, 2.5 kWp.	£5,000 - £8,000	£251	B 78	B 72	

Table E.9 The current and potential energy efficiency and environmental rating.

	Current[3]	Potential[4]
Energy Efficiency Rating*	D 61	C 78
Environmental Impact CO_2 Rating**	E 51	D 72

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.2.3 Alternative measures

There are alternative improvement measures which residences could also consider for the home. It would be advisable to seek further advice and illustration of the benefits and costs of such measures.

External insulation with cavity wall insulation.

Biomass boiler (Exempted Appliance if in Smoke Control Area).

Air or ground source heat pump.

Micro CHP.

E.2.4 Estimated energy costs for the house

The following table show how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.10 The current and potential energy cost.

	Current energy costs	Potential energy costs
Heating	£4,434 over three years	£3,351 over three years
Hot water	£897 over three years	£303 over three years
Lighting	£258 over three years	£258 over three years
Totals	£5,589	£3,912
Potential future savings over three years	£1,677	

E.2.5 Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.11 The estimated heat demand for space and water heating.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	25,310	N/A	(7,961)	N/A
Water heating (kWh per year)	5,365			

Table E.12 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 2

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Shading internal/ external	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Upgraded existing window (glass, fitting, etc.)	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			Biomass boiler
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.3 Case 3. Traditional house (age = 115)

The property comprises a two-floor, detached house. The subjects are situated to the south of Edinburgh's City Centre within a residential area where some surrounding features are of a similar age, type, and character.

Edinburgh
EH13 0DT

Gross internal floor area:

377 m²

Age:

115 (1902)

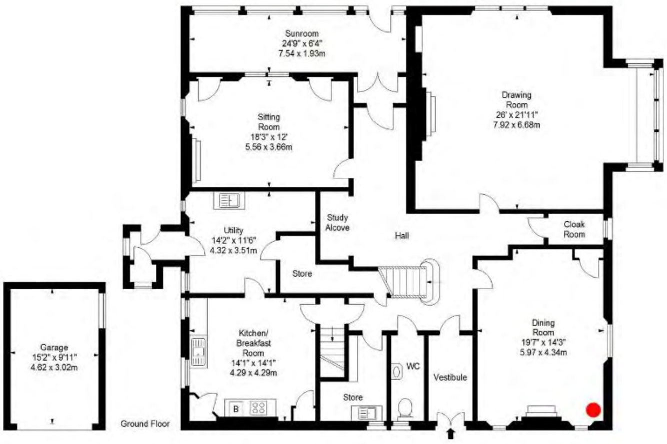


Figure E.3 The location, picture, DesignBuilder visualisation image and plan of case 3.

E.3.1 Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.13 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Sandstone, no insulation	★☆☆☆☆	1.93*
Roof	Pitched, no insulation	★☆☆☆☆	2.2
Floor	Suspended, no insulation	-	1.51
Windows	Single glazed	★☆☆☆☆	
Main heating	Boiler and radiators, mains gas	★★★★☆	
Main heating controls	Programmer and room thermostat	★★★★☆	
Secondary heating	Portable electric heaters	-	
Hot water	From the main system, no cylinder thermostat	★★★☆☆	
Lighting	Low energy lighting in 36% fixed outlets	★★★☆☆	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.3.2 Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.14 The recommended measures and their results on energy and environmental performance.

Recommended Measure	Indicative cost	Typical savings per year	Rating after improvement		Green Deal[2]
			Energy	Environment	
Internal or external wall insulation	£4,000 - £14,000	£1805	D55	E 46	✓
Floor insulation (suspended floor)	£800 - £1,200	£259	D 58	E 49	✓
Draught proofing	£80 - £120	£345	D 60	E 52	✓
Low energy lighting for all fixed outlets	£80	£61	D 61	E 52	
Hot water cylinder thermostat	£200- £400	£220	D 63	D 55	✓

Upgrade heating controls	£350 - £450	£174	D 65	D 57	
Replace boiler with new condensing boiler	£2,200 - £3,000	£981	C 75	D68	
Replace single glazed windows with low-E double glazed windows	£3,300 - £6,500	£264	C 78	C 71	
Solar photovoltaic panels, 2.5 kWp.	£5,000 - £8,000	£246	B 81	B 74	

Table E.15 The current and potential energy efficiency and environmental rating.

	Current[3]	**Potential[4]**
Energy Efficiency Rating*	F 36	B 81
Environmental Impact CO_2 Rating**	F 31	C 74

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.3.3 Alternative measures

There are alternative improvement measures which residences could also consider for the home. It would be advisable to seek further advice and illustration of the benefits and costs of such measures.

External insulation with cavity wall insulation.

Biomass boiler (Exempted Appliance if in Smoke Control Area).

Air or ground source heat pump.

Micro CHP.

E.3.4 Estimated energy costs for the house

The following table show how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.16 The current and potential energy cost.

	Current energy costs	**Potential energy costs**
Heating	£17,772 over 3 years	£6,108 over 3 years
Hot water	£822 over three years	£390 over three years
Lighting	£621 over three years	£387 over three years
Totals	£19,215	£6,885
Potential future savings over three years	£12,330	

E.3.5 Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.17 The estimated heat demand for space and water heating.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	83,235	(152)	N/A	(25,970)
Water heating (kWh per year)	4,284			

Table E.18 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 3

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Shading internal/ external	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Upgraded existing window (glass, fitting, etc.)	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			Biomass boiler
	Window replacement triple glazing				Portable electric heaters

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.4. Case 4. Traditional house (age = 126)

The house comprises a substantial detached Victorian Villa. It is situated in a well-established and popular residential area of Edinburgh to the south of the city centre in the Morningside district. Surrounding properties are generally of a similar age, type, and character.

Edinburgh
EH10 6DG

Gross internal floor area:

317.6 m²

Age:

126 (1891)

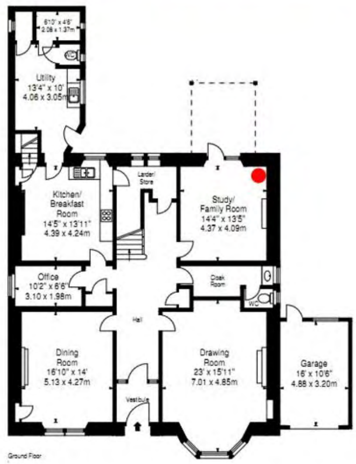


Figure E.4 The location, picture, DesignBuilder visualisation image and plan of case 4.

E.4.1 Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.19 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m²K)
Walls	Sandstone, no insulation	★★☆☆☆	1.4*
Roof	Pitched, no insulation	★☆☆☆☆	2.19
Floor	Suspended, no insulation	-	1.4
Windows	Some secondary glazing	★★☆☆☆	
Main heating	Boiler and radiators, mains gas	★★★★☆	
Main heating controls	Programmer, no room thermostat	★☆☆☆☆	
Secondary heating	Room heaters, coal	-	
Hot water	From main system	★★★★☆	
Lighting	Low energy lighting in 9% fixed outlets	★☆☆☆☆	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.4.2 Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.20 The recommended measures and their results on energy and environmental performance.

Recommended Measure	Indicative cost	Typical savings per year	Rating after improvement		Green Deal[2]
			Energy	Environment	
loft insulation	£300 - £400	£220	F 33	G 19	✔
Internal or external wall insulation	£4,000 - £14,000	£1725	E 54	E 37	✔
Floor insulation (suspended floor)	£800 - £1,200	£242	D 57	E 40	✔
Draught proofing	£80 - £120	£198	D 59	E 43	✔
Low energy lighting for all fixed outlets	£100	£81	D 60	E 43	

Upgrade heating controls	£350 - £450	£464	D 66	D 50	
Replace boiler with new condensing boiler	£2,200 - £3,000	£303	C 70	D 54	
Secondary glazing to single glazed windows	£1,000 - £1,500	£137	C 71	D 57	
Solar photovoltaic panels, 2.5 kWp.	£5,000 - £8,000	£249	B 75	D 60	

Table E.21 The current and potential energy efficiency and environmental rating.

	Current[3]	**Potential[4]**
Energy Efficiency Rating*	F 25	C 75
Environmental Impact CO_2 Rating**	G 13	D 60

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.4.3 Alternative measures

There are alternative improvement measures which residences could also consider for the home. It would be advisable to seek further advice and illustration of the benefits and costs of such measures.

Air or ground source heat pump.

Micro CHP.

E.4.4 Estimated energy costs for the house

The following table show how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.22 The current and potential energy cost.

	Current energy costs	**Potential energy costs**
Heating	£17,646 over three years	£6,141 over three years
Hot water	£543 over three years	£402 over three years
Lighting	£660 over three years	£354 over three years
Totals	£18,849	£6,897
Potential future savings over three years	£11,952	

E.4.5 Heat demand the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.23 The estimated heat demand for space and water heating.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	89,220	(12,939)	N/A	(26,782)
Water heating (kWh per year)	2,967			

Table E.24 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 4

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Secondary glazing	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Shading internal/ external	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			Room heaters, coal
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.5. Case 5. Traditional house (age = 132)

Converted flat placed at ground floor level in a two-story and attics flatted semidetached villa containing two big flats. The property is located in the Braids district of Edinburgh approximately 3 miles south of Edinburgh city centre and a good residential area.

Edinburgh
EH10 6AW

Gross internal floor area:

290 m²

Age:

132 (1885)

Figure E.5 The location, picture, DesignBuilder visualisation image and plan of case 5.

E.5.1 Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.25 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Sandstone, no insulation	★★☆☆☆	1.61*
Roof	(Another dwelling above)	-	2.19
Floor	Suspended, no insulation	-	1.6
Windows	Fully double glazed	★★★☆☆	
Main heating	Electric storage heaters	★☆☆☆☆	
Main heating controls	Manual charge control	★★☆☆☆	
Secondary heating	Room heaters, the main gas	-	
Hot water	Electric immersion, standard tariff	★☆☆☆☆	
Lighting	Low energy lighting in 88% fixed outlets	★★★★★	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.5.2 Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.26 The recommended measures and their results on energy and environmental performance.

Recommended Measure	Indicative cost	Typical savings per year	Rating after improvement		Green Deal[2]
			Energy	Environment	
Internal or external wall insulation	£4,000 - £14,000	£1363	E 39	E 47	
Floor insulation (suspended floor)	£800 - £1,200	£282	E 44	E 51	
Change heating to gas condensing boiler	£3,000 - £7,000	£1960	C 79	C 75	
Replacement glazing units	£1,000 - £1,400	£65	C 80	C 77	

Table E.27 The current and potential energy efficiency and environmental rating.

	Current[3]	Potential[4]
Energy Efficiency Rating*	F 21	C 80
Environmental Impact CO_2 Rating**	F 32	C 77

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.5.3 Alternative measures

There are alternative improvement measures which residences could also consider for the home. It would be advisable to seek further advice and illustration of the benefits and costs of such measures.

Biomass boiler (Exempted Appliance if in Smoke Control Area).

Air or ground source heat pump.

Micro CHP.

E.5.4 Estimated energy costs for the house

The following table show how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.28 The current and potential energy cost.

	Current energy costs	Potential energy costs
Heating	£13,074 over three years	£2,667 over three year
Hot water	£996 over three years	£387 over three years
Lighting	£348 over three years	£348 over three years
Totals	£14,418	£3,402
Potential future savings over three years	£11,016	

E.5.5 Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.29 The estimated heat demand for space and water heating.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	30,241	N/A	N/A	(9,682)
Water heating (kWh per year)	2,202			

Table E.30 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 5

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Electric storage heaters
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Secondary glazing	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Shading internal/ external	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			Room heaters, the main gas
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.6. Case 6. Traditional house (age = 140)

The property is a two-floor, and attic semi detached villa. The property forms part of an established residential area lying a short distance to the South West of the City Centre that surrounding buildings are broadly similar regarding age, type, and character.

Edinburgh
EH11 1NN

Gross internal floor area:

269 m²

Age:

140 (1877)

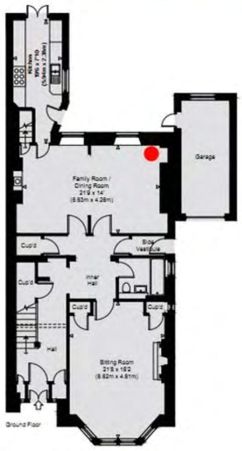


Figure E.6 The location, picture, DesignBuilder visualisation image and plan of case 6.

E.6.1. Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.31 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Sandstone, no insulation	★★☆☆☆	1.82*
Roof	Pitched, no insulation	★★☆☆☆	2.36
Floor	Suspended, no insulation	-	1.54
Windows	Fully double glazed	★★★☆☆	
Main heating	Boiler and radiators, mains gas	★★★★☆	
Main heating controls	Programmer, room thermostat and TVRs	★★★★☆	
Secondary heating	None	-	
Hot water	From main system	★★★★☆	
Lighting	Low energy lighting in 50% fixed outlets	★★★☆☆	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.6.2 Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.32 The recommended measures and their results on energy and environmental performance.

Recommended Measure	Indicative cost	Typical savings per year	Rating after improvement		Green Deal[2]
			Energy	Environment	
Internal or external wall insulation	£4,000 - £14,000	£501	C 74	C 70	✔
Floor insulation (suspended floor)	£800 - £1,200	£87	C 75	C 71	✔
Low energy lighting for all fixed outlets	£75	£44	C 76	C 72	
Solar photovoltaic panels, 2.5 kWp.	£9,000 - £14,000	£223	C 80	C 76	✔

Table E.33 The current and potential energy efficiency and environmental rating.

	Current[3]	Potential[4]
Energy Efficiency Rating*	F 25	C 75
Environmental Impact CO_2 Rating**	G 13	D 60

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.6.3. Estimated energy costs for the house

The following table shows how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.34 The current and potential energy cost.

	Current energy costs	Potential energy costs
Heating	£5,895 over three years	£4,155 over three years
Hot water	£369 over three years	£369 over three years
Lighting	£471 over three years	£312 over three years
Totals	£6,735	£4,836
Potential future savings over three years	£1,899	

E.6.4. Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.35 The estimated heat demand for space and water heating.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	40,792	N/A	N/A	(11,187)
Water heating (kWh per year)	2,631			

Table E.36 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 6

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators, mains gas
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Secondary glazing	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Shading internal/ external	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.7. Case 7. Traditional house (age = 151)

The subjects form the northeast most half of two semi-detached villas. Eskbank lies some eight miles or so to the east of the City of Edinburgh. The subject under report lies a short distance from Dalkeith Town Centre. In the house two kinds of the wall have been measured, one is insulated brick construction, and another one is brick/block construction without the insulation layer.

Dalkeith
EH22 3DF

Gross internal floor area:

249 m²

Age:

151 (1866)

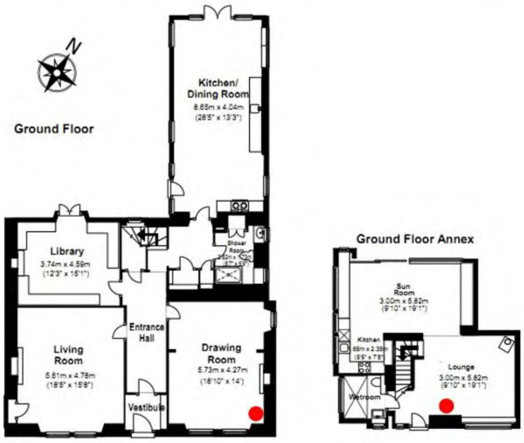


Figure E.7 The location, picture, DesignBuilder visualisation image and plan of case 7.

E.7.1 Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.37 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Sandstone, no insulation	★☆☆☆☆	1.43*
	Cavity brick wall, insulated	★★★★☆	0.32*
Roof	Pitched, no insulation	★☆☆☆☆	2.21
	Roof rooms, ceiling insulated	★★☆☆☆	0.93
Floor	Suspended, no insulation Solid, no insulation	-	1.57
Windows	Some double glazing	★★☆☆☆	
Main heating	Boiler and radiators, LPG	★★☆☆☆	
Main heating controls	Programmer and room thermostat and TVRs	★★★★☆	
Secondary heating	Room heaters, dual fuel (mineral and wood)	-	
Hot water	From main system	★★☆☆☆	
Lighting	Low energy lighting in 12% fixed outlets	★★☆☆☆	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.7.2. Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.38 The recommended measures and their results on energy and environmental performance.

Recommended Measure	**Indicative cost**	**Typical savings per year**	**Rating after improvement**		**Green Deal[2]**
			Energy	Environment	
Room-in-roof insulation	£1,500 - £2,700	£602	G 19	F 38	✓
Internal or external wall insulation	£4,000 - £14,000	£522	F 25	E 42	✓
Floor insulation (suspended floor)	£800 - £1,200	£148	F 26	E 44	✓
Low energy lighting for all fixed outlets	£295	£63	F 27	E 44	
Solar water heating	£4,000- £6,000	£110	F 29	E 45	✓
Replace single glazed windows with low-E double glazed windows	£3,300 - £6,500	£205	F 31	E 47	✓
Solar photovoltaic panels, 2.5 kWp.	£5,000 - £8,000	£250	F 35	E 50	✓

Table E.39 The current and potential energy efficiency and environmental rating.

	Current[3]	**Potential[4]**
Energy Efficiency Rating*	G 13	F 35
Environmental Impact CO_2 Rating**	F 33	E 50

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.7.3. Estimated energy costs for the house

The following table shows how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.40 The current and potential energy cost.

	Current energy costs	**Potential energy costs**
Heating	£15,846 over three years	£11,511 over three years
Hot water	£876 over three years	£519 over three years
Lighting	£567 over three years	£306 over three years
Totals	£17,289	£12,336
Potential future savings over three years	£4,953	

E.7.4. Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.41 The estimated heat demand for space and water heating.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	57,346	(4,976)	N/A	(13,959)
Water heating (kWh per year)	3,028			

Table E.42 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 7

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators, LPG
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Secondary glazing	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Shading internal/ external	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			Room heaters, dual fuel (mineral and wood)
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.8. Case 8. Traditional house (age = 160)

A double upper flat.

The Property is situated in the popular Morningside district of Edinburgh City, the immediate locality being comprised of compatible properties similar in age, construction, and character.

Edinburgh
EH10 5NN

Gross internal floor area:

124 m²

Age:

160 (1857)

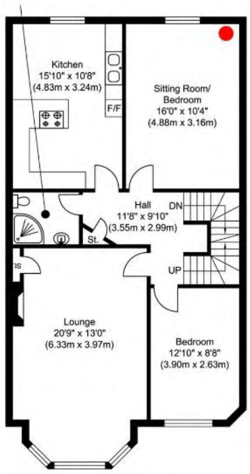


Figure E.8 The location, picture, DesignBuilder visualisation image and plan of case 8.

E.8.1. Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.43 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Sandstone, no insulation	★★☆☆☆	1.93*
Roof	Pitched, no insulation	★☆☆☆☆	2.55
Floor	(Another dwelling below)	-	1.56
Windows	Fully double glazed	★★★★☆	
Main heating	Boiler and radiators, mains gas	★★★★☆	
Main heating controls	Programmer, room thermostat and TVRs	★★★★☆	
Secondary heating	Room heaters, the main gas	-	
Hot water	From main system.	★★★★☆	
Lighting	Low energy lighting in all fixed outlets	★★★★★	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.8.2. Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.44 The recommended measures and their results on energy and environmental performance.

Recommended Measure	Indicative cost	Typical savings per year	Rating after improvement		Green Deal[2]
			Energy	Environment	
Loft					
Internal or external wall insulation	£4,000 - £14,000	£138	C 69	D 63	✔

Table E.45 The current and potential energy efficiency and environmental rating.

	Current[3]	**Potential[4]**
Energy Efficiency Rating*	D 65	C 69
Environmental Impact CO_2 Rating**	D 58	D 63

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.8.3. Estimated energy costs for the house

The following table shows how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.46 The current and potential energy cost.

	Current energy costs	**Potential energy costs**
Heating	£3,237 over three years	£2,823 over three years
Hot water	£333 over three years	£333 over three years
Lighting	£225 over three years	£225 over three years
Totals	£3,795	£3,381
Potential future savings over three years	£414	

E.8.4. Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.47 The estimated heat demand for space and water heating.

Heat demand	**Existing dwelling**	**Impact of loft insulation**	**Impact of cavity wall insulation**	**Impact of solid wall insulation**
Space heating (kWh per year)	15,116	(4,157)	N/A	(2.484)
Water heating (kWh per year)	2,296			

Table E.48 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 8

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators, mains gas
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Secondary glazing	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Shading internal/ external	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			Room heaters, the main gas
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.9. Case 9. Traditional house (age = 164)

The property comprises an end terraced dwelling house. There is a flat located below the property at street level under separate ownership. The property is situated in the Borders town of Lauder where surrounding properties vary regarding age, type, and character.

Lauder
TD2 6SU

Gross internal floor area:

287 m²

Age:

164 (1853)

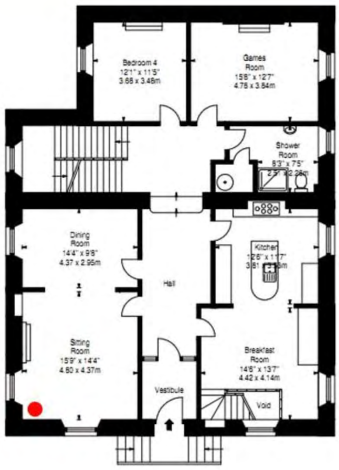


Figure E.9 The location, picture, DesignBuilder visualisation image and plan of case 9.

E.9.1. Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.49 The energy efficiency and environment rating, and U-values of house components.

Element Description	**Description**	**Energy Efficiency/ Environmental[1]**	**U-value (W/m^2K)**
Walls	Sandstone, no insulation	★★☆☆☆	1.44*
Roof	Pitched, no insulation	★★☆☆☆	2.64
Floor	Other premises below	-	1.63
Windows	Fully double glazed	★★★☆☆	
Main heating	Boiler and radiators, mains gas	★★★★☆	
Main heating controls	Programmer, TVRs and bypass	★★★☆☆	
Secondary heating	None	-	
Hot water	Electric immersion, standard tarrif	★☆☆☆☆	
Lighting	Low energy lighting in 25% fixed outlets	★★★☆☆	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.9.2. Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.50 The recommended measures and their results on energy and environmental performance.

Recommended Measure	**Indicative cost**	**Typical savings per year**	**Rating after improvement**		**Green Deal[2]**
			Energy	Environment	
Internal or external wall insulation	£4,000 - £14,000	£529	D 66	D 62	✓
Low energy lighting for all fixed outlets	£75	£64	D 67	D 63	
Upgrade heating controls	£350 - £450	£93	D 68	D 65	✓
Replace boiler with new condensing boiler	£2,200 - £3,000	£378	C 74	C 70	✓
Solar photovoltaic panels, 2.5 kWp.	£9,000 - £14,000	£221	C 78	C 73	✓

Table E.51 The current and potential energy efficiency and environmental rating.

	Current[3]	Potential[4]
Energy Efficiency Rating*	D 58	C 78
Environmental Impact CO_2 Rating**	E 52	C 73

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.9.3. Alternative measures

There are alternative improvement measures which residences could also consider for the home. It would be advisable to seek further advice and illustration of the benefits and costs of such measures.

Air or ground source heat pump.

Micro CHP.

E.9.4. Estimated energy costs for the house

The following table shows how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.52 The current and potential energy cost.

	Current energy costs	Potential energy costs
Heating	£6,153 over three years	£3,960 over three years
Hot water	£1,548 over three years	£786 over three years
Lighting	£552 over three years	£315 over three years
Totals	£8,253	£5,061
Potential future savings over three years	£3,192	

E.9.5. Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.53 The estimated heat demand for space and water heating.

Heat demand	**Existing dwelling**	**Impact of loft insulation**	**Impact of cavity wall insulation**	**Impact of solid wall insulation**
Space heating (kWh per year)	37,137	N/A	N/A	(10,284)
Water heating (kWh per year)	3,680			

Table E.54 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 9

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators, mains gas
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Secondary glazing	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Shading internal/ external	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.10. Case 10. Traditional house (age = 169)

The subjects comprise a two-floor semi-detached house. The neighbourhood is mainly residential, the location is urban, and the site is relatively level.

Bonnyrigg
EH19 2DE

Gross internal floor area:

93 m²

Age:

169 (1848)

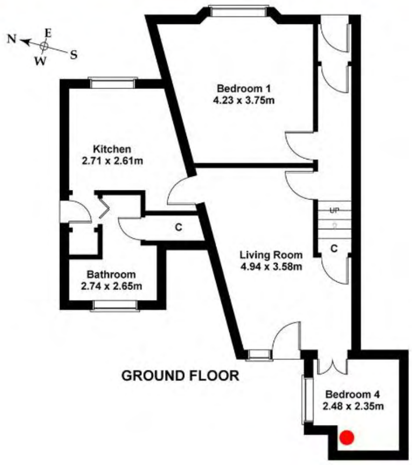


Figure E.10 The location, picture, DesignBuilder visualisation image and plan of case 10.

E.10.1. Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.55 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Sandstone, no insulation Cavity wall, no insulation Solid brick, no insulation	★☆☆☆☆	1.45*
Roof	Pitched, no insulation	★☆☆☆☆	2.67
Floor	Suspended, no insulation	-	1.74
Windows	Partial double glazing	★★☆☆☆	
Main heating	Boiler and radiators, mains gas	★★★★☆	
Main heating controls	Programmer and room thermostat	★★★☆☆	
Secondary heating	None	-	
Hot water	From main system	★★★★☆	
Lighting	Low energy lighting in 23% fixed outlets	★★☆☆☆	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.10.2. Recommendations for improvement

The measures below will improve the energy and environmental performance of this dwellinE. The performance ratings after improvements listed below are cumulative; that is, they assume the improvements have been installed in the order that they appear in the table.

Table E.56 The recommended measures and their results on energy and environmental performance.

Recommended Measure	Indicative cost	Typical savings per year	Rating after improvement Energy	Environment	Green Deal[2]
Cavity wall insulation	£500 - £1,500	£47	D 58	E 50	
Internal or external wall insulation	£4,000 - £14,000	£253	D 66	D 61	
Floor insulation (suspended floor)	£800 - £1,200	£58	D 68	D 64	
Draught proofing	£80 - £120	£16	D 68	D 65	
Low energy lighting for all fixed outlets	£50	£38	C 70	D 66	
Solar water heating	£350 - £450	£30	C 71	D 68	
Replace boiler with new condensing boiler	£4,000 - £6,000	£51	C 73	C 70	
Replace single glazed windows with low-E double glazed windows	£3,300 - £6,500	£55	C 75	C 73	
Solar photovoltaic panels, 2.5 kWp.	£5,000 - £8,000	£249	D 84	B 82	

Table E.57 The current and potential energy efficiency and environmental rating.

	Current[3]	Potential[4]
Energy Efficiency Rating*	D 56	B 84
Environmental Impact CO_2 Rating**	E 48	B 82

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.10.3. Estimated energy costs for the house

The following table shows how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.58 The current and potential energy cost.

	Current energy costs	Potential energy costs
Heating	£3,027 over three years	£1,683 over three years
Hot water	£423 over three years	£255 over three years
Lighting	£303 over three years	£174 over three years
Totals	£3,753	£2,112
Potential future savings over three years	£1,641	

E.10.4. Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.59 The estimated heat demand for space and water heating.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	18,780	(346)	(1,016)	(5,512)
Water heating (kWh per year)	2,886			

Table E.60 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 10

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators, mains gas
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Secondary glazing	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Shading internal/ external	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.11. Case 11. Traditional house (age = 171)

The subjects comprise an end terraced house, with attached former shop premises. The property is located in the village of Grantshouse, where restricted amenities are available.

DUNS
TD11 3RW

Gross internal floor area:

196 m²

Age:

171 (1846)

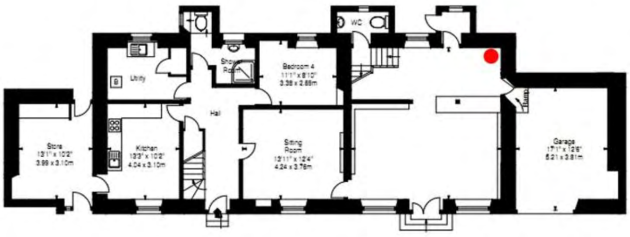


Figure E.11 The location, picture, DesignBuilder visualisation image and plan of case 11.

E.11.1. Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.61 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Sandstone, no insulation Cavity wall, no insulation	★☆☆☆☆	0.99*
Roof	Pitched, no insulation	★☆☆☆☆	2.58
Floor	To external air, no insulation	-	1.66
Windows	Partial double glazing	★★☆☆☆	
Main heating	Boiler and radiators, oil	★★★☆☆	
Main heating controls	Programmer, room thermostat and TVRs	★★★★☆	
Secondary heating	Room heaters, electric	-	
Hot water	From main system	★★★☆☆	
Lighting	No low energy lighting	★☆☆☆☆	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.11.2. Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.62 The recommended measures and their results on energy and environmental performance.

Recommended Measure	Indicative cost	Typical savings per year	Rating after improvement		Green Deal[2]
			Energy	Environment	
Room-in-roof insulation	£1,500 - £2,700	£783	E 51	E 45	
Cavity wall insulation	£500 - £1,500	£33	E 52	E 46	
Internal or external wall insulation	£4,000 - £14,000	£229	D 59	E 53	
Floor insulation (suspended floor)	£800 - £1,200	£223	D 66	D 60	
Draught proofing	£80 - £120	£33	D 66	D 61	
Low energy lighting for all fixed outlets	£60	£53	D 68	D 63	
Solar Water heating	£4,000 - £6,000	£63	C 70	D 66	
Replace single glazed windows with low-E double glazed windows	£3,300 - £6,500	£104	C 74	C 70	
Solar photovoltaic panels, 2.5 kWp.	£5,000 - £8,000	£262	B 82	C 77	

Table E.63 The current and potential energy efficiency and environmental rating.

	Current[3]	Potential[4]
Energy Efficiency Rating*	F 30	B 82
Environmental Impact CO_2 Rating**	F 28	C 77

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.11.3. Estimated energy costs for the house

The following table shows how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.64 The current and potential energy cost.

	Current energy costs	Potential energy costs
Heating	£6,219 over three years	£2,061 over three years
Hot water	£528 over three years	£327 over three years
Lighting	£405 over three years	£204 over three years
Totals	£7,152	£2,592
Potential future savings over three years	£4,560	

E.11.4. Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.65 The estimated heat demand for space and water heating.

Heat demand	**Existing dwelling**	**Impact of loft insulation**	**Impact of cavity wall insulation**	**Impact of solid wall insulation**
Space heating (kWh per year)	29,919	(139)	(454)	(3,042)
Water heating (kWh per year)	2,848			

Table E.66 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 11

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators, oil
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Secondary glazing	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Shading internal/ external	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			Room heaters, electric
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

E.12. Case 12. Traditional house (age = 223)

The house is a proportioned 5-bedroom townhouse arranged over three floors; the location is in the heart of the Georgian Newtown, one of the most desirable residential areas of Edinburgh.

Edinburgh
EH3 6PW

Gross internal floor area:

363 m²

Age:

223 (1794)

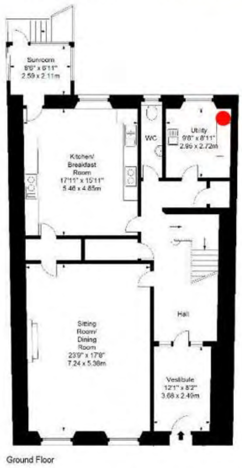


Figure E.12 The location, picture, DesignBuilder visualisation image and plan of case 12.

E.12.1. Summary of the energy performance regards to the features of the house

The following table sets out the outcomes of the survey that lists the current energy regards to the features of the house. Each part is assessed by the national calculation methodology; 1 star = very poor (least efficient), 2 stars = poor, 3 stars = average, 4 stars = good and 5 stars = very good (most efficient).

Table E.67 The energy efficiency and environment rating, and U-values of house components.

Element Description	Description	Energy Efficiency/ Environmental[1]	U-value (W/m^2K)
Walls	Sandstone, no insulation	★☆☆☆☆	2.04*
Roof	Pitched, no insulation	★☆☆☆☆	2.94
Floor	Suspended, no insulation	-	1.84
Windows	Single glazed	★☆☆☆☆	
Main heating	Boiler and radiators, oil	★★☆☆☆	
Main heating controls	Programmer, room thermostat and TRVs	★★★★☆	
Secondary heating	None	-	
Hot water	From main system	★★☆☆☆	
Lighting	Now low energy lighting	★☆☆☆☆	

*The value obtained from in situ measurement, the rest of the values calculated by DesignBuilder energy simulation software.

E.12.2. Recommendations for improvement

The following table illustrates measurement that will enhance the energy and environmental performance of the building. The performance ratings after the enhancements listed below are cumulative; the assessors assume the enhancements have been applied in the order which they demonstrate in the table.

Table E.68 The recommended measures and their results on energy and environmental performance.

Recommended Measure	**Indicative cost**	**Typical savings per year**	**Rating after improvement**		**Green Deal**[2]
			Energy	Environment	
Loft insulation	£300- £400	£120	F 33	F29	✓
Internal or external wall insulation	£4,000 - £14,000	£923	E 50	E 43	✓
Floor insulation (suspended floor)	£800 - £1,200	£182	E 54	E 46	✓
Low energy lighting for all fixed outlets	£100	£70	D 55	E 47	
Replace boiler with new condensing boiler	£2,200 - £3,000	£553	D 56	D 58	✓
Solar water heating	£4,000 - £6,000	£61	D 67	D 59	✓
Replace single glazed windows with low-E double glazed windows	£3,300 - £6,500	£210	C 71	D 65	✓
Solar photovoltaic panels, 2.5 kWp.	£5,000 - £8,000	£251	C 76	C 70	✓
Wind turbine	£5,000 - £8,000	£538	B 87	C 79	✓

Table E.69 The current and potential energy efficiency and environmental rating.

	Current[3]	**Potential**[4]
Energy Efficiency Rating*	F 31	B 87
Environmental Impact CO_2 Rating**	F 28	C 79

* Not energy efficient - higher running costs.

** Not environmentally friendly - higher CO_2 emissions.

E.12.3. Alternative measures

There are alternative improvement measures which residences could also consider for the home. It would be advisable to seek further advice and illustration of the benefits and costs of such measures.

Air or ground source heat pump.

Micro CHP.

E.12.4. Estimated energy costs for the house

The following table shows how much the average household would spend on this property for heating, lighting and hot water. It excludes energy used for running appliances such as TVs, computers, and cookers, and the benefits of any electricity generated by the home (for example, from photovoltaic panels). The potential savings in energy costs show the effect of undertaking all of the recommended measures listed above.

Table E.70 The current and potential energy cost.

	Current energy costs	Potential energy costs
Heating	£9,822 over three years	£4,146 over three years
Hot water	£711 over three years	£306 over three years
Lighting	£561 over three years	£288 over three years
Totals	£11,094	£4,740
Potential future savings over three years	£6,354	

E.12.5. Heat demand of the house

It is possible to receive Renewable Heat Incentive (RHI) payments and help reduce carbon emissions by replacing the existing heating system with one that generates renewable heat and, where appropriate, having your loft insulated and cavity walls filled. The estimated energy required for space and water heating will form the basis of the payments.

Table E.71 The estimated heat demand for space and water heating.

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	42,375	(1,564)	N/A	(12,083)
Water heating (kWh per year)	2,914			

Table E.72 The current situation, possible recommendation for enhancement and the required actions to reach zero carbon house for case 12

House elements				**Installations**	
Exterior Wall	Windows	Roof	Basement Ceiling	Ventilation	Heat Source
No insulation	Single glazing	Flat roof slab no insulation	No insulation	Natural Ventilation	Boiler and radiators, oil
Little/outdated insulation	French windows	Pitched roof no insulation	No insulation, basement heated space	Controlled mechanical exhaust	CPH installation
Exterior insulation, ventilated façade	Box windows	Insulation on the top floor	Insulation on top of the basement ceiling slab	Ventilation system with heat recovery (HR)	Air-water heat pump
Interior insulation	Double glazing	Pitched/flat roof insulation	Insulation under the basement ceiling slab		Solar collectors
Exterior thermal insulation	Secondary glazing	Green roof	VIP panels under the basement ceiling slab		Geothermal heat pump
Double skin façade	Shading internal/ external	Additional floor			District/ community heating
Photovoltaic	Window replacement double glazing	Photovoltaic			
	Window replacement triple glazing				

	Current situation of the house
	Possible recommendations for improving
	The required actions to reach zero carbon house

Explanatory note:

The following notes are applicable to Appendix E.

[1] **The energy efficiency rating of the home**

The Energy Efficiency Rating is calculated using the standard UK methodology, RdSAP. The calculates energy used for ventilation, hot water, heating and lighting; and then applies fuel costs to the energy use to give an overall rating for the house. The rating is given on a scale of 1 to 100. In addition to the cost of fuel for electrical appliances and for cooking, a house with a rating of 100 would almost cost nothing to run.

As we all use the house in different methods, the energy rating is calculated using standard occupancy assumptions that may be different from the method that has been used. Also, the rating uses national weather data to allow comparison between houses in different locations of Scotland. However, to make more relevant information to the house, local weather information is used to calculate the running costs, energy use, CO_2 emissions, and the savings possible from making enhancements.

The influence of the house on the environment

One of the significant contributors to global warming now is carbon dioxide. The energy that has been used for power, heating, and lighting in the houses produces over a quarter of the UK's carbon dioxide emissions. The different types of fuels expand different amounts of carbon dioxide for every kilowatt-hour (kWh) of energy used. The Environmental Impact Rating of the home is calculated by applying these 'carbon factors' for the fuels that have been used to the overall energy use.

The average Scottish household expands about 6 tonnes of carbon dioxide every year. Based on this assessment, the lighting, and heating of the house currently produces approximately 7.7 tonnes of carbon dioxide every year. Adopting suggestions can decrease emissions and support the environment. If all of these recommendations are installed, this could decrease emissions by 4.0 tonnes per year. It is possible to decrease even more emissions by switching to renewable energy sources.

[2] Measures which have a green deal tick are likely to be eligible for Green Deal finance plans based on indicative costs. The subsidy also may be available for some measures, such as solid wall insulation. Additional support may also be available for individual households in receipt of means-tested benefits. Measures which have an orange tick may need additional finance.

Appendix F. In-situ measurement values of the wall in case 4

The achievement of the in-situ measured walls in case 4 is presented in Table 5 and also shown graphically in Figure 4. In practice, data should be recorded at intervals up to a maximum of 30 minutes. For this sample, the table illustrates data recorded at 3 hours intervals.

Table F1. The achievement of in situ measurement of the wall in case 4.

Date and Time	Heat flow data from data logger	Calibration factor	Calculated Heat flux *q*	T Internal	T External
	mV	-	W/m2	°C	°C
	A	B	C=A/B*1000	D	E
04/05/2017 16:00	0.60242	56	10.75741	12.69	9.99254
04/05/2017 19:00	0.64646	56	11.54393	13.1325	8.58375
04/05/2017 22:00	0.63444	56	11.32929	13.4325	7.455
05/05/2017 01:00	0.55439	56	9.899875	13.2225	6.72872
05/05/2017 04:00	0.61444	56	10.97205	13.0425	6.3
05/05/2017 07:00	0.61844	56	11.04361	13.155	6.95625
05/05/2017 10:00	0.44832	56	8.005643	13.035	7.18379
05/05/2017 13:00	0.41229	56	7.362232	12.7875	7.00875
05/05/2017 16:00	0.4143	56	7.398268	12.3825	6.86879
05/05/2017 19:00	0.52237	56	9.328	12.495	6.825
05/05/2017 22:00	0.5684	56	10.15004	12.87	6.32625
06/05/2017 01:00	0.48836	56	8.720625	12.84	5.97629
06/05/2017 04:00	0.51435	56	9.184893	12.7575	4.96997
06/05/2017 07:00	0.51237	56	9.149393	12.7725	4.43625
06/05/2017 10:00	0.4303	56	7.683946	12.495	3.92879
06/05/2017 13:00	0.40629	56	7.255179	12.075	4.49747
06/05/2017 16:00	0.43229	56	7.719446	11.88	4.79504
06/05/2017 19:00	0.63646	56	11.36532	12.1575	4.52372
06/05/2017 22:00	0.58642	56	10.47173	12.5175	3.64875
07/05/2017 01:00	0.57642	56	10.29313	12.45	3.27254

07/05/2017 04:00	0.58241	56	10.4002	12.285	2.59004
07/05/2017 07:00	0.50634	56	9.041804	10.5866	1.23375
07/05/2017 10:00	0.59642	56	10.65036	11.1208	1.39997
07/05/2017 13:00	0.65845	56	11.75805	11.8125	3.16754
07/05/2017 16:00	0.62444	56	11.15068	11.91	4.24379
07/05/2017 19:00	0.59042	56	10.54329	11.805	3.48254
07/05/2017 22:00	0.77724	56	31.73639	12.28	2.70375
06/05/2017 01:00	0.60629	56	7.255179	11.15	1.64504
08/05/2017 04:00	0.61444	56	10.97205	10.6667	1.6
08/05/2017 07:00	0.73051	56	13.04489	10.6583	1.4
08/05/2017 10:00	0.58642	56	10.47173	10.1083	1.5
Average			**10.53738**	**12.21204**	**4.68529**

Average U-value: 1.4 W/m^{2}K U = 10.53738/ (12.21204-4.68529) = 1.39999

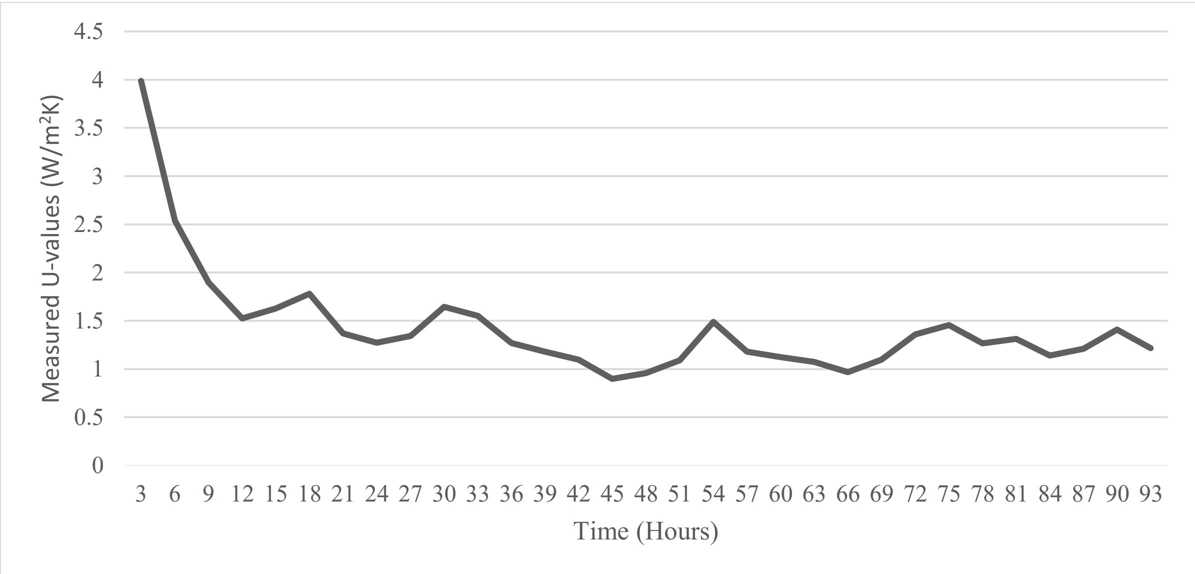


Figure F1. The trend of thermal transmittance of the wall in case 4.

The graphs shows fluctuations of the measured U-value with the time. It is not stable during the first day or so, and become slightly stable after that. It explains why short periods of measurements would not be sufficient.

Appendix G. The RIBA Plan of Work

G.1. A design approach for historic houses

Teams working with old houses need to develop a well-integrated strategic approach, a shared understanding and take a holistic view of problems. They need to develop integrated solutions which can tackle a range of connected issues simultaneously.

Figure G1 illustrated an approach to upgrading and renewing services or improving energy efficiency in traditional houses, allowing change to be managed appropriately and sympathetically in the interests of the house, of the residence and the environment. The approach is intended to be used flexibly. Each house is different, so it is not suitable to be too rigid and prescriptive, for example, in assessing the significance and vulnerability of a house, a case study 10, an unlisted 169 years old house might need an assessment of the form and plan of the house; the importance of the frontage; the tiling in the entrance porch; the windows; the internal fireplaces, ceiling roses; and its contribution to the appearance and character of the surrounding area. In contrast, a case study 12, the significant 223-year-old listed house would need more considerable care, and input from dedicated specialists such as archaeologists, and perhaps a detailed conservation plan covering the house, its condition, its existing and intended use, its fabric, its site and its setting.

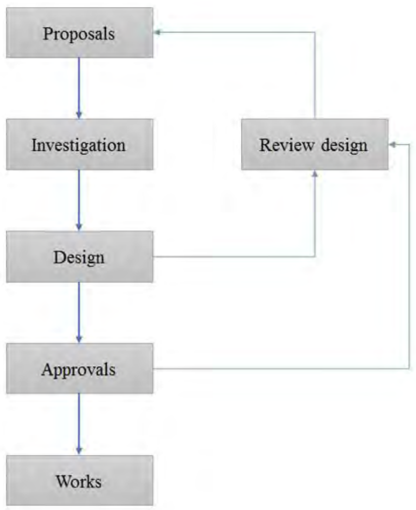


Figure G1. A flowchart illustrating the design approach appropriate for many historic buildings. Source: Own elaboration.

The principles below are adapted from the list in *The repair of historic houses: advice on principles and method.*

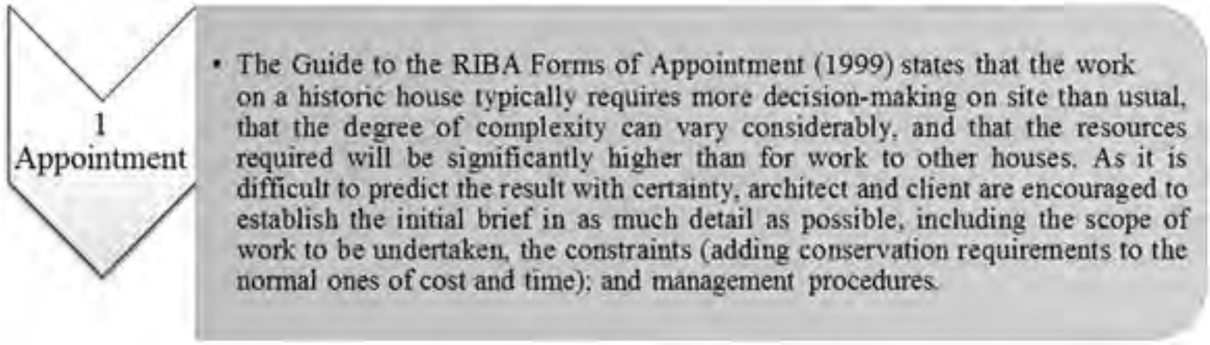
They are relevant to all historic houses and provide a good starting.

- Understand the purpose of repair or alteration; The primary purpose of repair, or of any changes to an older house, must be to prevent or slow down the processes of decay without damaging their character, altering the features which give them their historical or architectural importance, or unnecessarily disturbing or destroying the historic fabric.
- Minimise intervention: Interventions must be kept to the minimum necessary to meet the requirements of any appropriate use, within a structure which is sound enough to ensure long-term survival.
- Avoid unnecessary damage: The authenticity of a historic house or monument depends crucially on its design and the integrity of its fabric. Unnecessary replacement of traditional element, no matter how carefully done, will adversely affect the appearance of a house or monument, severely diminish its authenticity, and reduce its value as a source of historical information.
- Seek reversibility and minimise irreversible damage: When carrying out alterations, always aim for solutions which can be reversed quickly, i.e. minimise vulnerability to irreversible damage and plan new work so that it can be removed and the house revert to its former state with minimum damage to the pre-existing fabric (as in case study 1 where unwanted historical features were protected and covered-up rather than damaged or discarded). It is particularly important when installing services, as their life is usually very much less than that of the house as a whole. Short-term solutions and gains in comfort or efficiency should not put fabric that has survived at unnecessary risk.

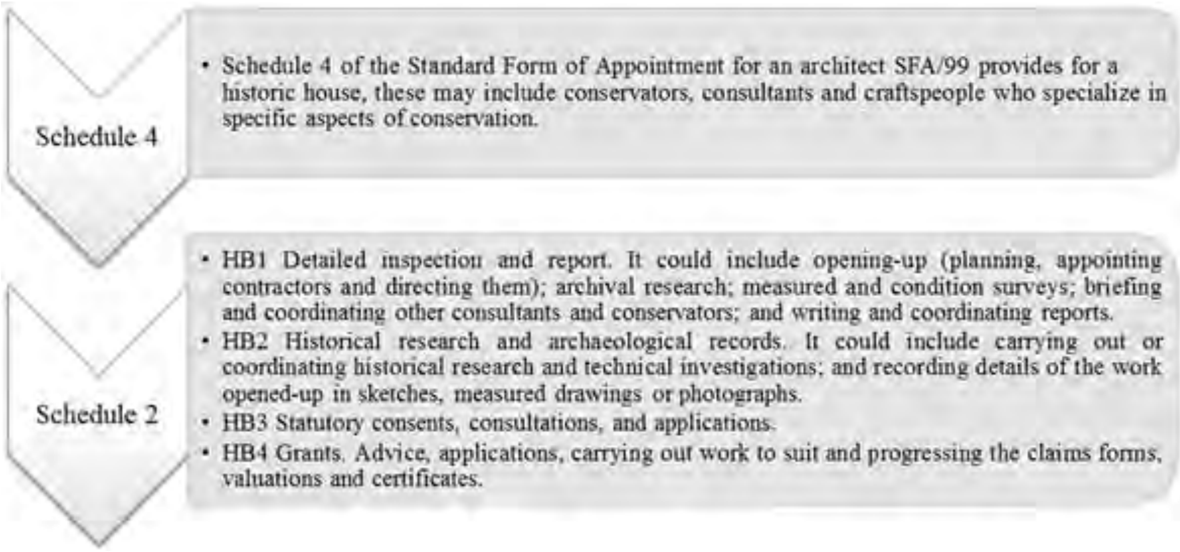
The individual and complex nature of many older houses mean that extra time must be allowed between conception and planning and implementation of the project. Applications for consents and approvals often cause delays, and unforeseen problems are often exposed once works are started. Therefore, it is essential to plan the project with anticipation of delay, and then try to avoid it by consulting early and keeping people well informed.

G.2. The RIBA Plan of Work

G.2.1 Appointment

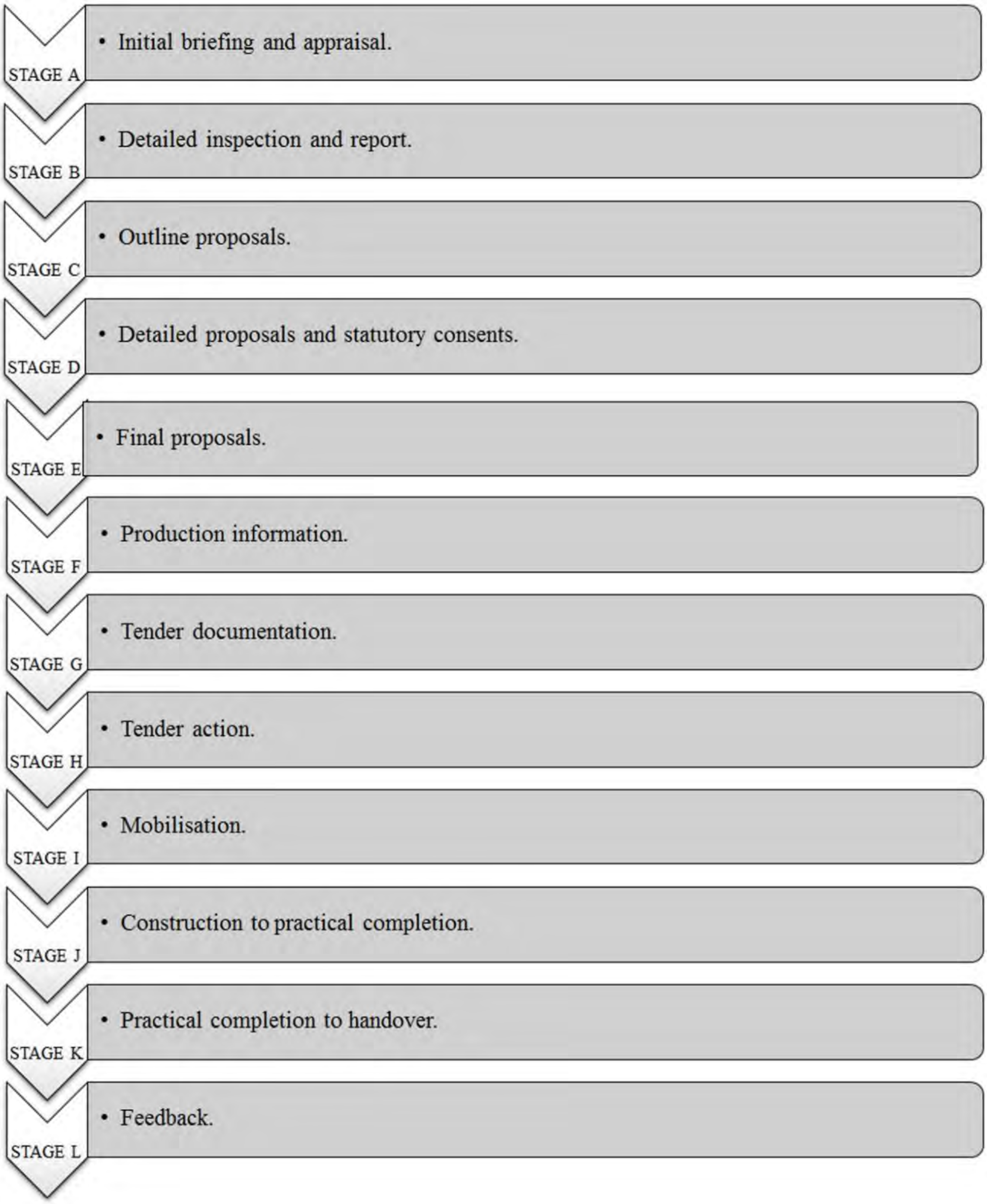


G.2.2. Service



G.2.3. Plan of work

The Plan of Work is widely used by architects to help organize their activities and coordinate with other members of the design team.



In the paragraphs below, house services and energy efficiency activities related to the RIBA Plan of Work stages have been explained.

Stage A: initial briefing and appraisal.

The initial briefing is the time to begin to understand the ambitions of the client and colleagues on the project team.

Stage B: detailed inspection and report.

It is the time to begin to think about how the house might be improved to meet a client, conservation, functionality and sustainability requirements. Before any firm design proposals are produced, it is imperative that the professional team gain a shared understanding of the house and the work to be done, so that the design truly suits and enhances the house. The information required to help to understand the house may well include, detailed drawings and elevations of the house, its site and its immediate environment; physical and documentary research into the house's history and significance; detailed surveys to assess the condition and performance of the house; service inspection and tests; air pressure tests; SAP ratings for houses; and identification of areas that require further investigation.

Stage C: outline proposals.

Now is the time to develop options in principle and to test them against the requirements and constraints. The outline proposals will need to be checked against the conservation policy and the results of the initial investigations. Further on-site investigation and testing may be needed. Mismatches will require changes to the proposals, and perhaps a review of the conservation policy.

Stage D: detailed proposals.

Once the outline proposals have been agreed by all those involved, it is time to proceed with the detailed proposals; it may require still more site investigation. As details of the project are agreed, they will need checking against statutory and conservation requirements.

Stages E to G: final proposals, production, and tender information

Once the detailed proposals have been agreed, design development, preparation of detailed drawings and drafting of specifications are often carried out in parallel. It is necessary to submit the drawings and to support information for approval. Sufficient time needs to be allowed for the application to be processed. Amendments and revisions may be needed to meet conditions of approval, and these will need to be fed back into the design.

Stage H: tender action.

The most critical aspects of the tendering stage are that the prospective contractors have appropriate understanding and experience of work on historic houses; can manage the site diligently; can deliver work of the required quality; and have operatives who understand conservation issues and can work in a sympathetic manner.

Stage I: mobilization.

The workforce must be made aware of the importance and sensitivity of the house and its fabric. Therefore, consider training, for all new staff coming on site, about the objectives and priorities of the project and any special procedures to be followed

Stage J: construction to practical completion work to a historic house needs much more collaboration

- Testing: The house services systems must be tested as the work proceeds to ensure that they conform to the installation requirements of the specification.
- Commissioning: Activities must be planned and agreed with the professional team well before the start of commissioning.
- As installed or record drawings: The working drawings must be updated as the work proceeds. They are the basis for recording accurately what has been installed, and the information can then be transferred to the record drawings.

Stage K: practical completion and handover.

Commissioning of the house services installation must be completed by the contractor, and the results agreed with the professional team before practical completion is achieved. Commissioning data and results must be inserted into the operating and maintenance manual. The document should enable the client to operate everything safely and efficiently.

Stage L: Feedback.

It mainly applies to control of the internal environment, the effectiveness of energy efficiency measures and the condition of the fabric. Monitoring should also include monthly readings of all water and energy meters (electricity, gas, oil and so forth.) as these can often pinpoint changes that may otherwise go undetected.

Appendix H. Results of LNBL software

H.1. The whole window

H.1.1 The condition of the window

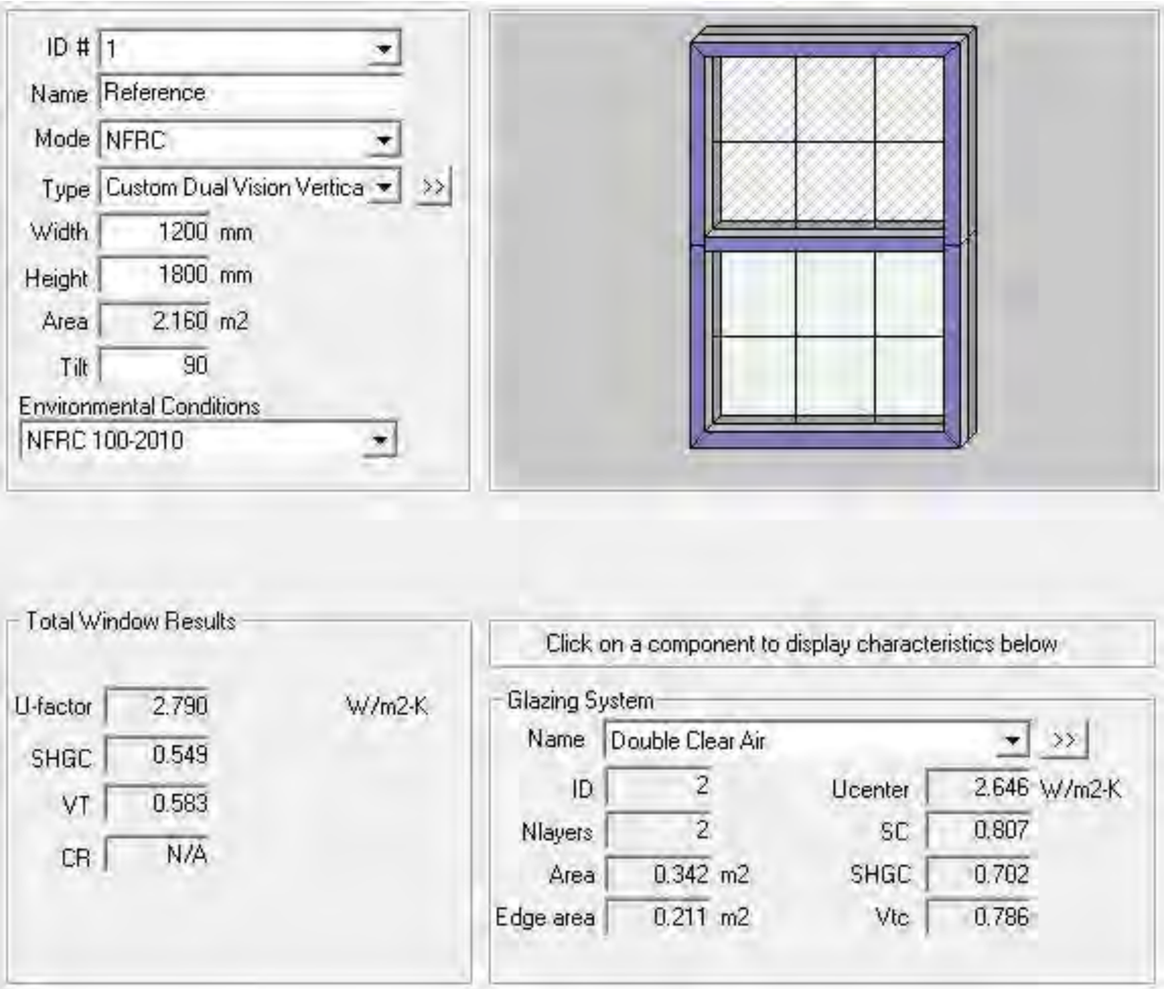


Figure H.1 Characteristic of the reference model window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

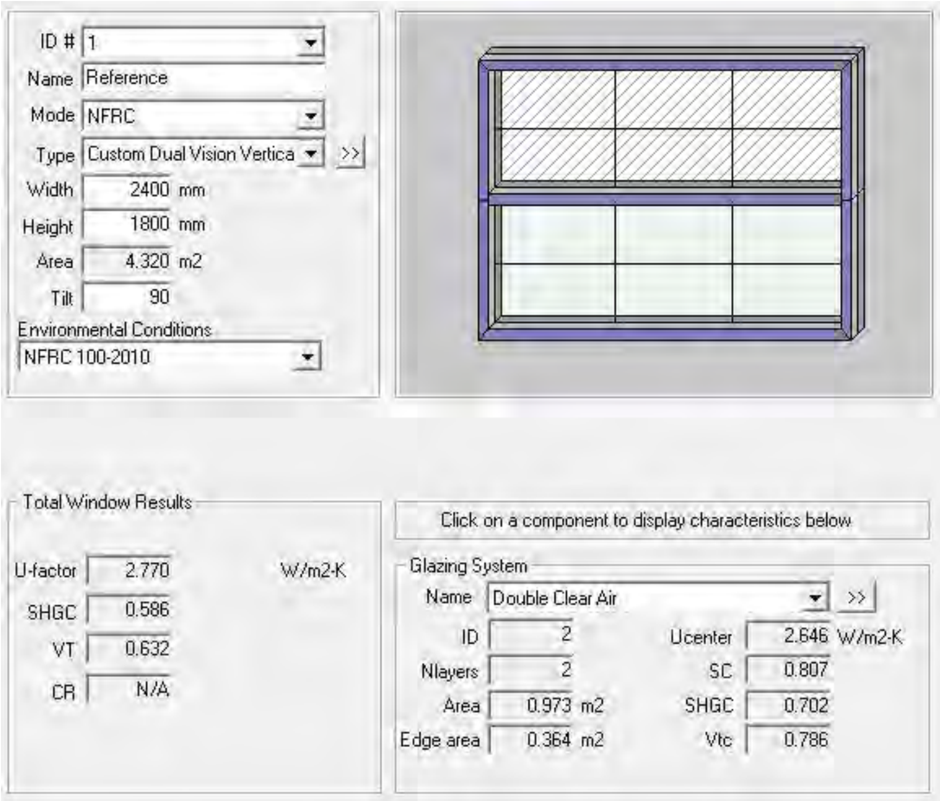


Figure H.2 Characteristic of option number 1 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

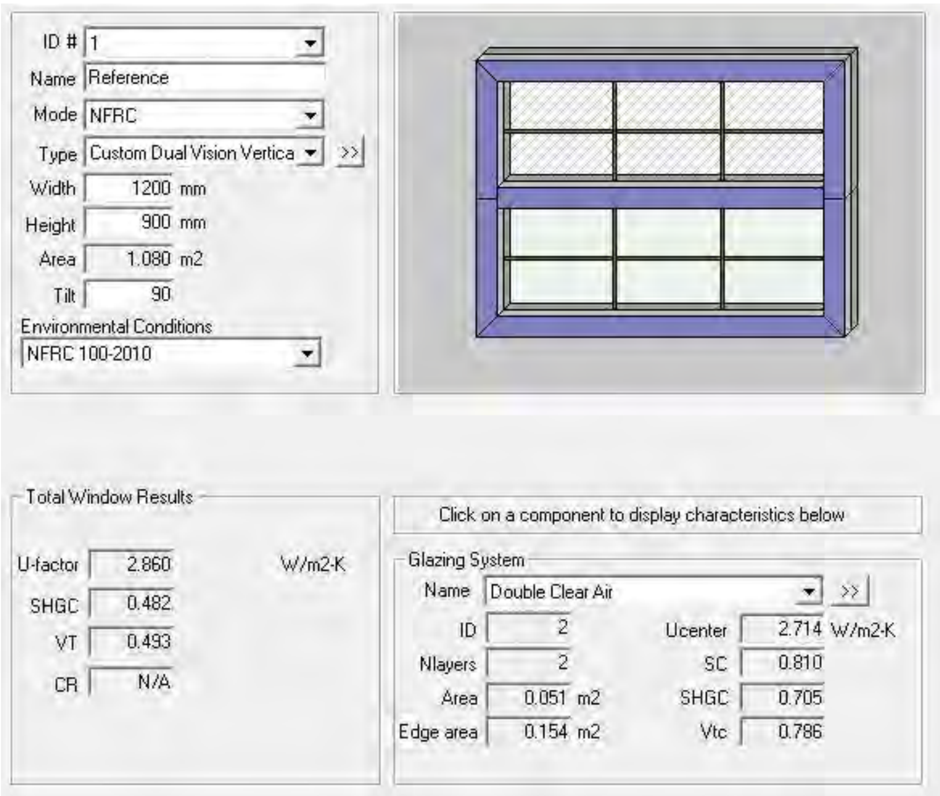


Figure H.3 Characteristic of option number 2 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

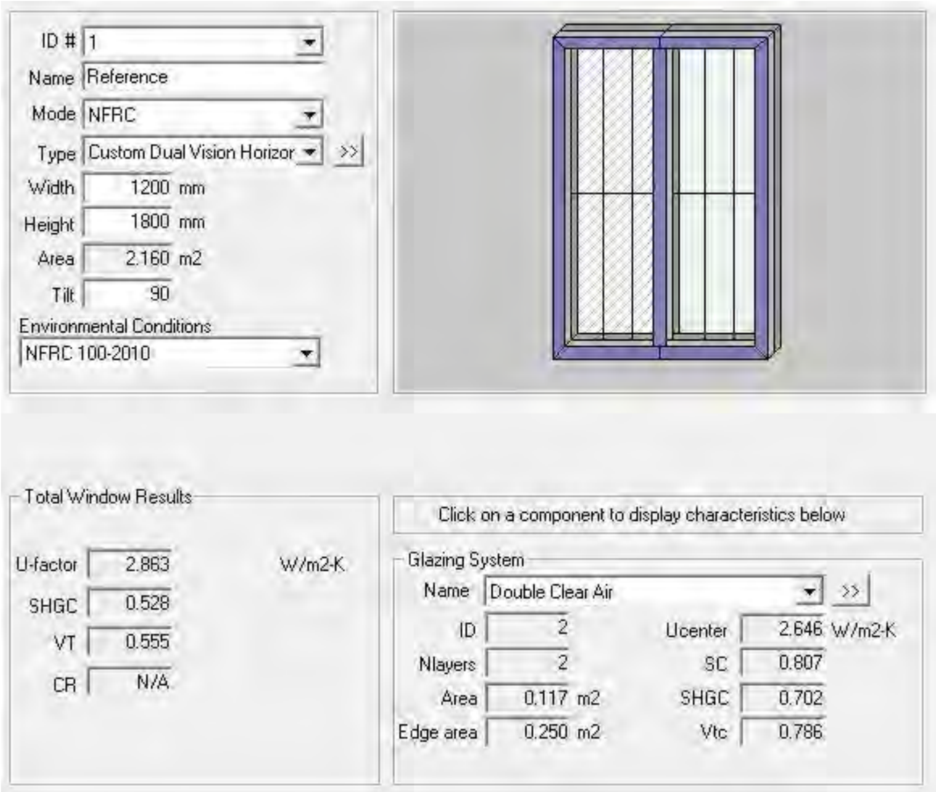


Figure H.4 Characteristic of option number 3 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

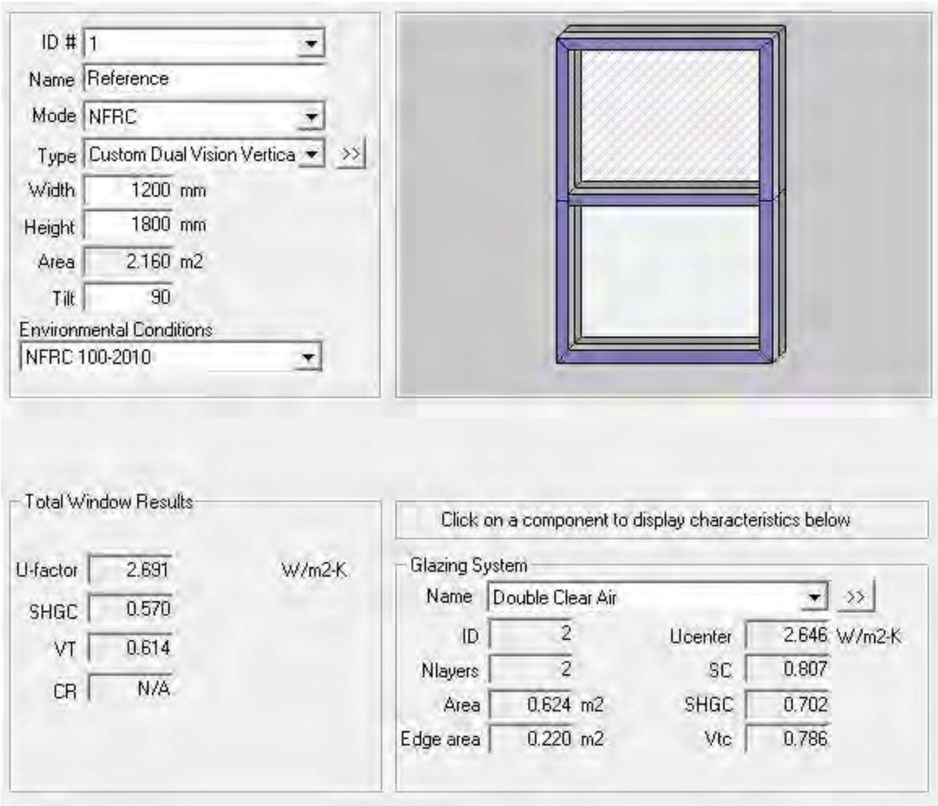


Figure H.5 Characteristic of option number 4 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

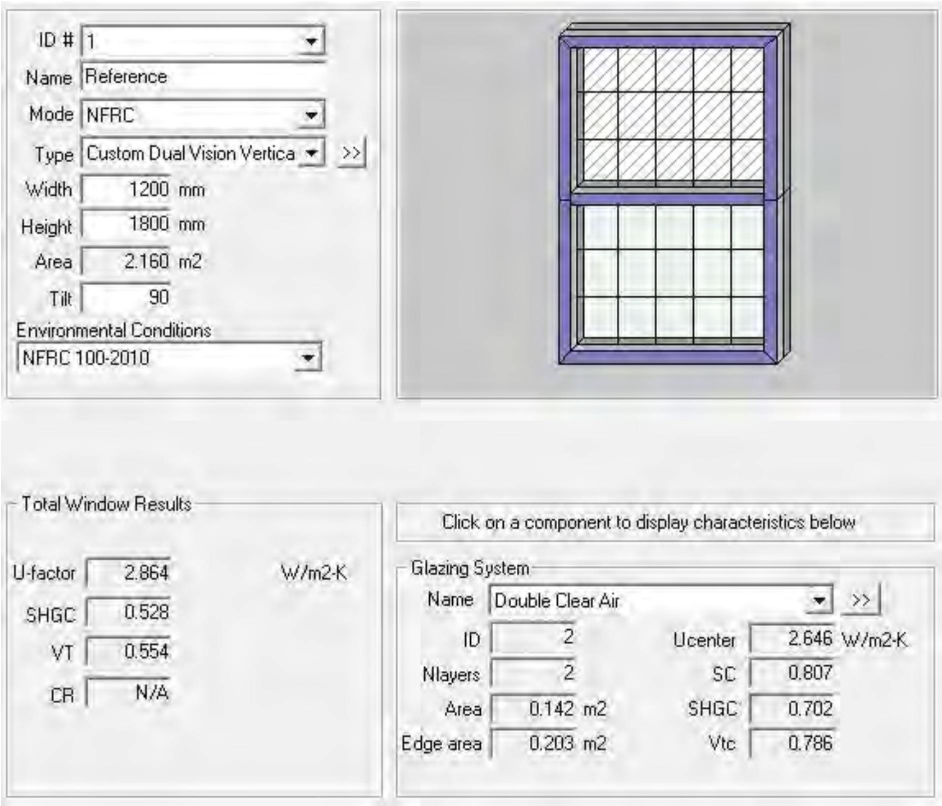


Figure H.6 Characteristic of option number 5 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

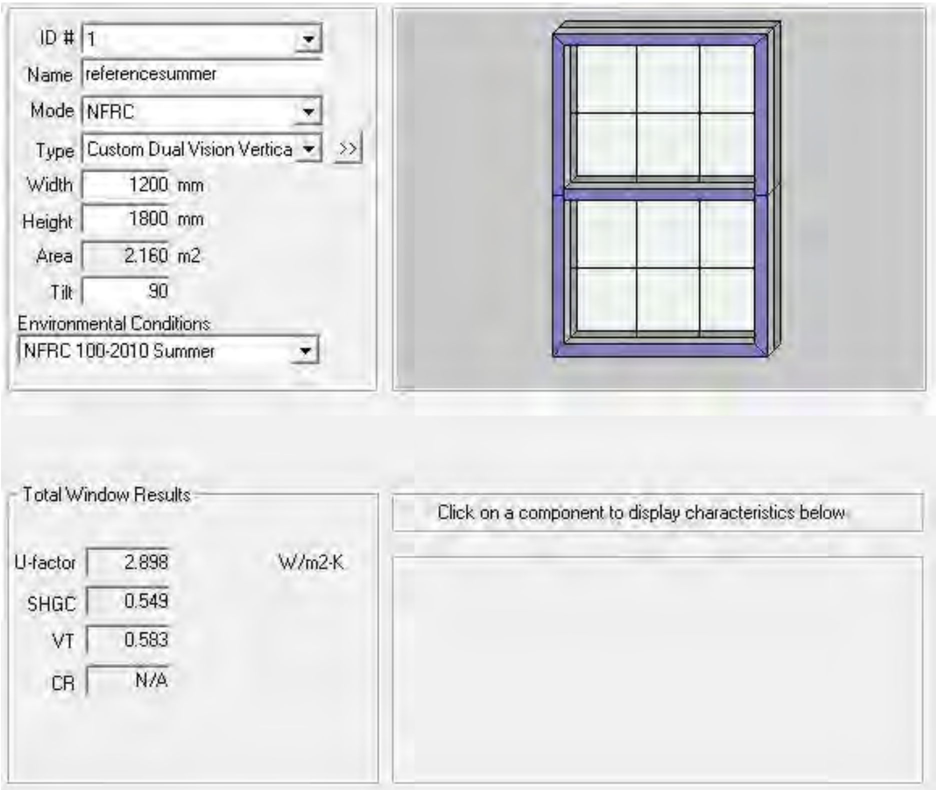


Figure H.7 Characteristic of option number 6 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

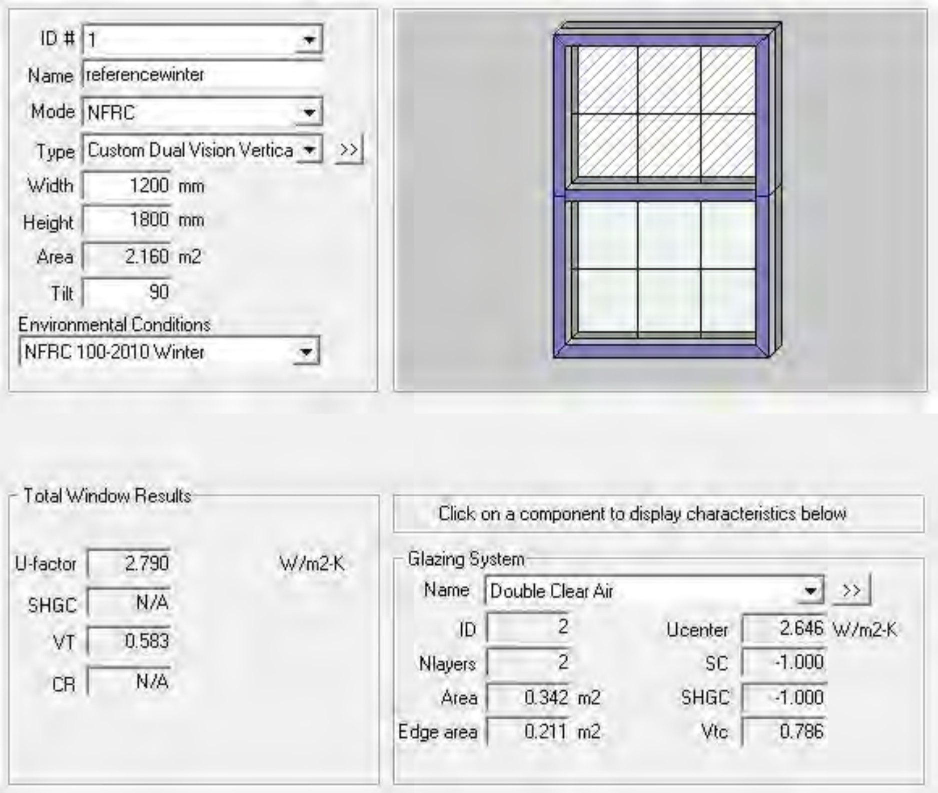


Figure H.8 Characteristic of option number 7 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

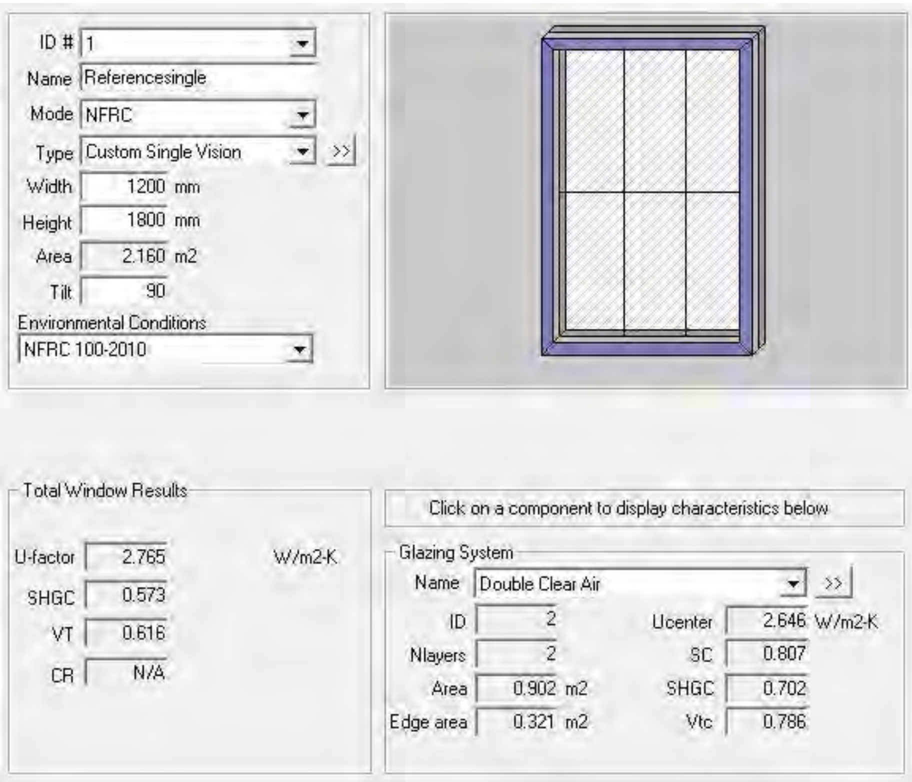


Figure H.9 Characteristic of option number 8 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

H.1.2. Kind of window.

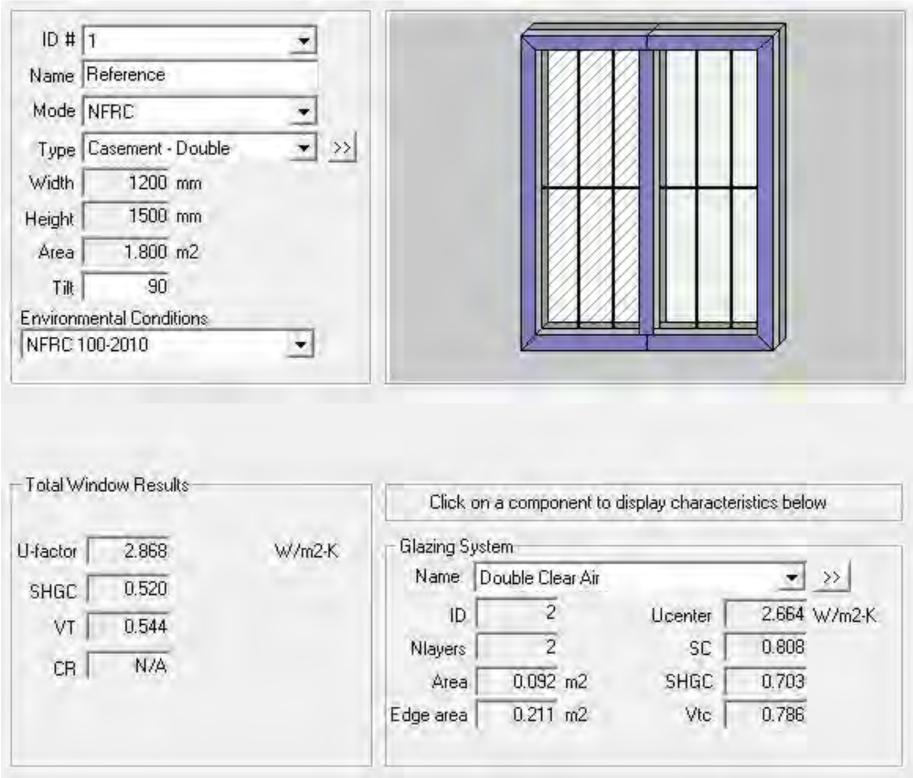


Figure H.10 Characteristic of option number 9 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

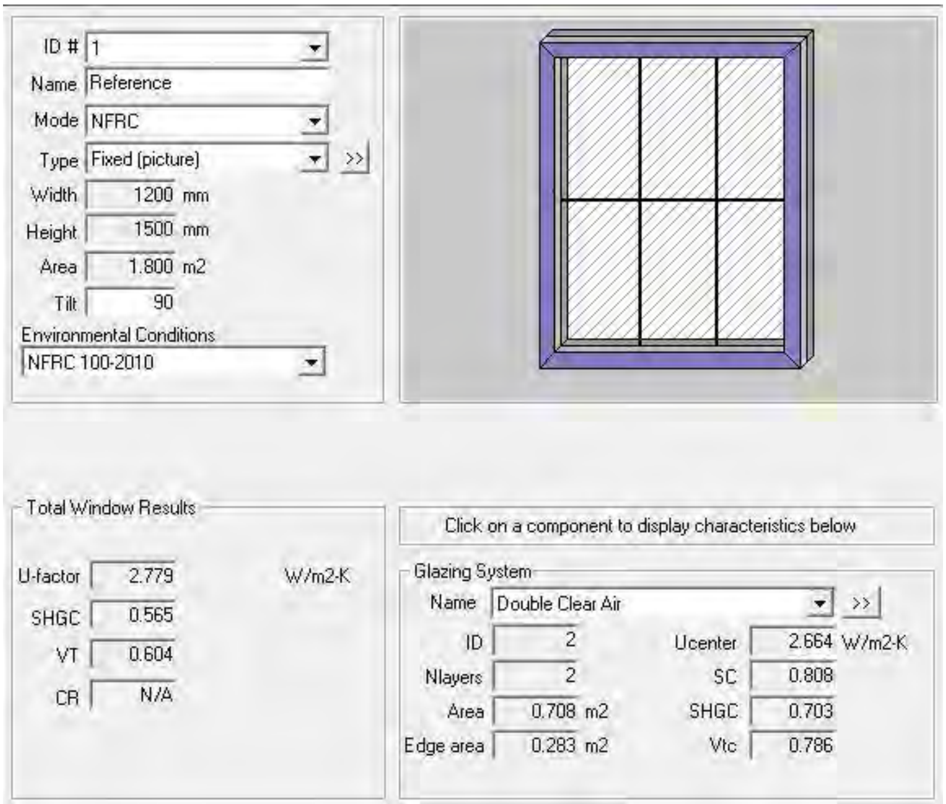


Figure H.11 Characteristic of option number 10 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

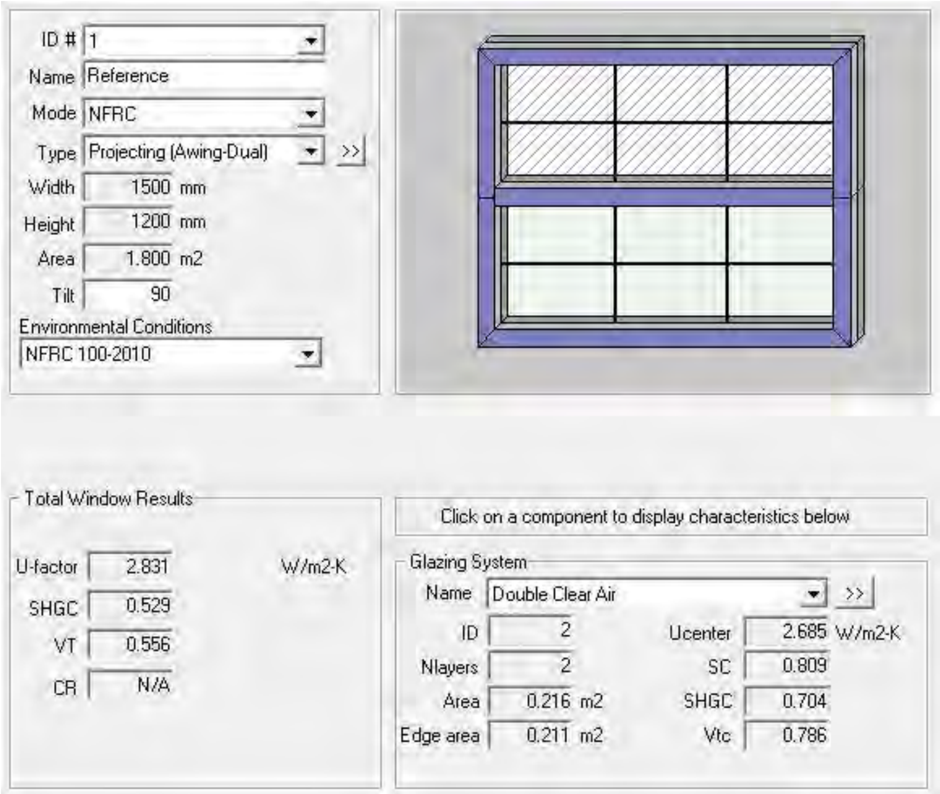


Figure H.12 Characteristic of option number 11 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

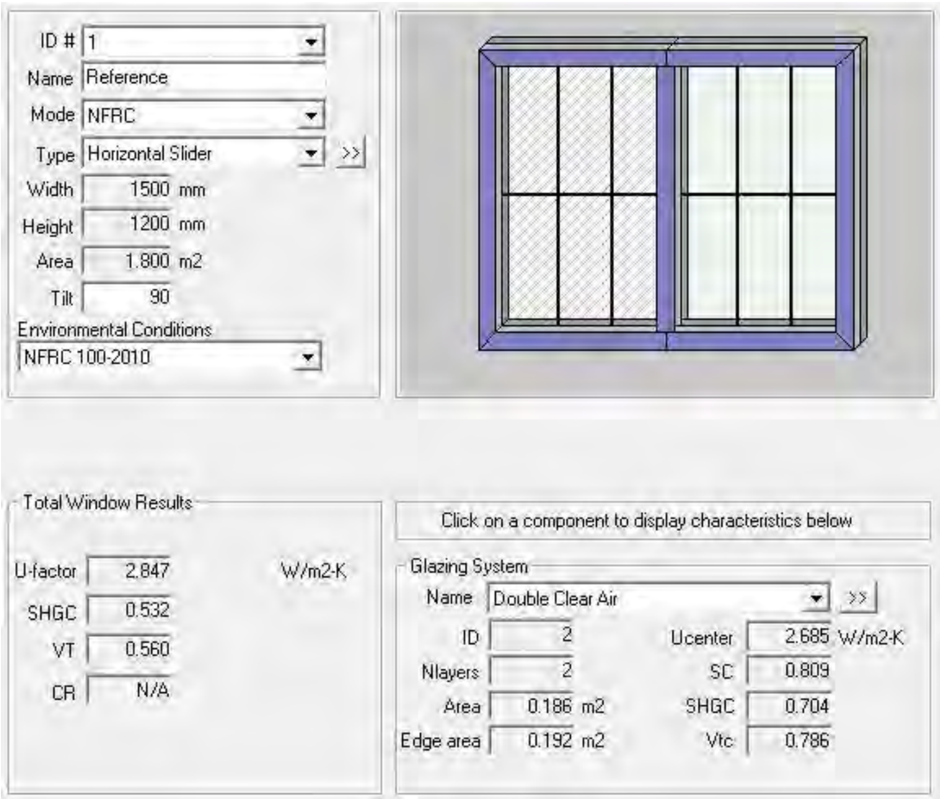


Figure H.13 Characteristic of option number 12 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

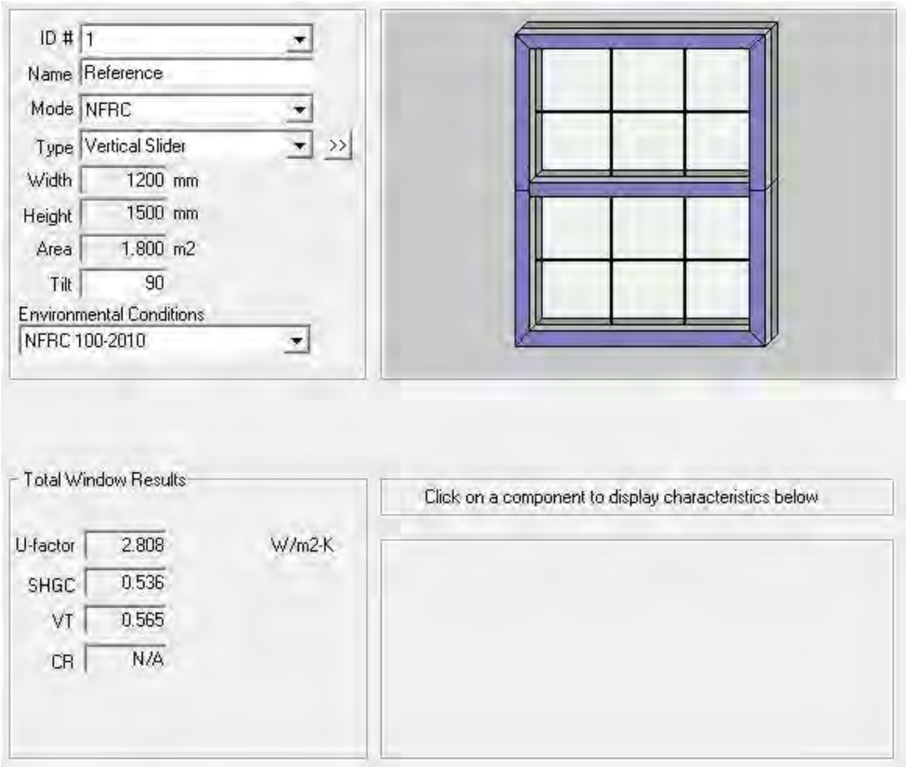


Figure H.14 Characteristic of option number 13 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

H.1.3. Kind of frame and divider

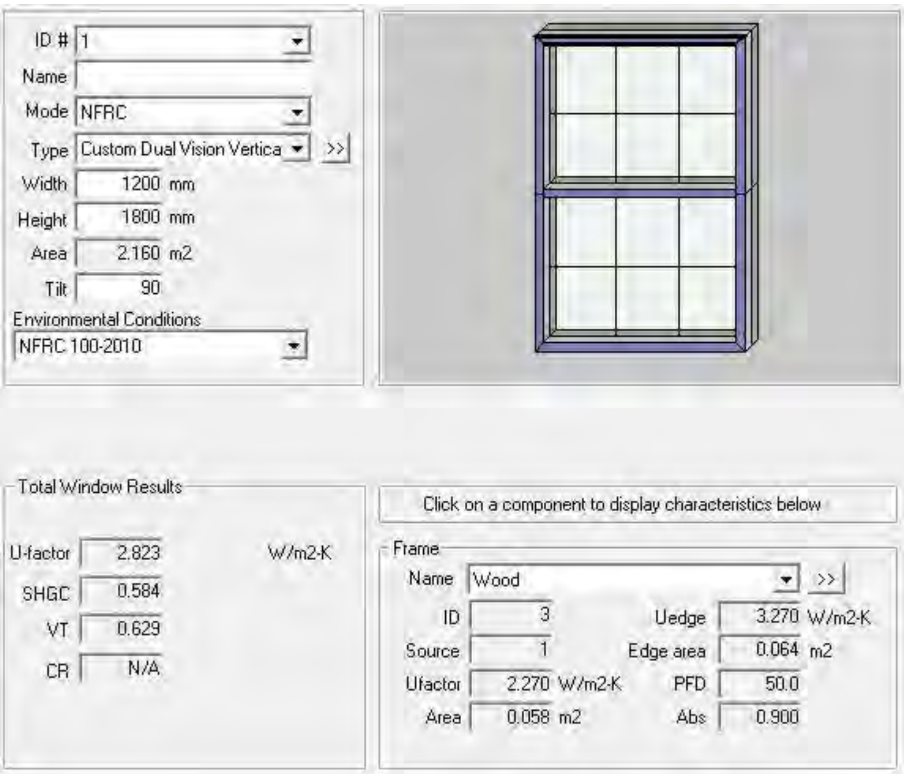


Figure H.15 Characteristic of option number 14 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

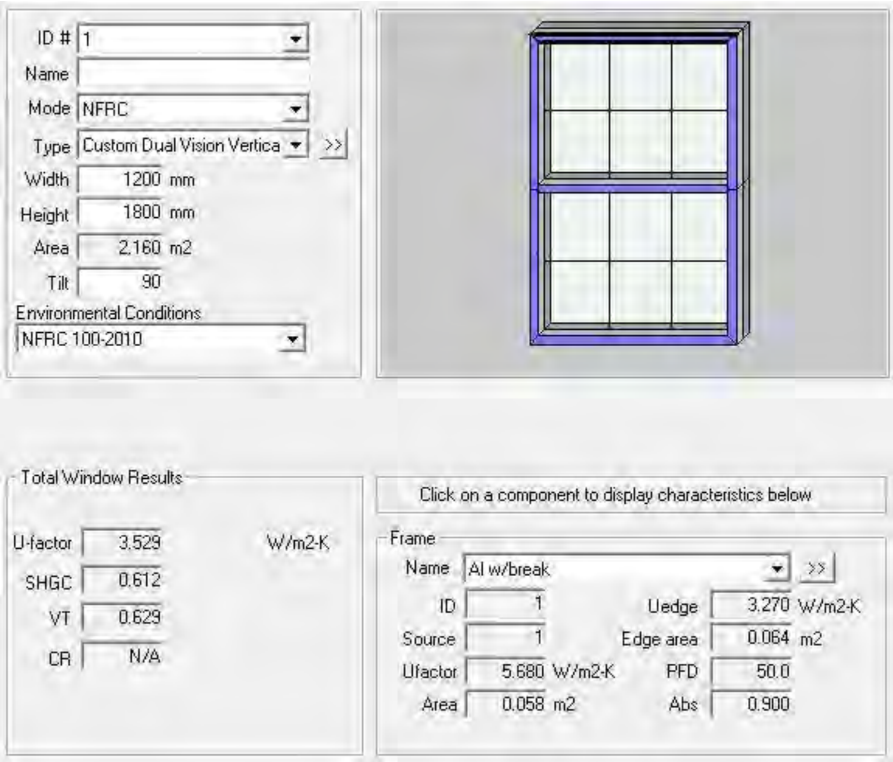


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Figure H.16 Characteristic of option number 15 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

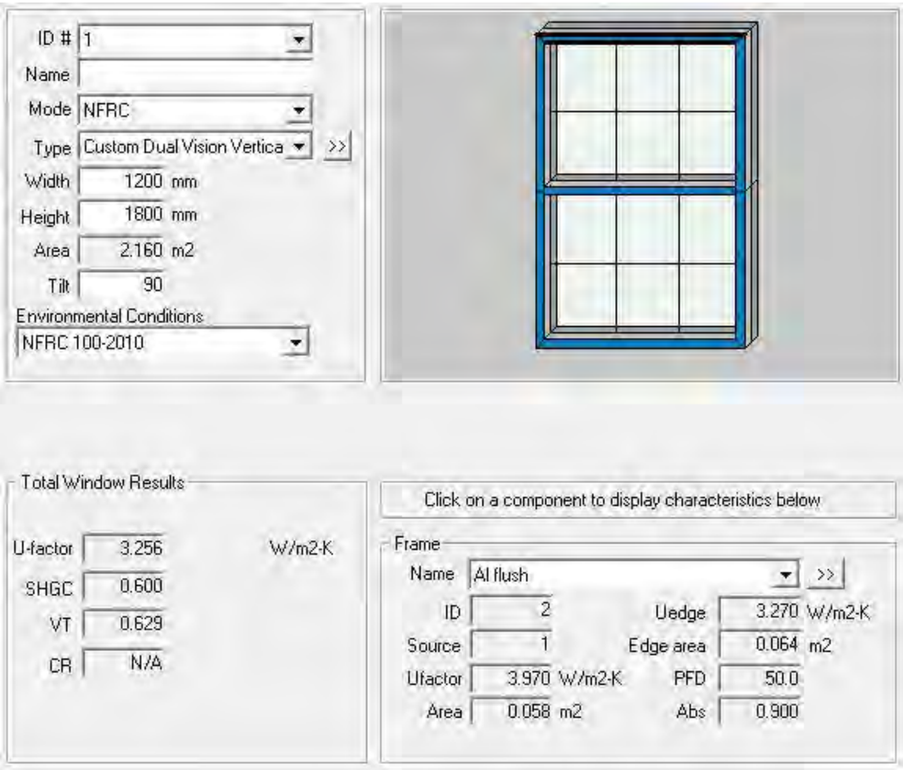


Figure H.17 Characteristic of option number 16 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

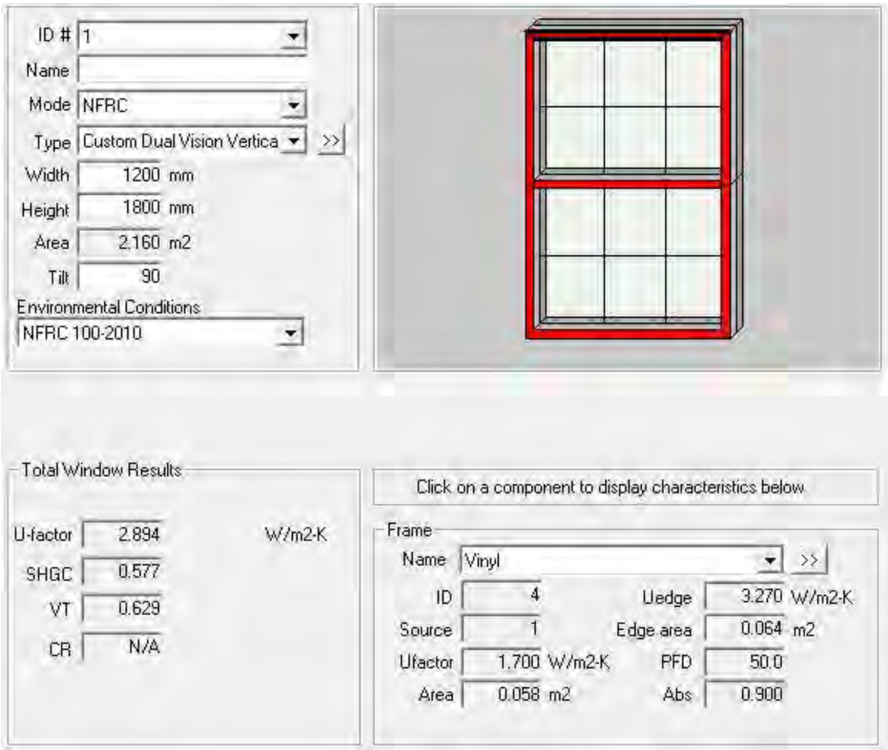


Figure H.18 Characteristic of option number 17 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

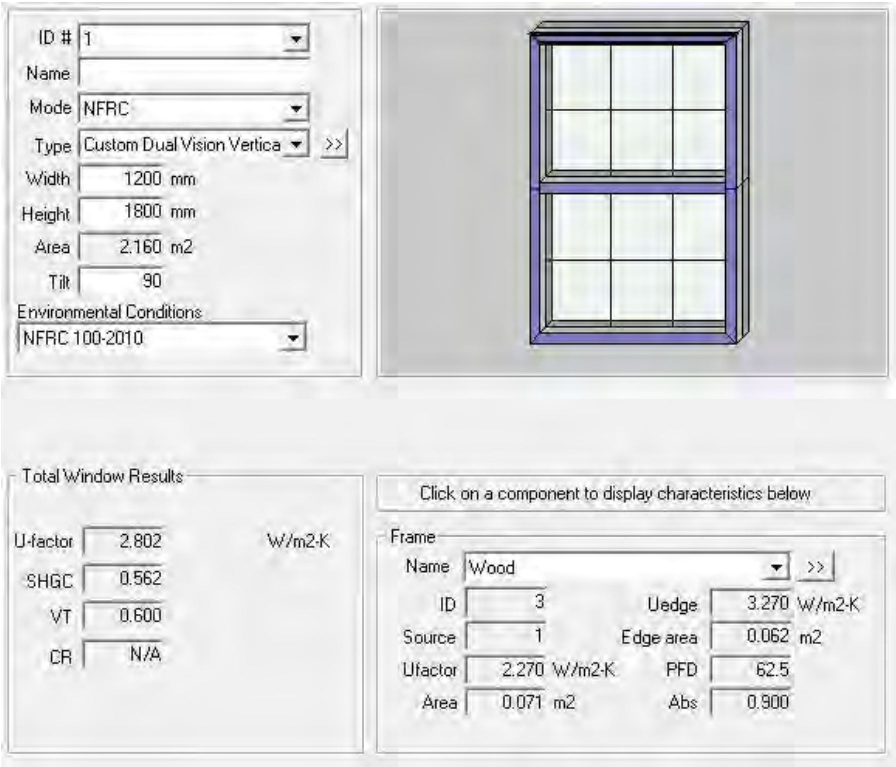


Figure H.19 Characteristic of option number 18 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

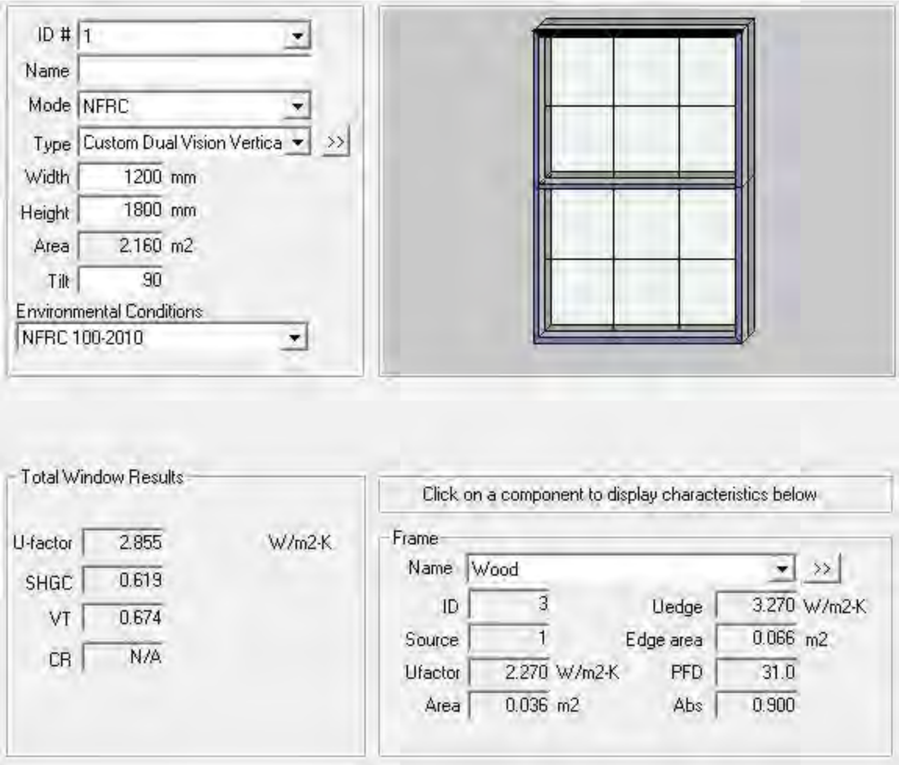


Figure H.20 Characteristic of option number 19 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

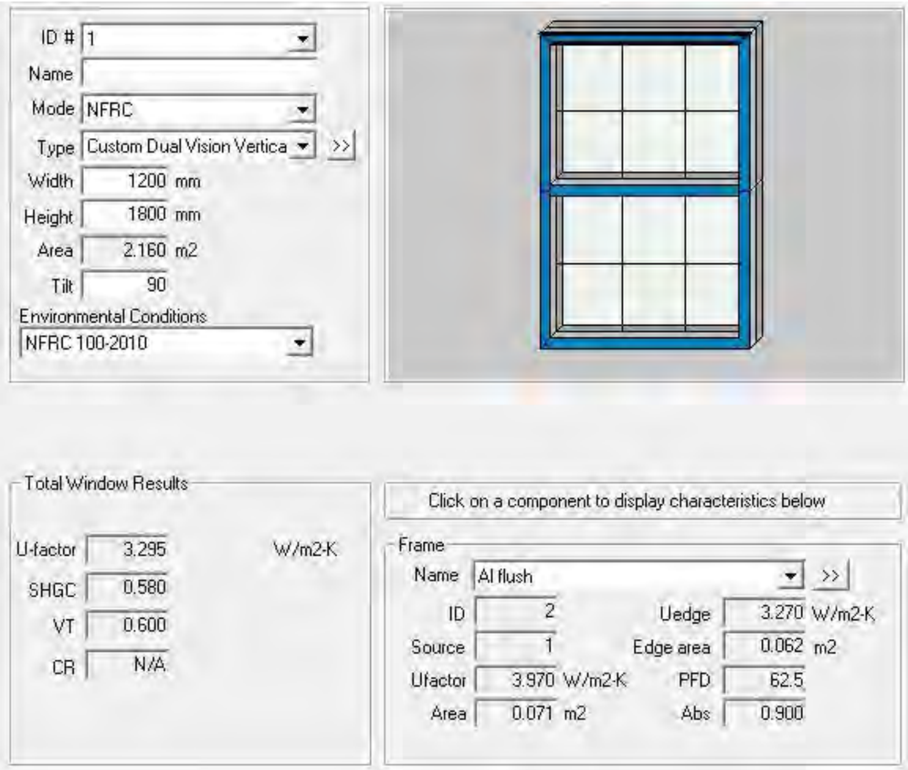


Figure H.21 Characteristic of option number 20 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

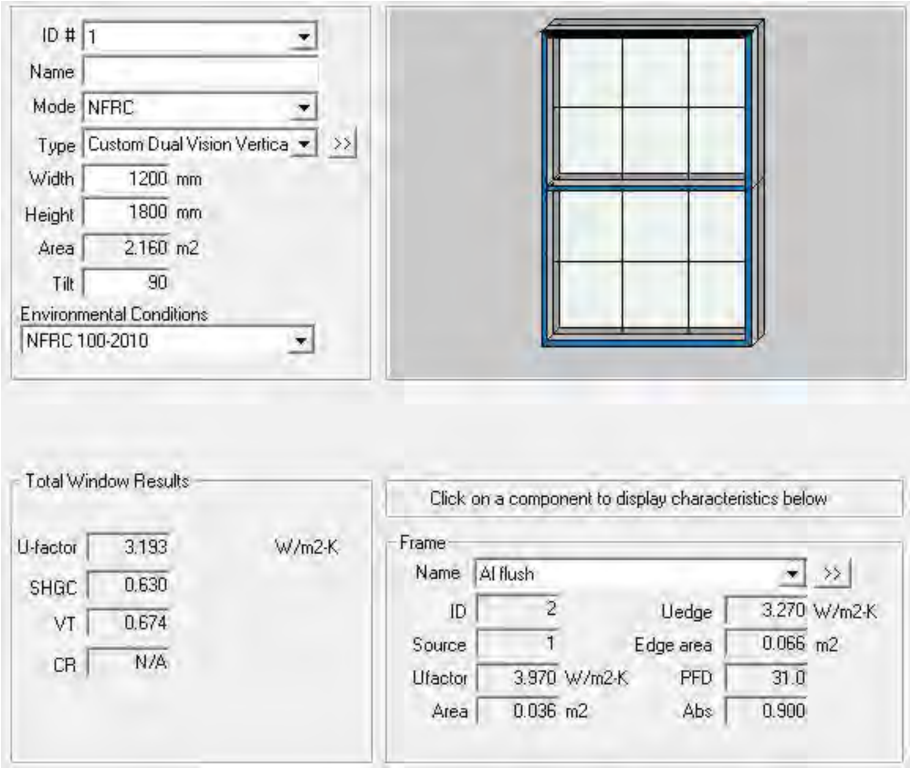


Figure H.22 Characteristic of option number 21 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

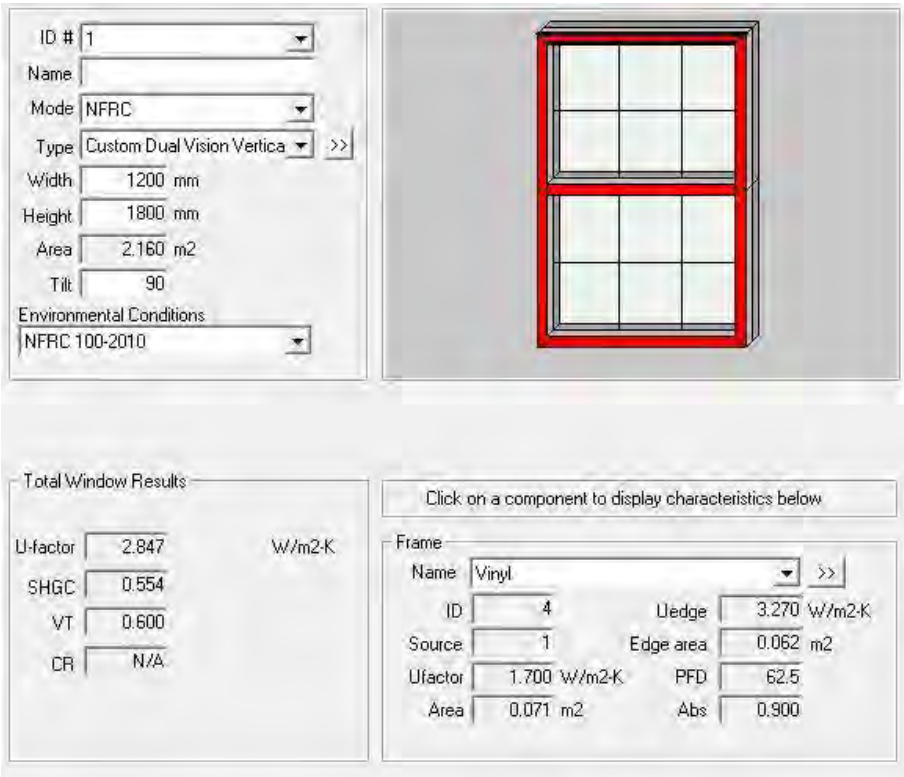


Figure H.23 Characteristic of option number 22 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

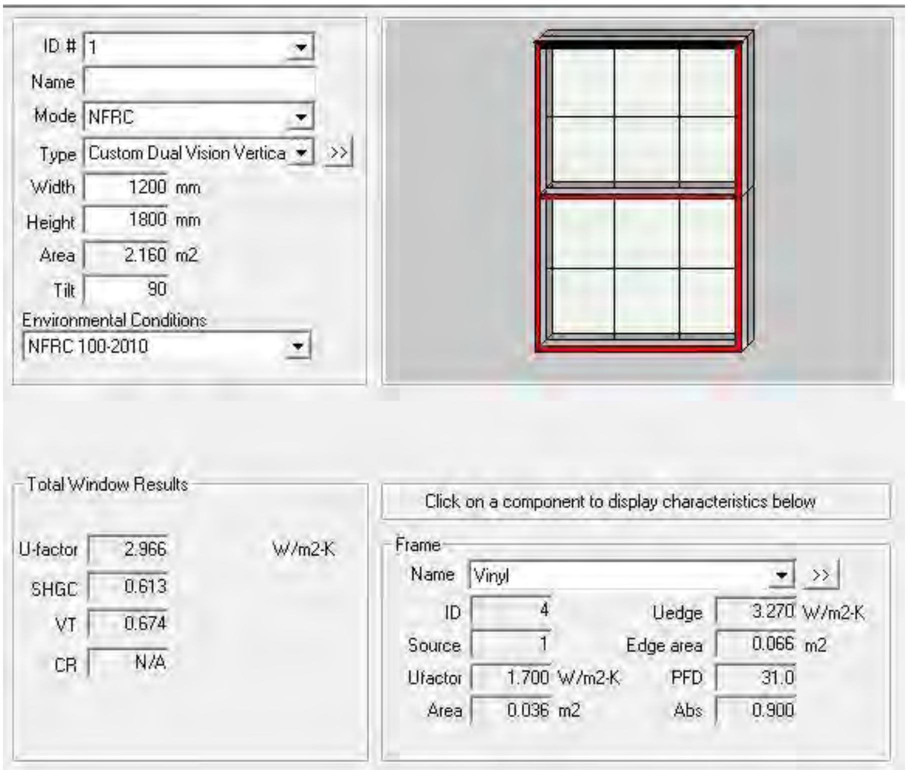


Figure H.24 Characteristic of option number 23 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

H.1.4. Kind of glazing system

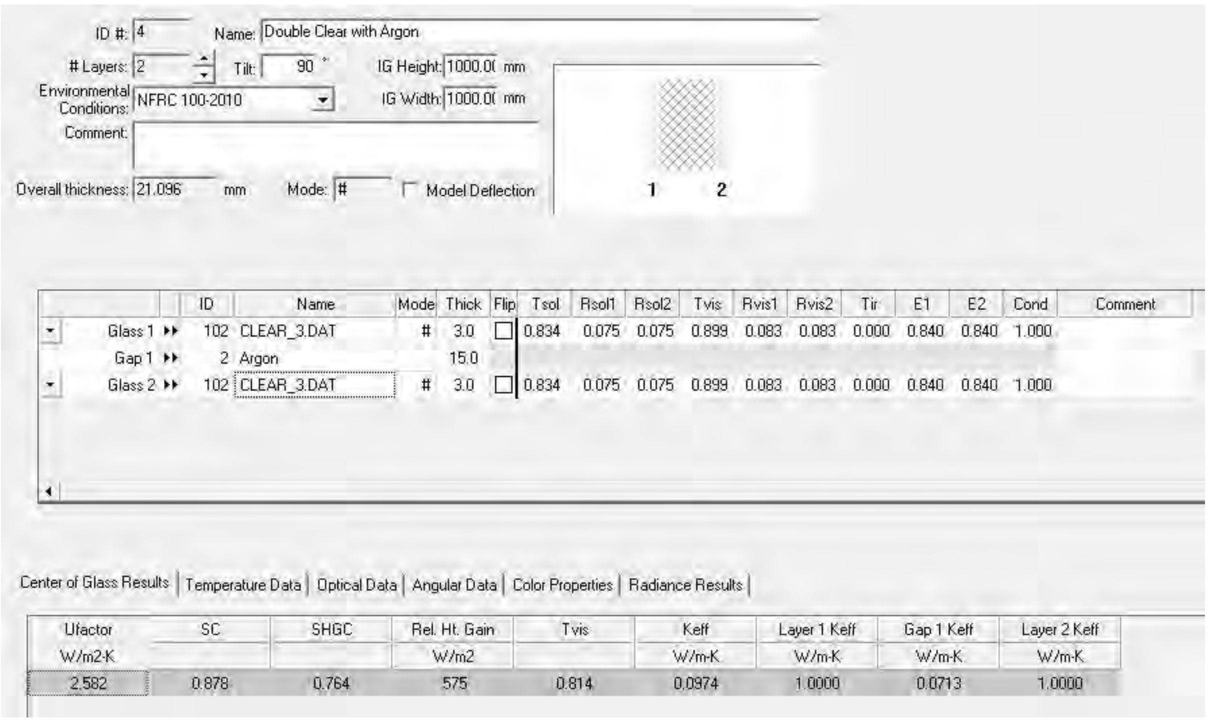


Figure H25. The characteristic of the glazing system of option number 24 windows.

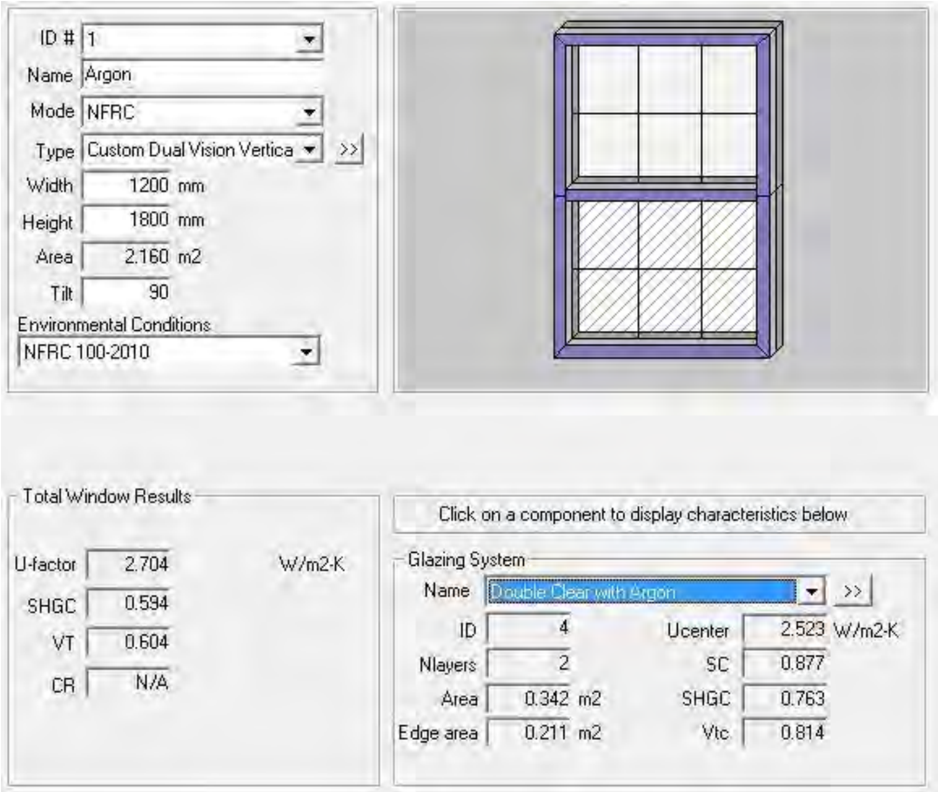


Figure H.26 Characteristic of option number 24 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

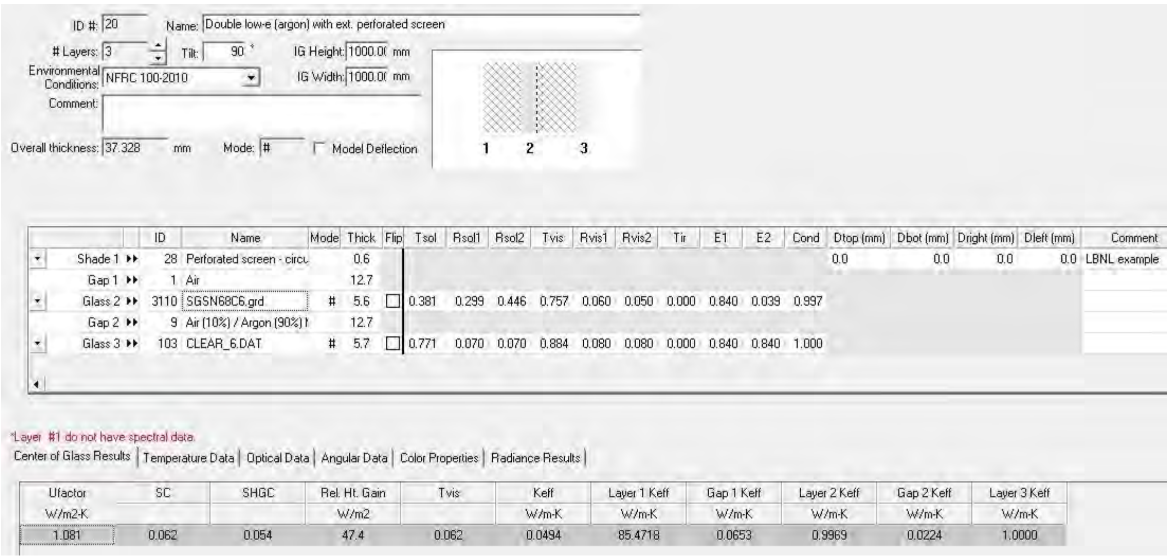


Figure H27. The characteristic of the glazing system of option number 25 windows.

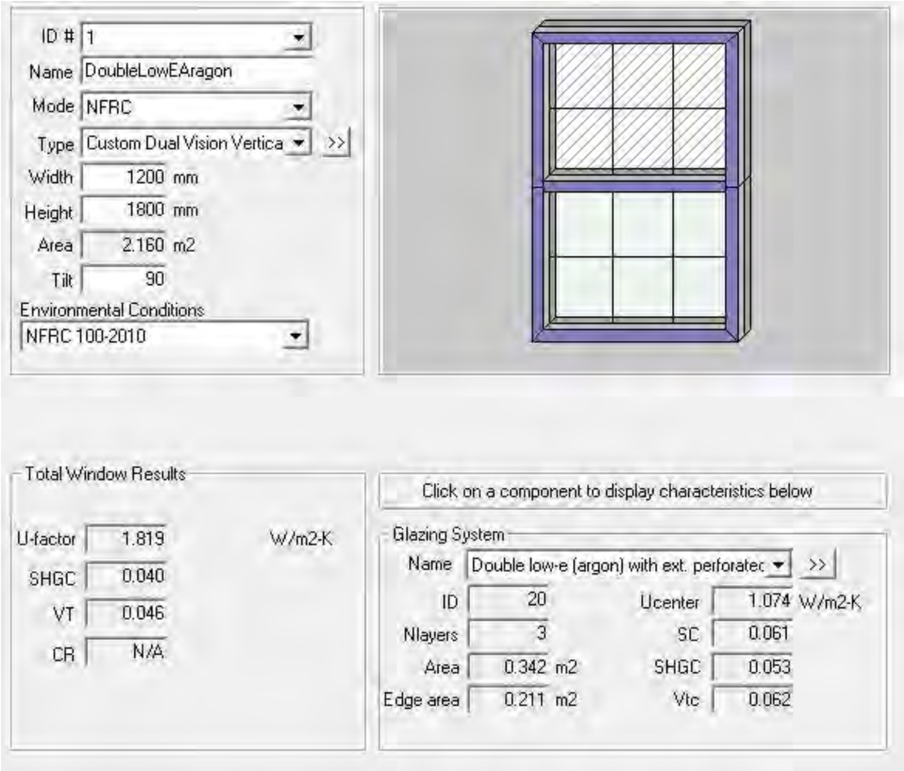


Figure H.28 Characteristic of option number 25 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

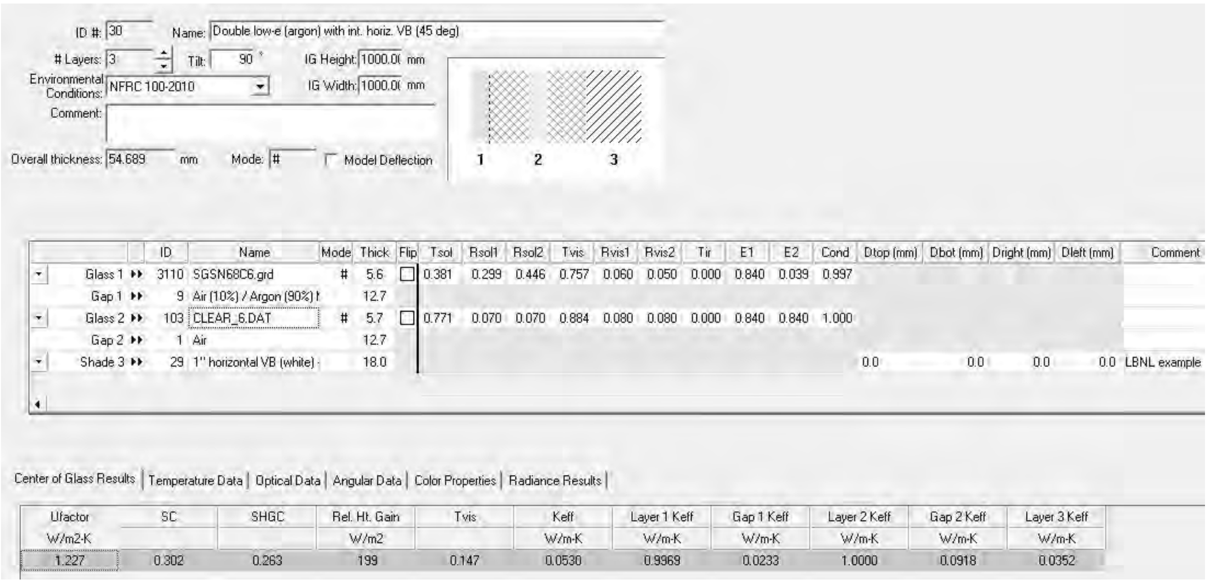


Figure H29. The characteristic of the glazing system of option number 26 windows.

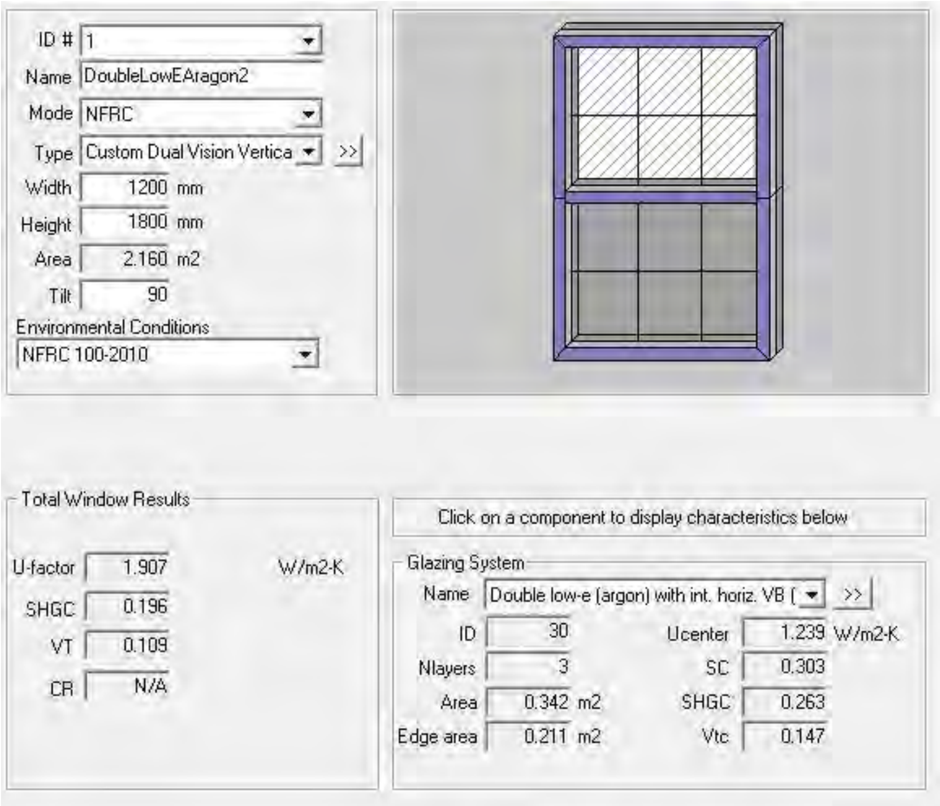


Figure H.30 Characteristic of option number 26 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

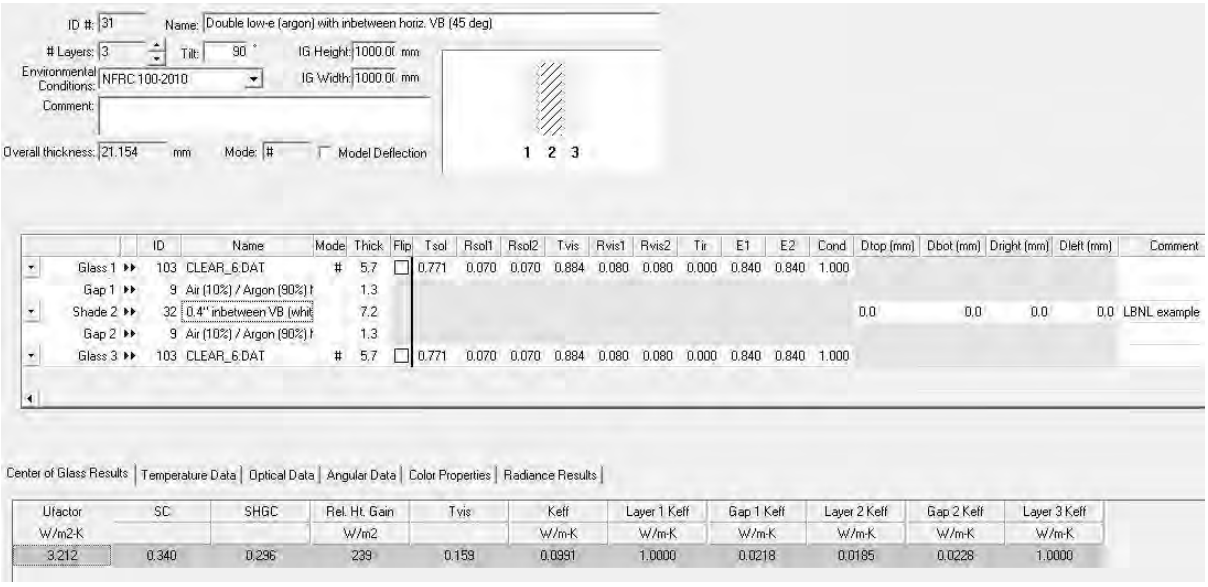


Figure H31. The characteristic of the glazing system of option number 27 windows.

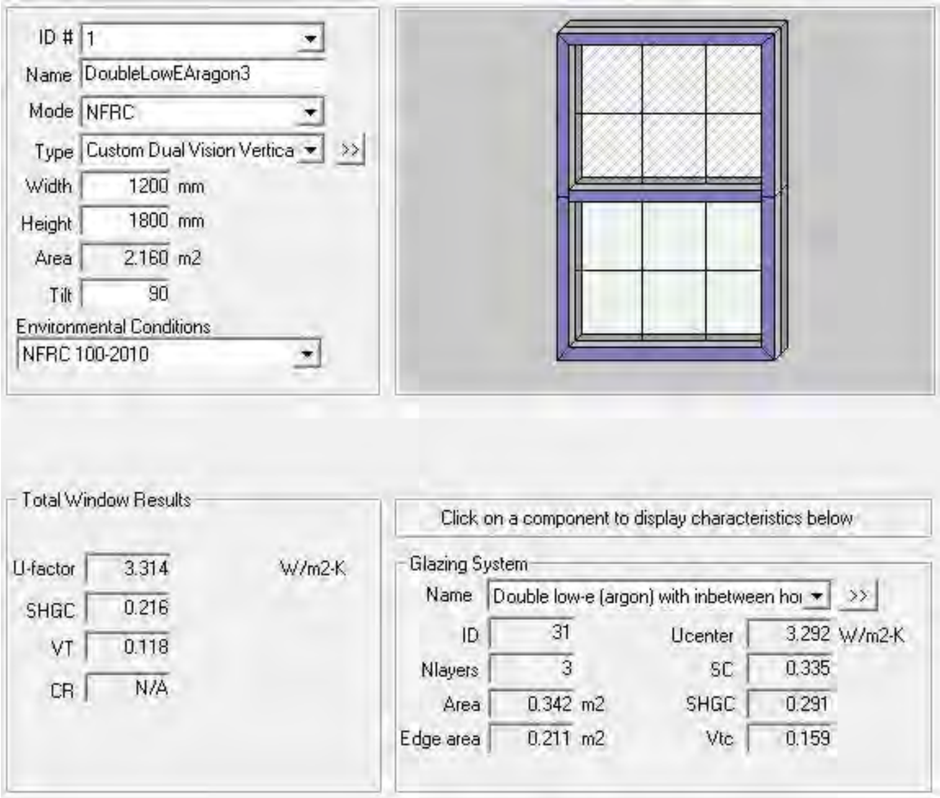


Figure H.32 Characteristic of option number 27 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

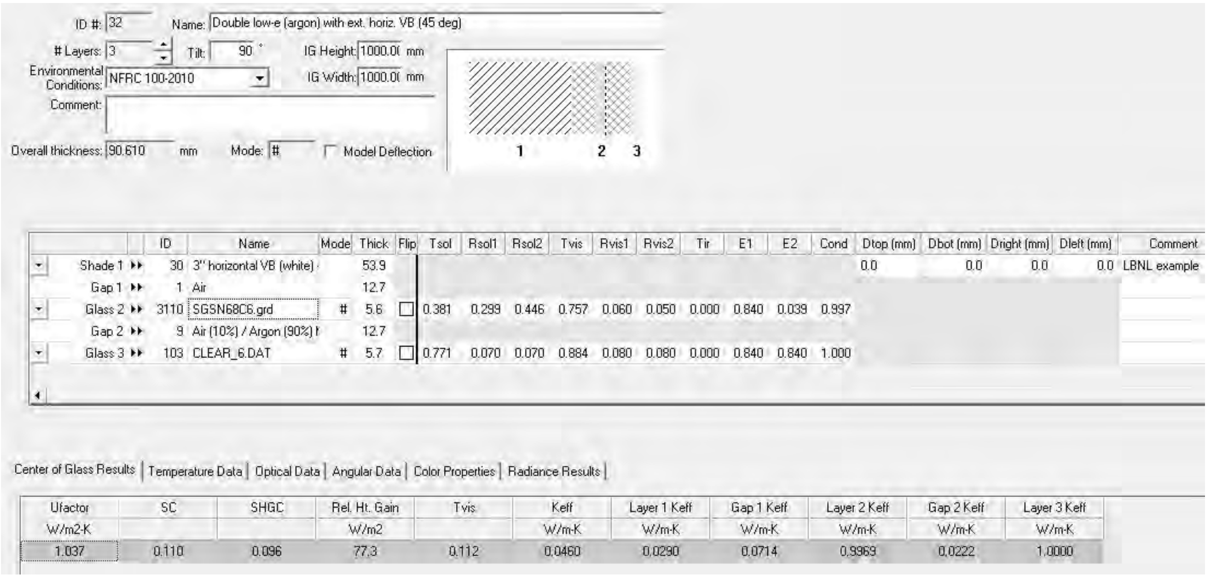


Figure H33. The characteristic of the glazing system of option number 28 windows.

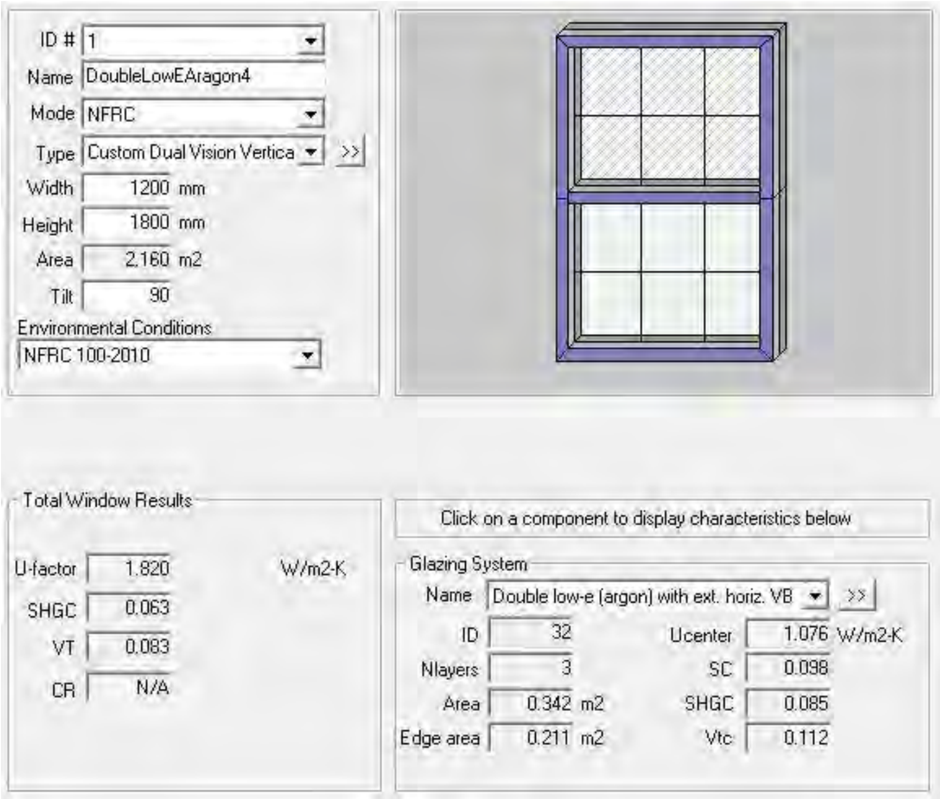


Figure H.34 Characteristic of option number 28 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

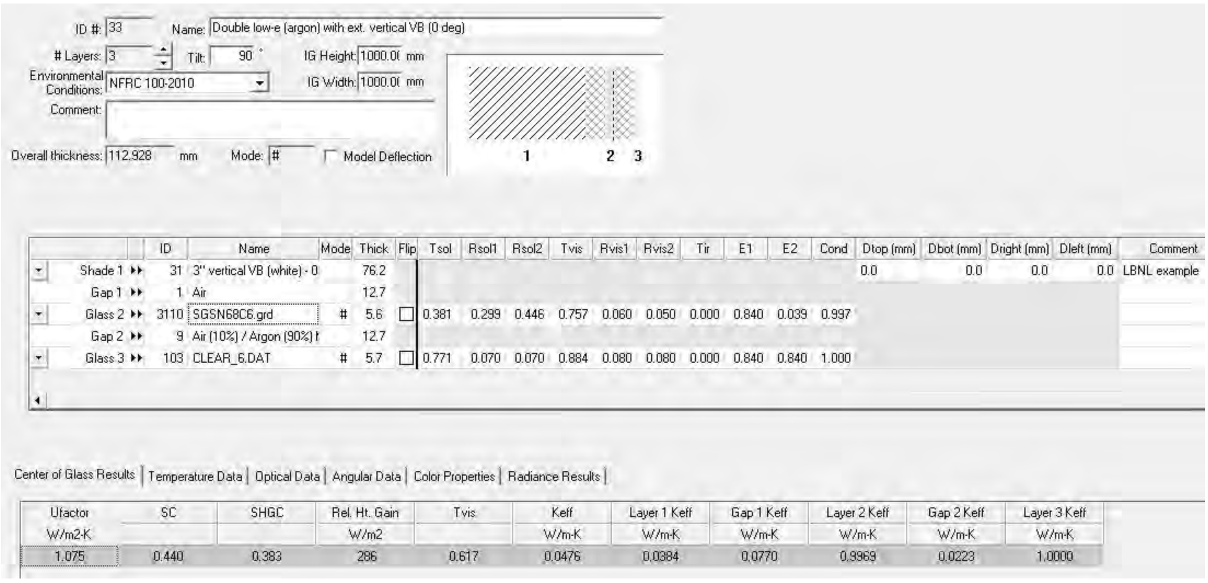


Figure H35. The characteristic of the glazing system of option number 29 windows.

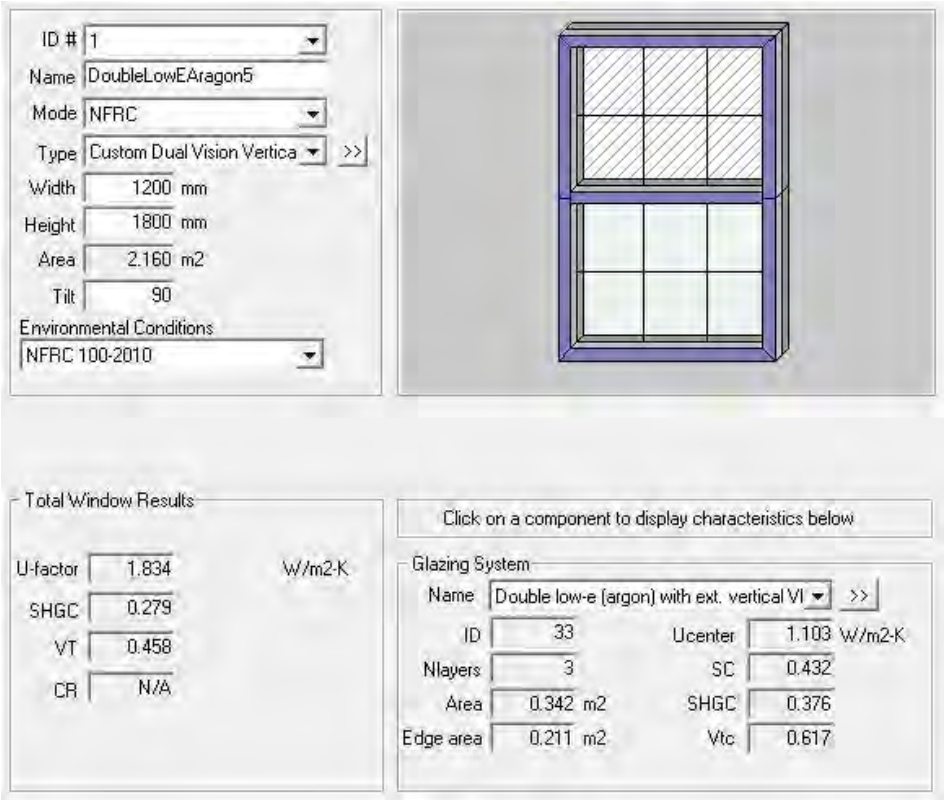


Figure H.36 Characteristic of option number 29 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

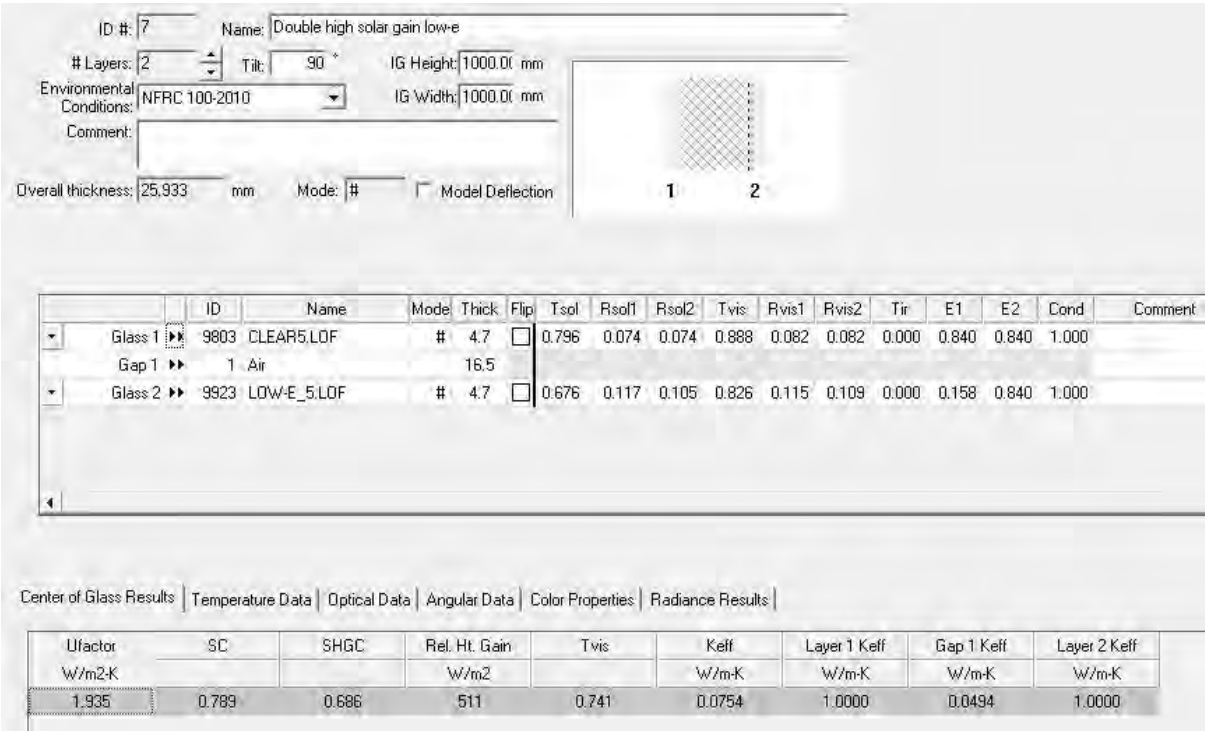


Figure H37. The characteristic of the glazing system of option number 30 windows.

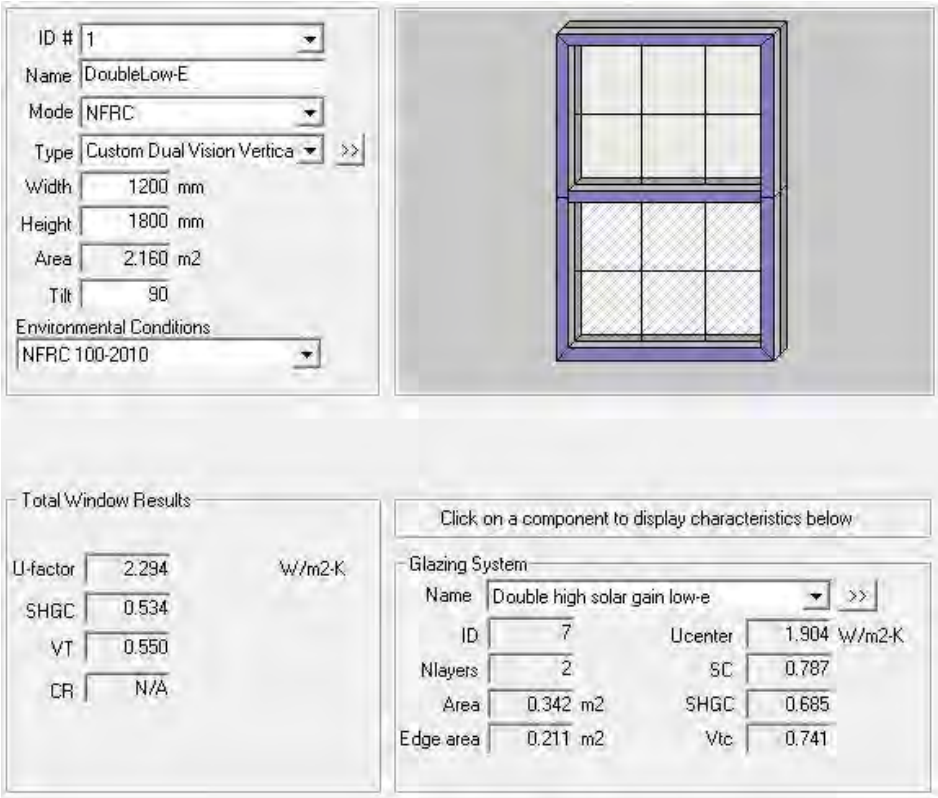


Figure H.38 Characteristic of option number 30 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

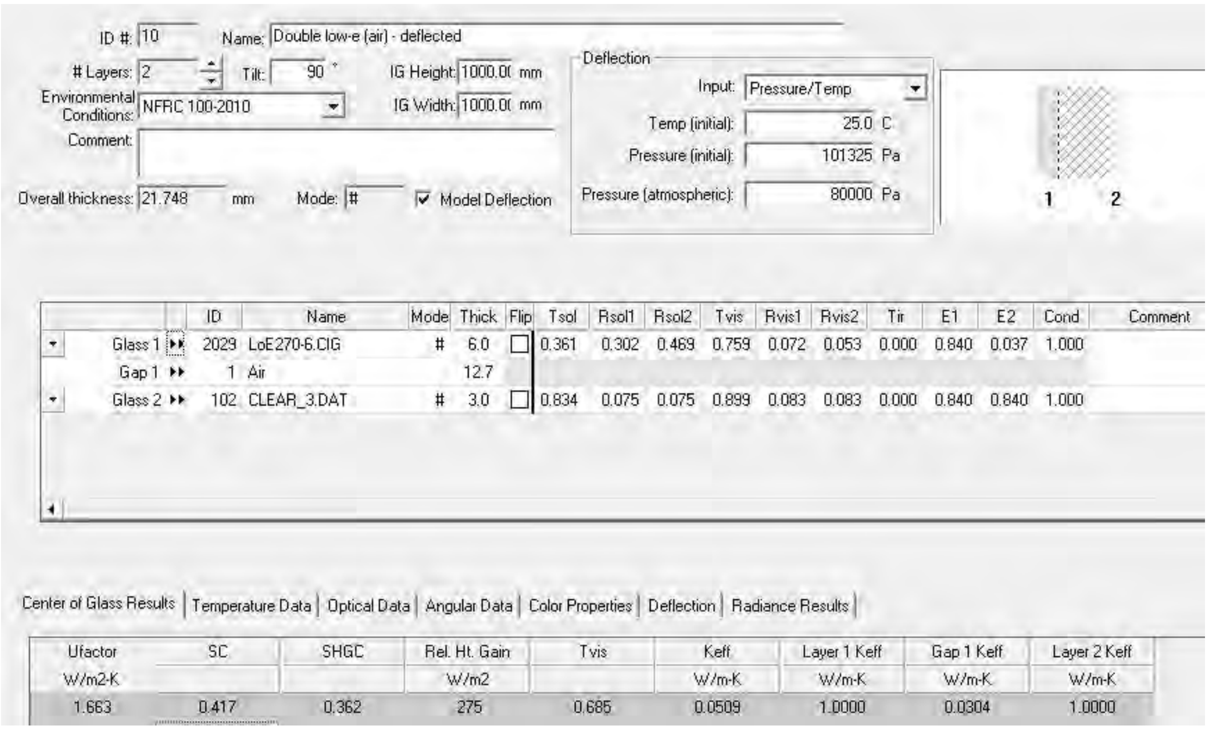


Figure H39. The characteristic of the glazing system of option number 31 windows.

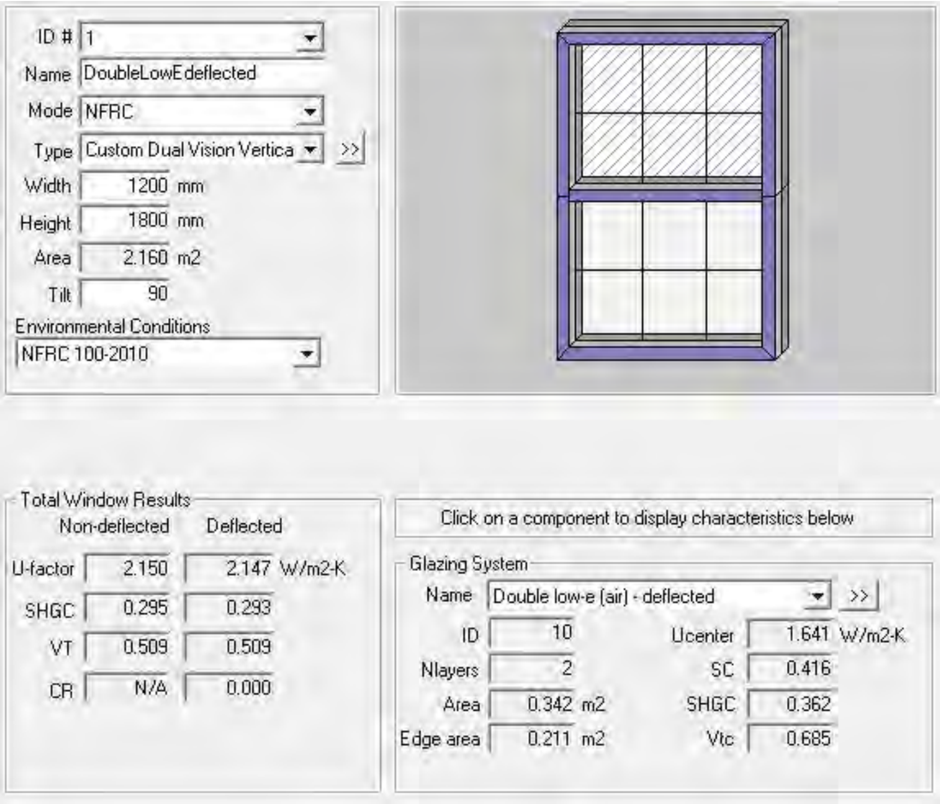


Figure H.40 Characteristic of option number 31 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

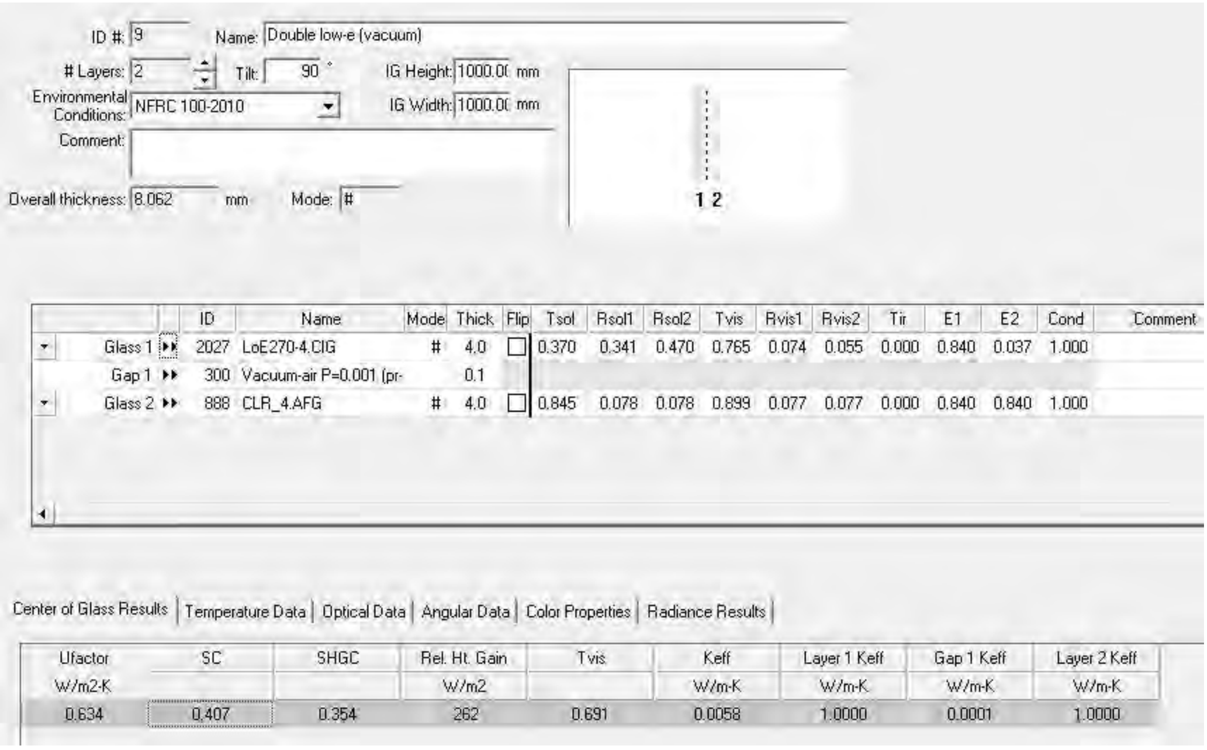


Figure H41. The characteristic of the glazing system of option number 32 windows.

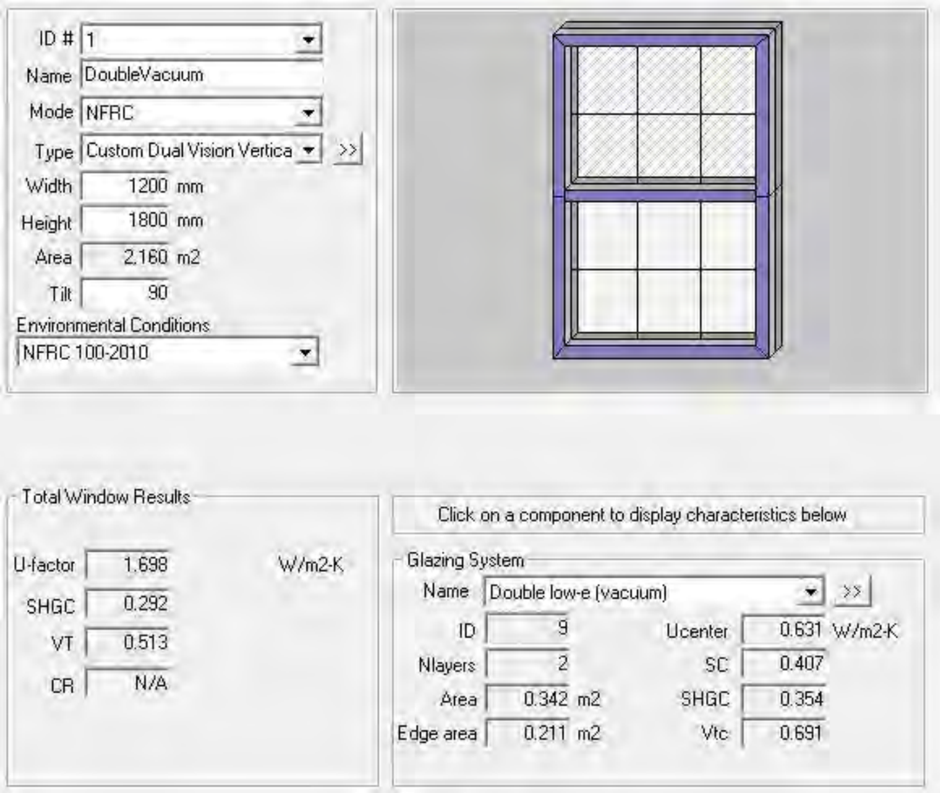


Figure H.42 Characteristic of option number 32 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

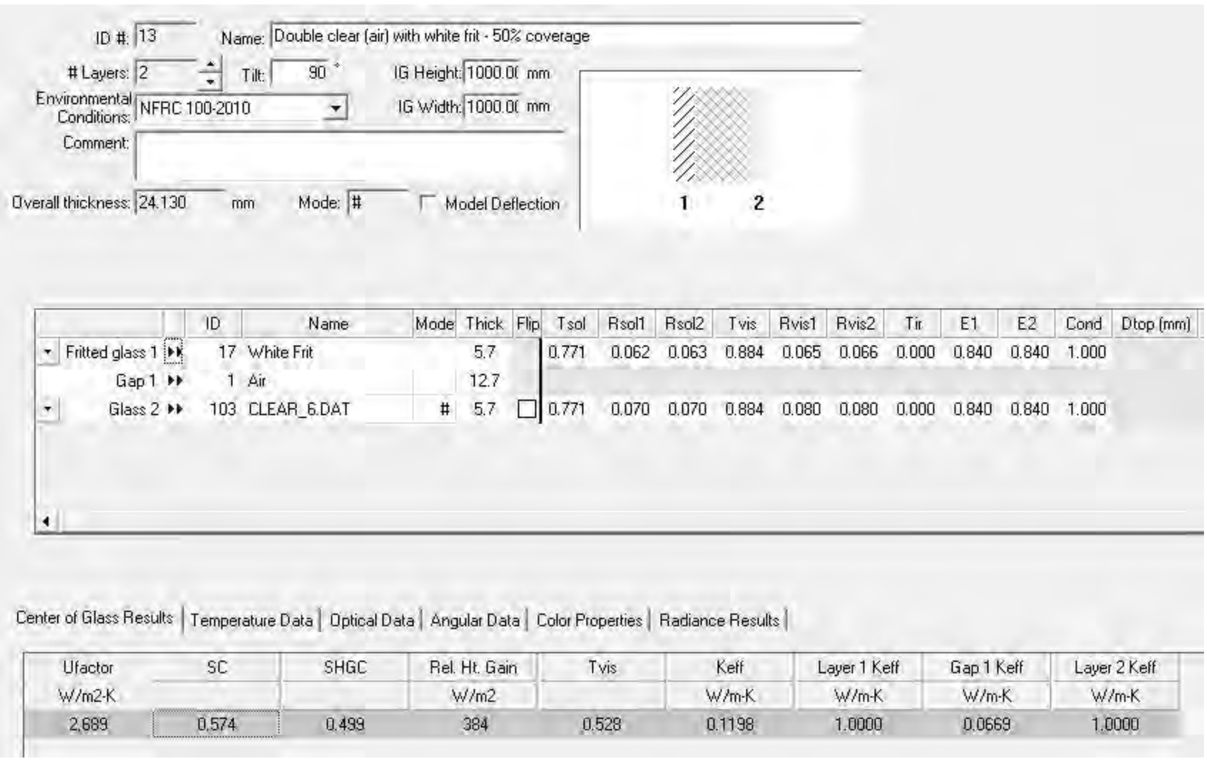


Figure H43. The characteristic of the glazing system of option number 33 windows.

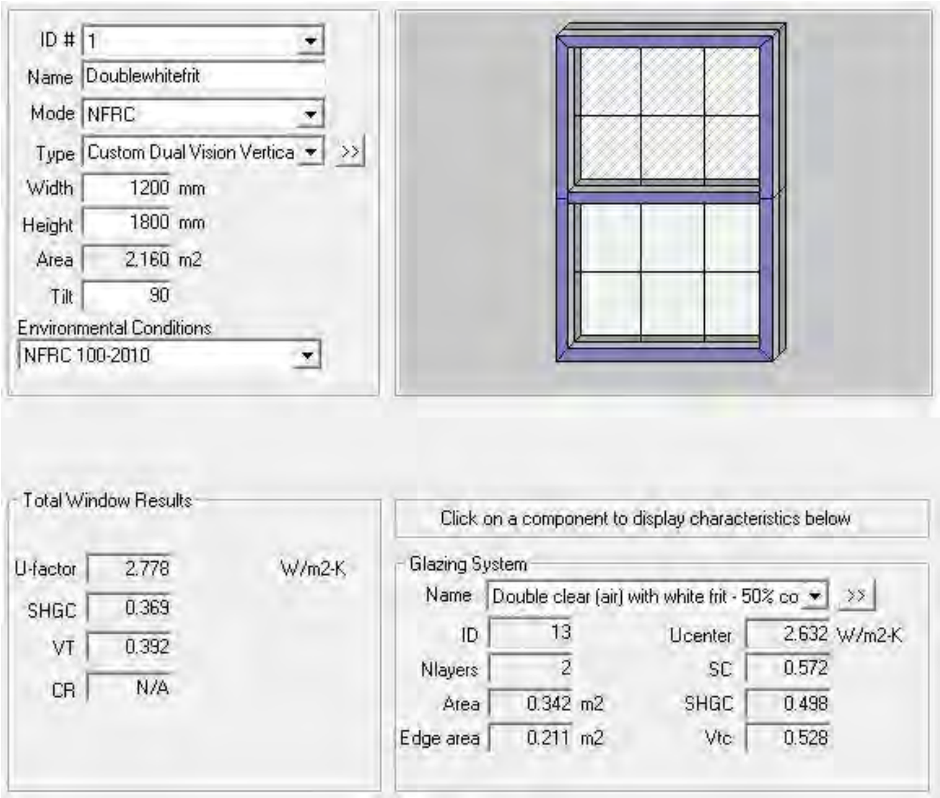


Figure H.44 Characteristic of option number 33 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

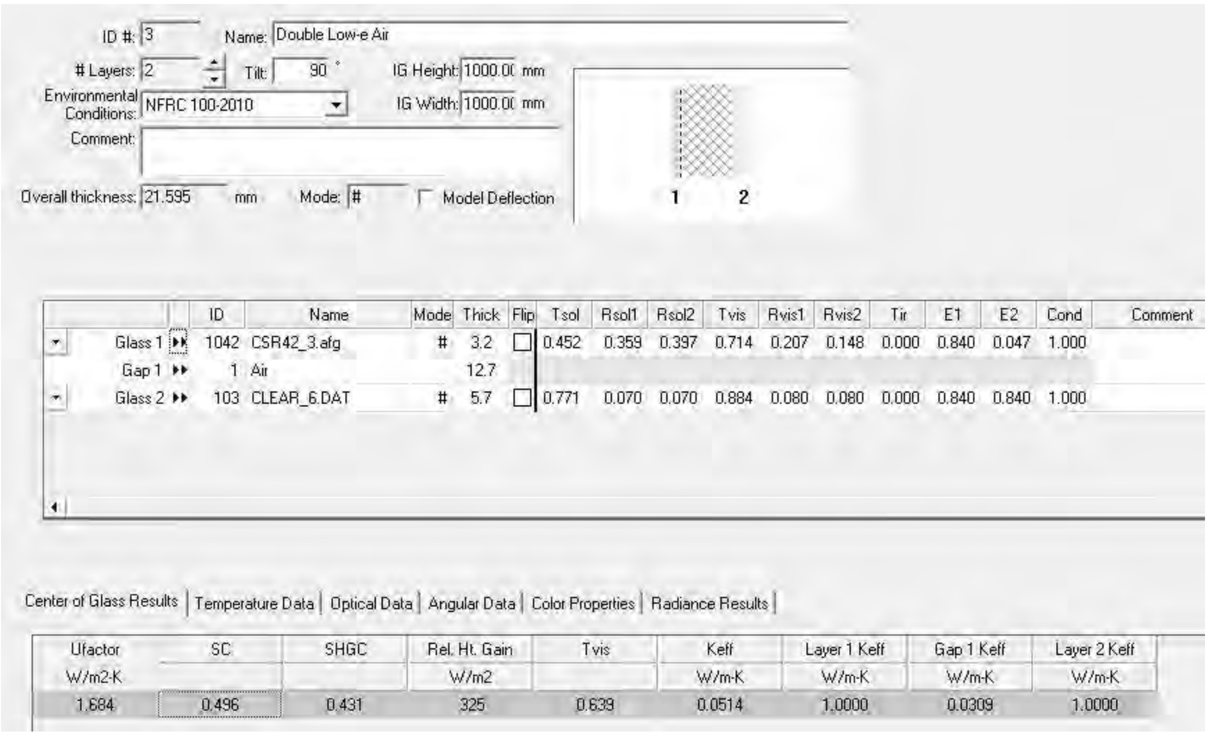


Figure H45. The characteristic of the glazing system of option number 34 windows.

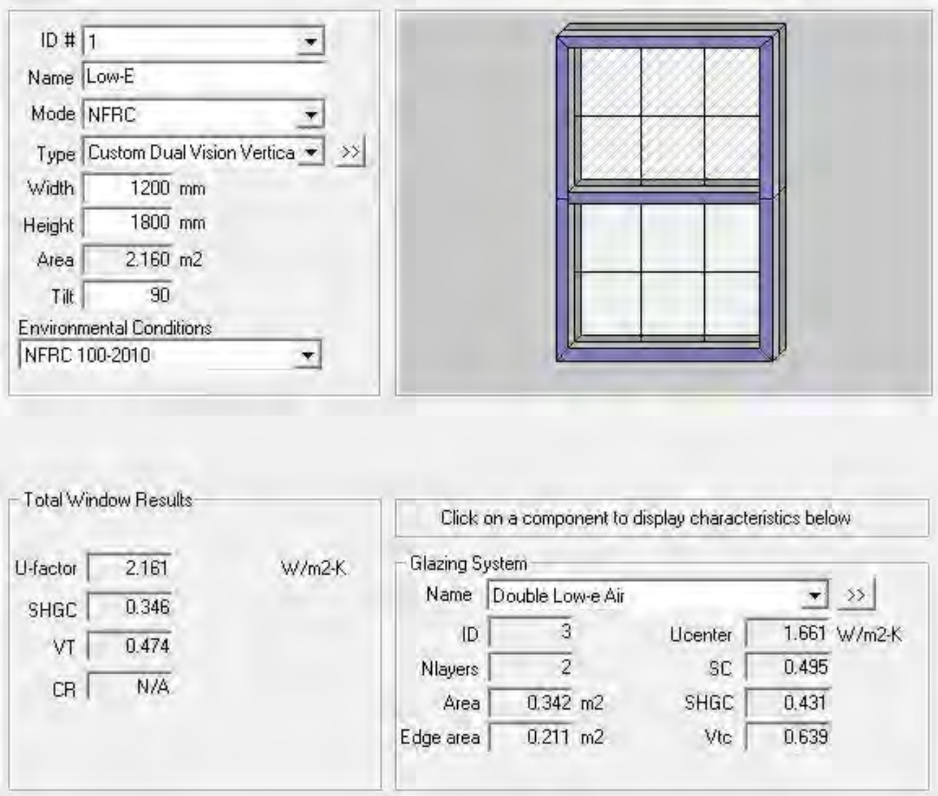


Figure H.46 Characteristic of option number 34 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

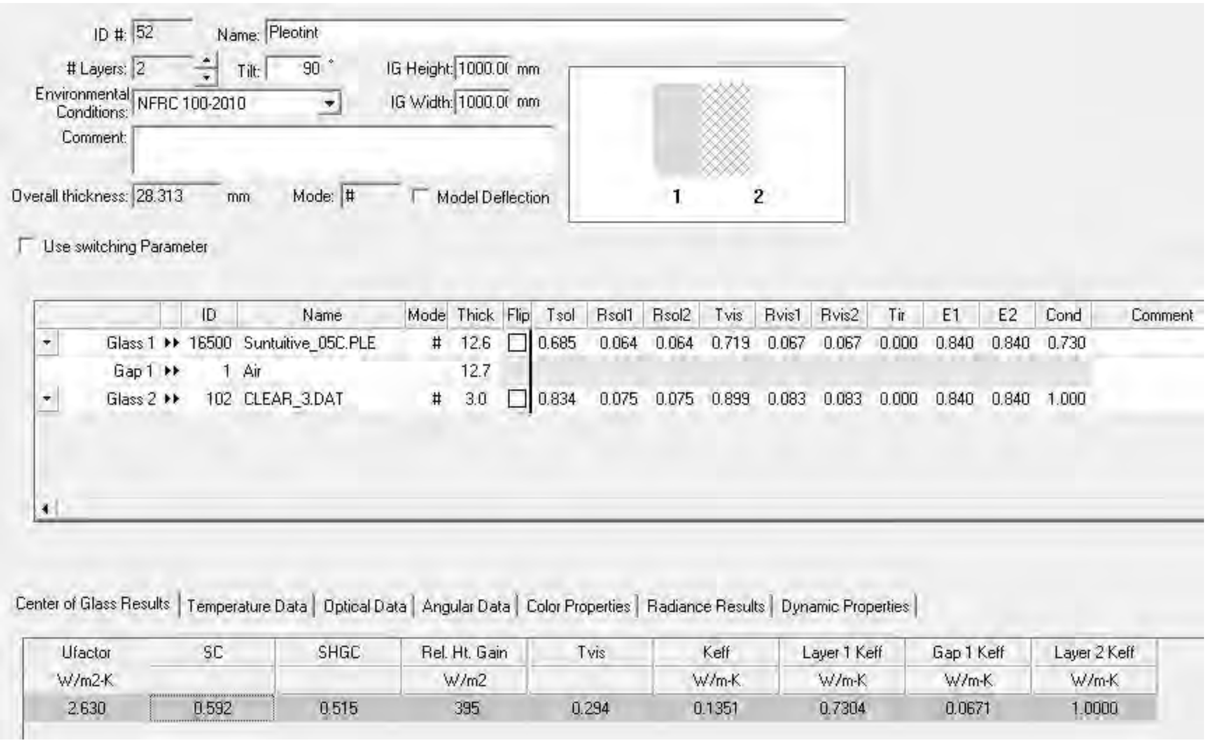


Figure H47. The characteristic of the glazing system of option number 35 windows.

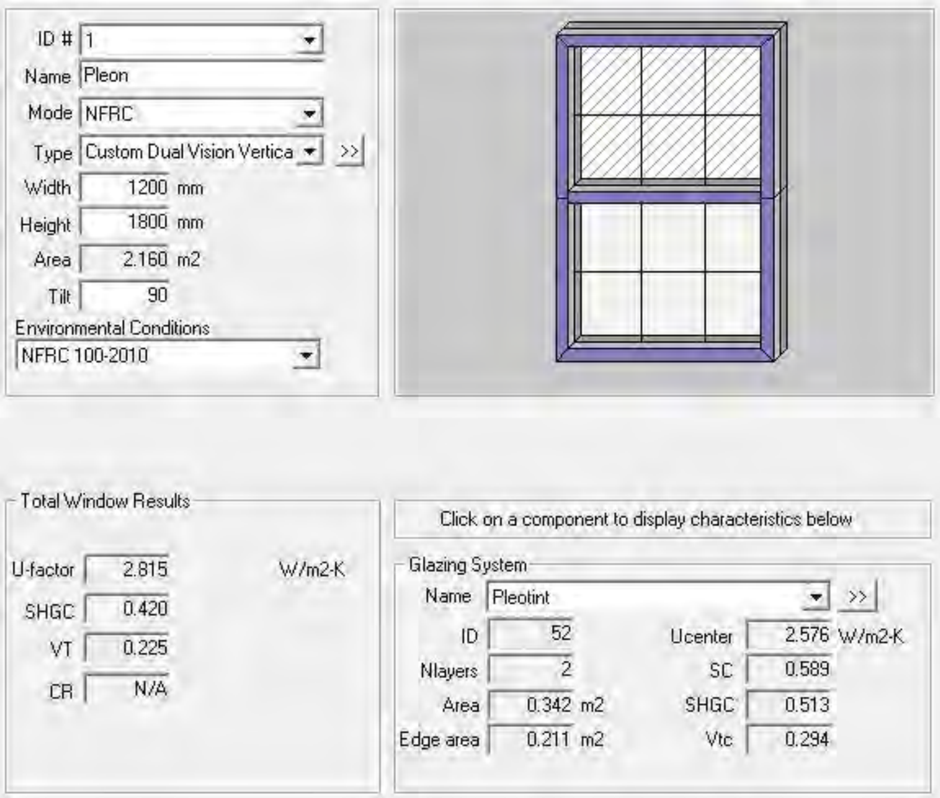


Figure H.48 Characteristic of option number 35 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

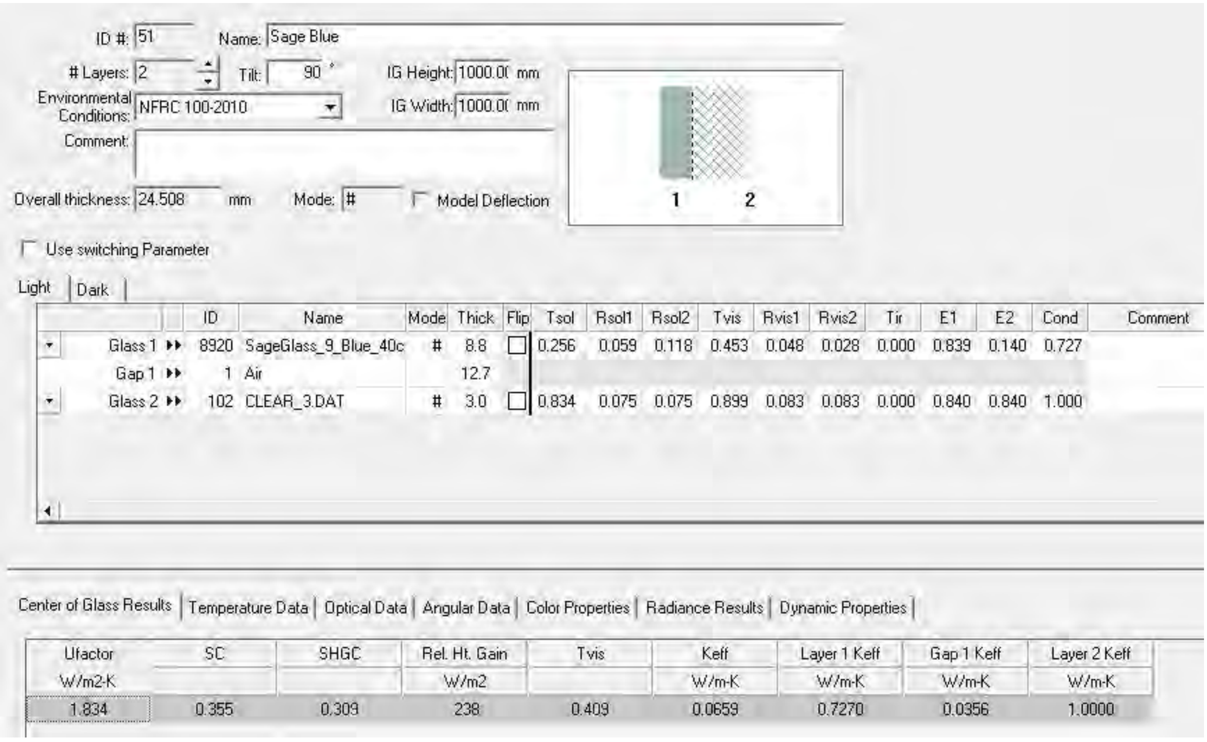


Figure H49. The characteristic of the glazing system of option number 36 windows.

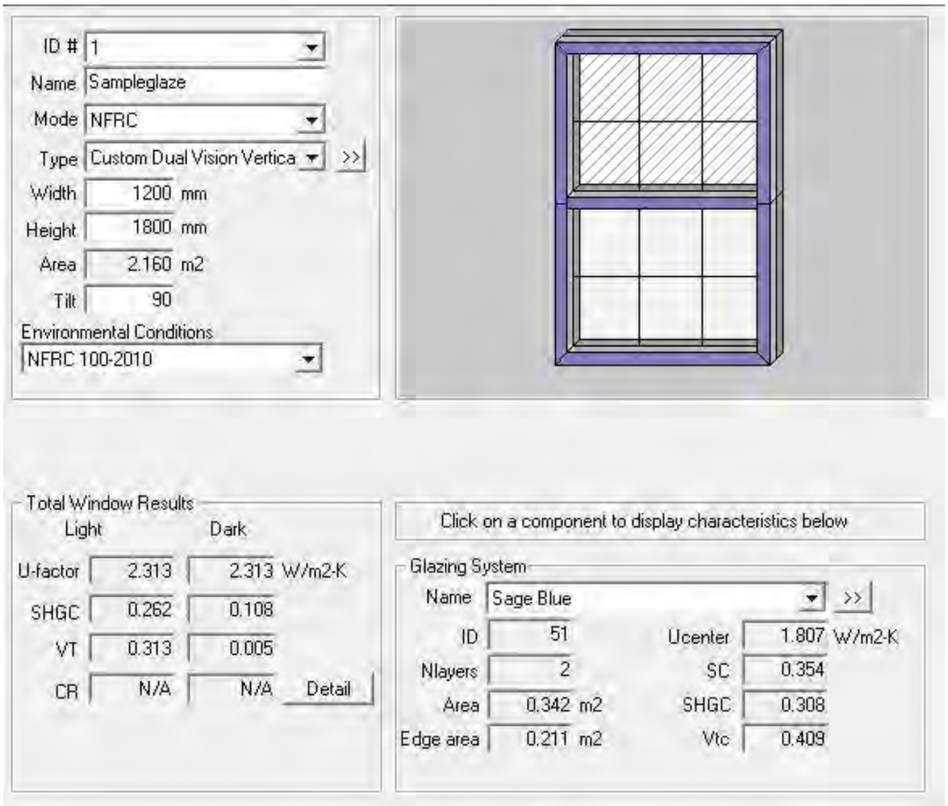


Figure H.50 Characteristic of option number 36 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

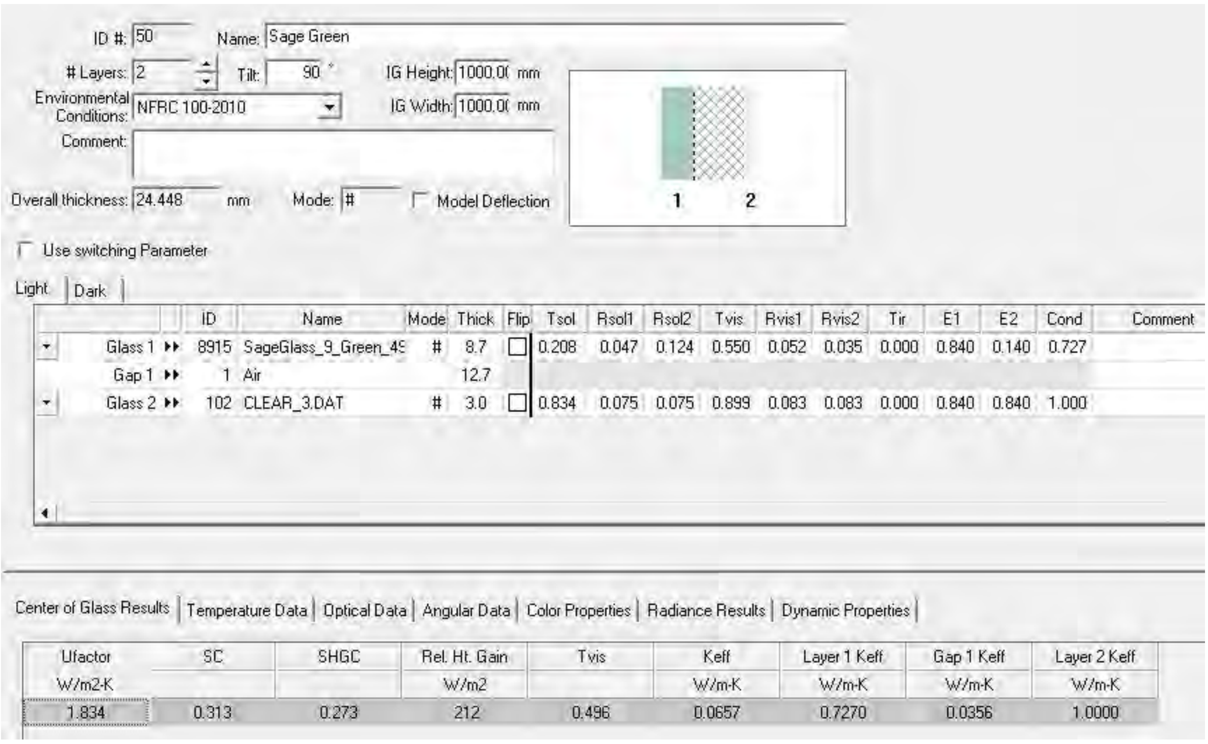


Figure H51. The characteristic of the glazing system of option number 37 windows.

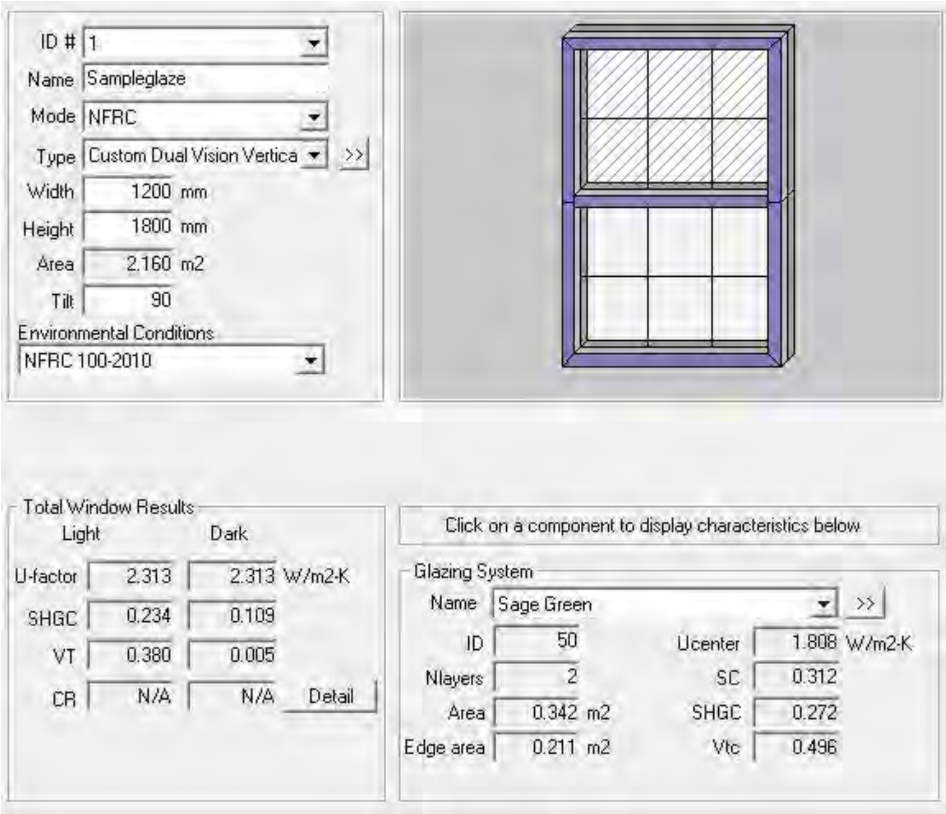


Figure H.52 Characteristic of option number 37 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

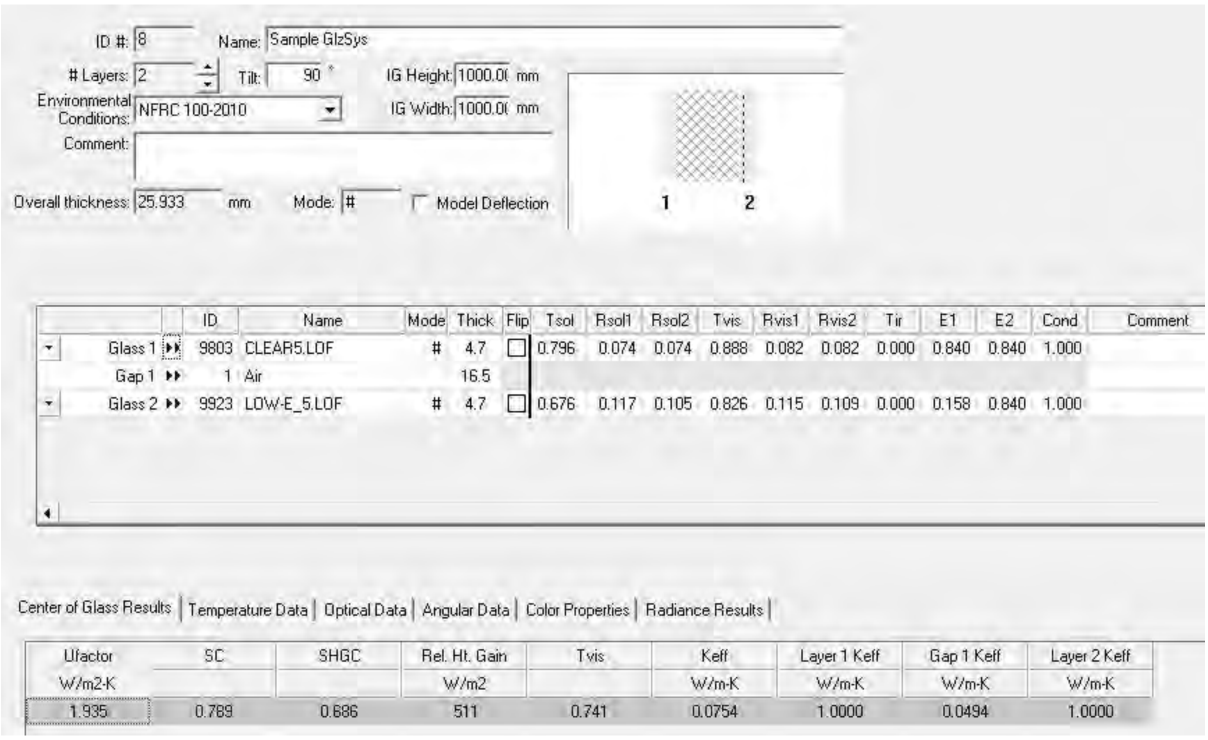


Figure H53. The characteristic of the glazing system of option number 38 windows.

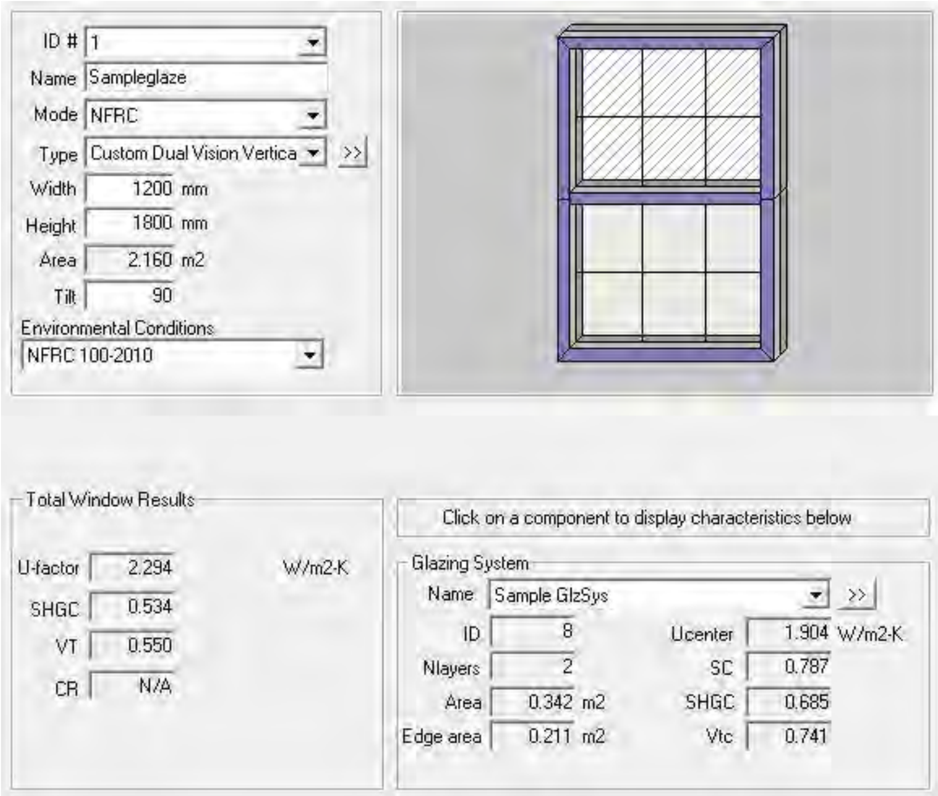


Figure H.54 Characteristic of option number 38 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

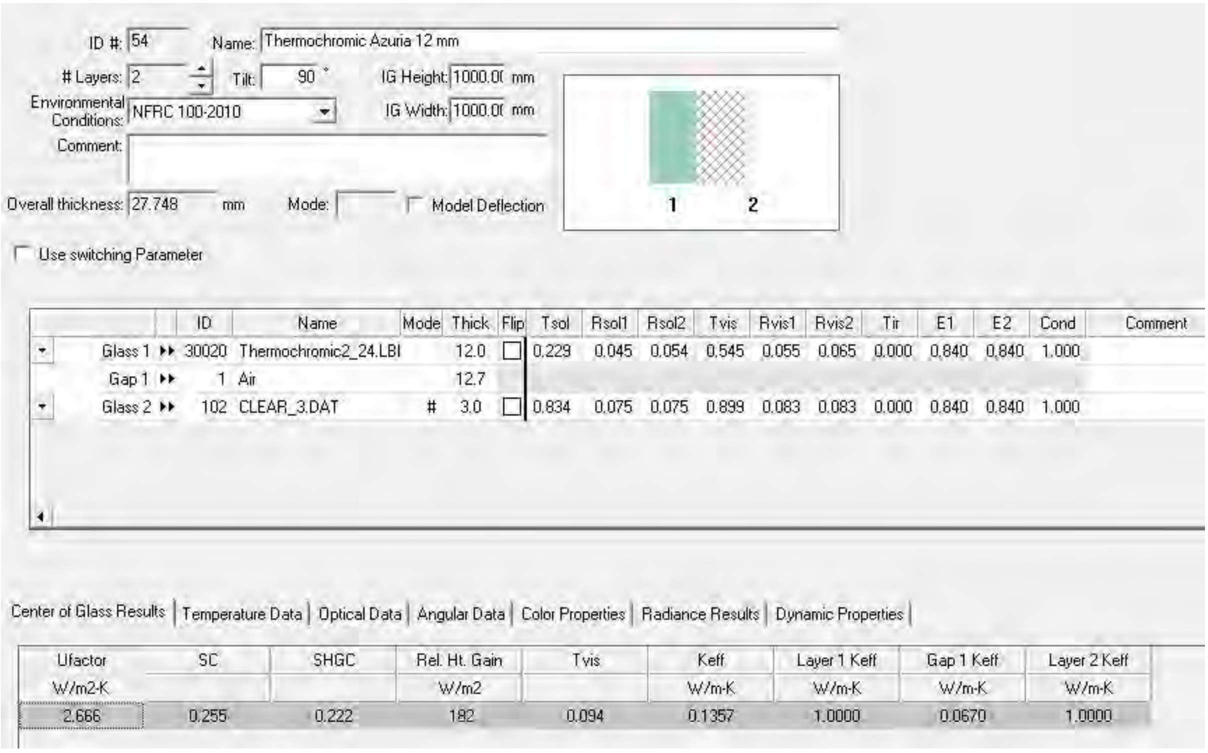


Figure H55. The characteristic of the glazing system of option number 39 windows.

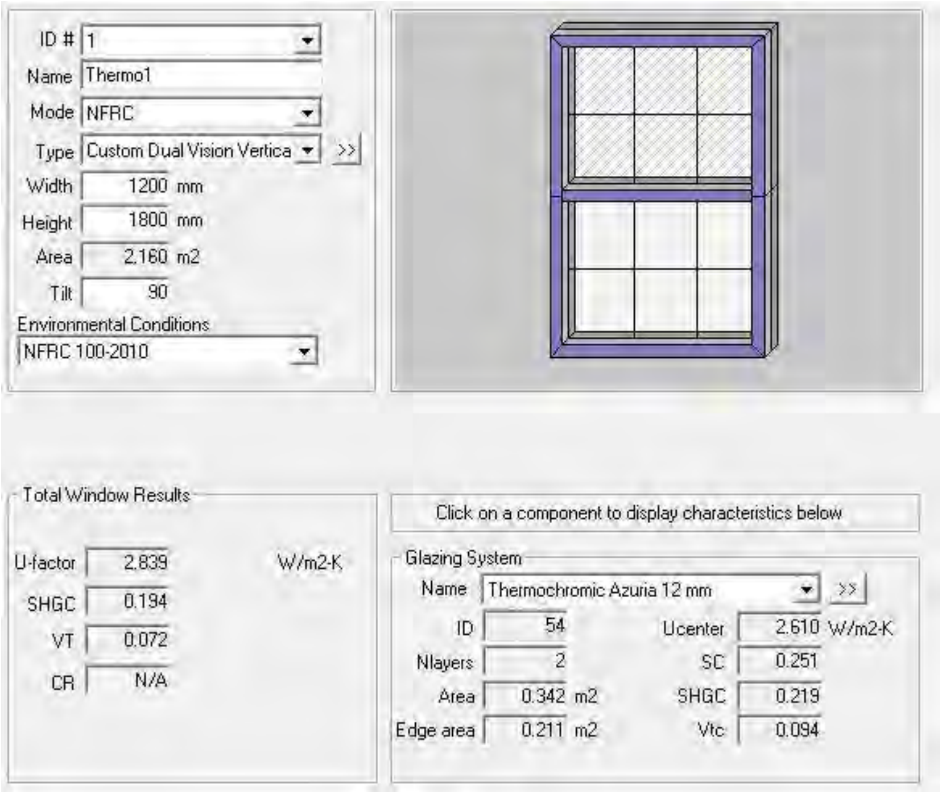


Figure H.56 Characteristic of option number 39 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

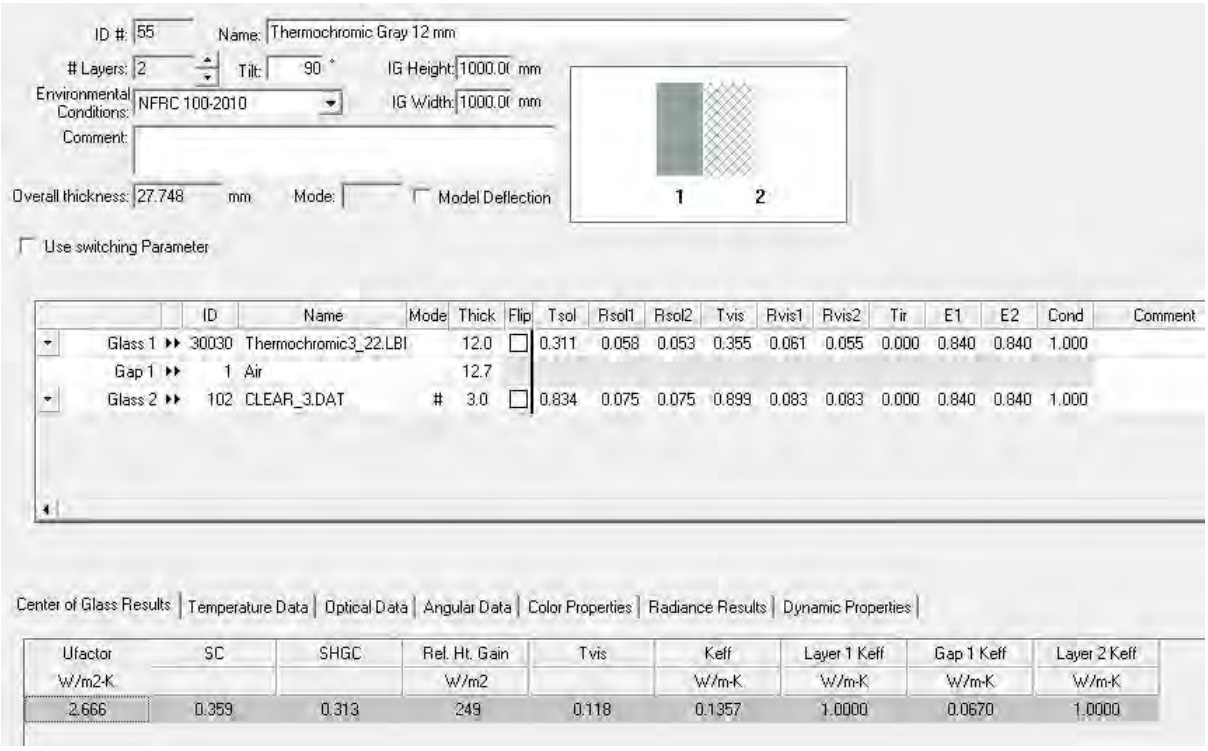


Figure H57. The characteristic of the glazing system of option number 40 windows.

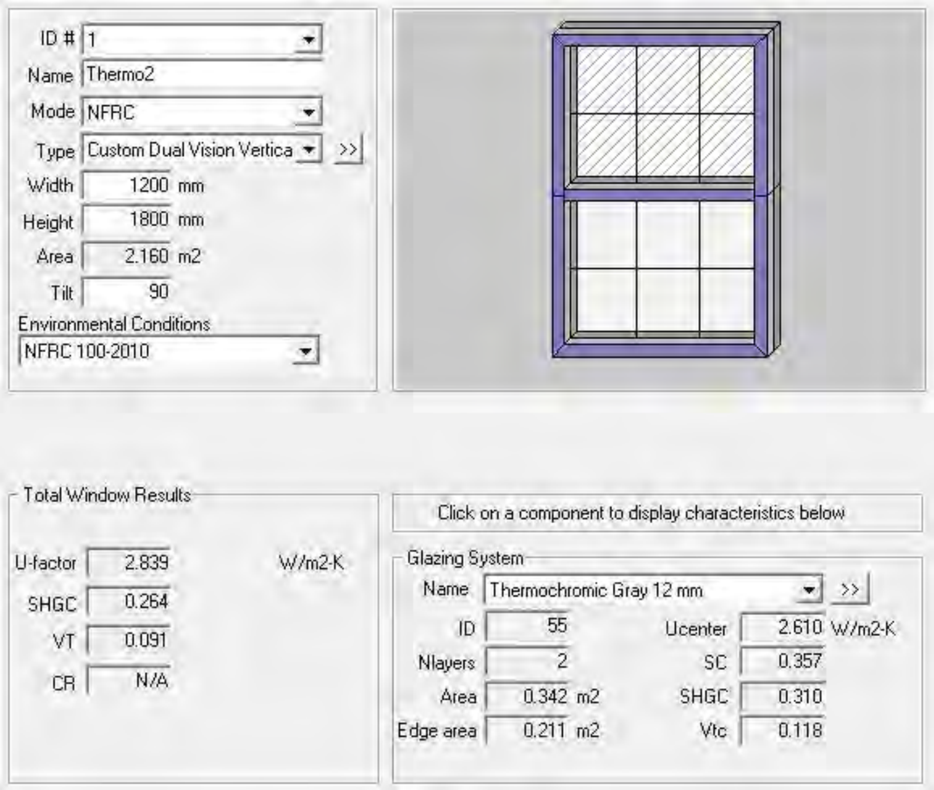


Figure H.58 Characteristic of option number 40 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

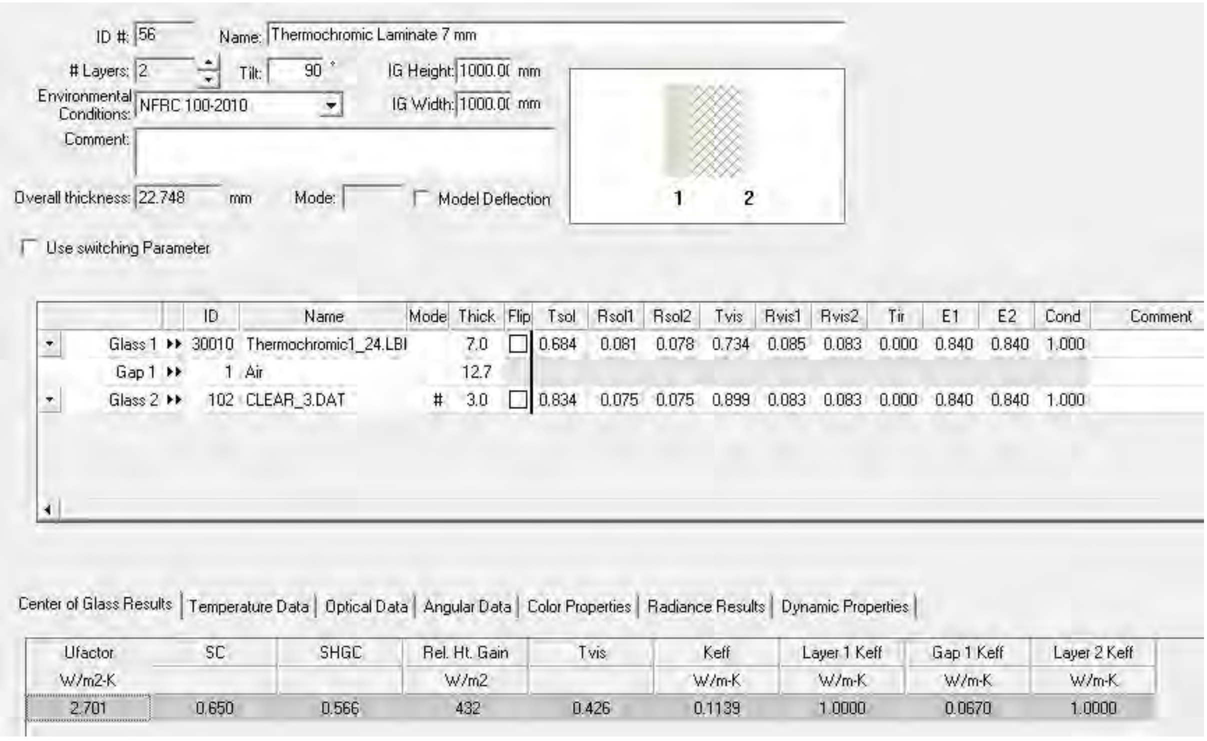


Figure H59. The characteristic of the glazing system of option number 41 windows.

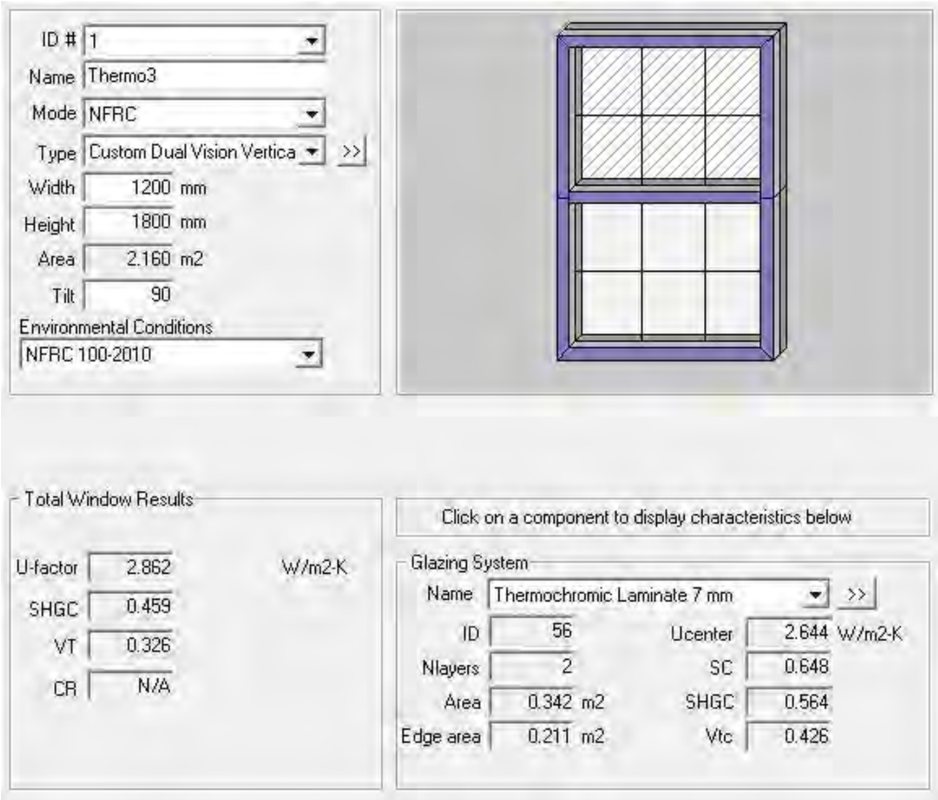
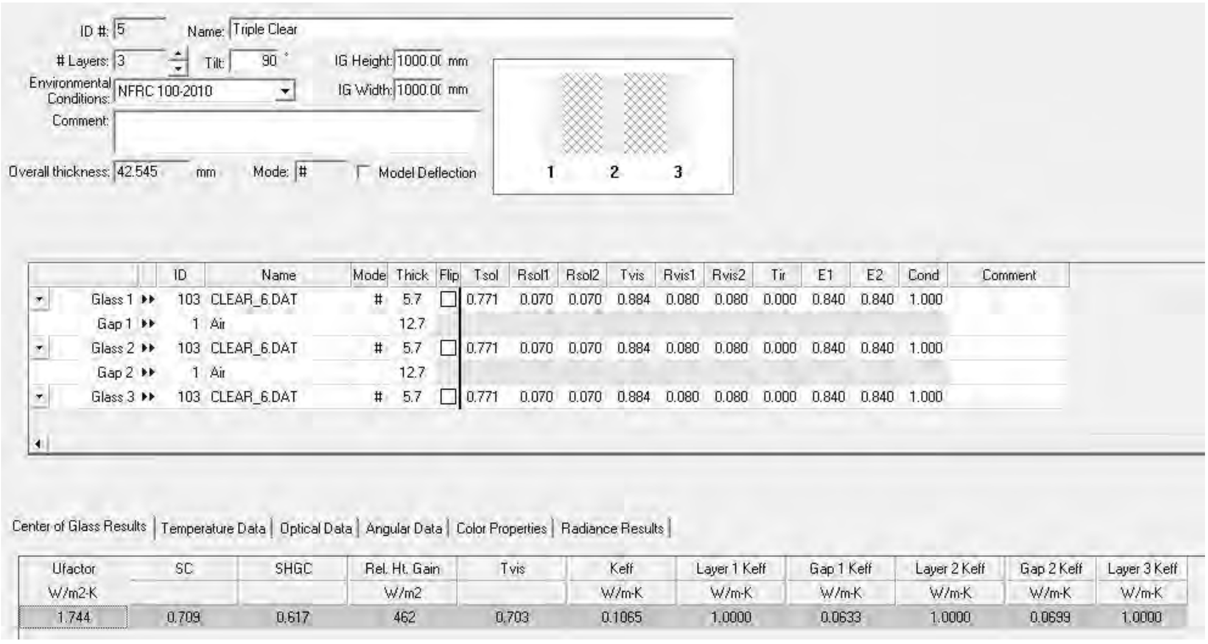


Figure H.60 Characteristic of option number 41 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	103	CLEAR_6.DAT	#	5.7		0.771	0.070	0.070	0.884	0.080	0.080	0.000	0.840	0.840	1.000	
Gap 1	1	Air		12.7												
Glass 2	103	CLEAR_6.DAT	#	5.7		0.771	0.070	0.070	0.884	0.080	0.080	0.000	0.840	0.840	1.000	
Gap 2	1	Air		12.7												
Glass 3	103	CLEAR_6.DAT	#	5.7		0.771	0.070	0.070	0.884	0.080	0.080	0.000	0.840	0.840	1.000	

Ufactor W/m2-K	SC	SHGC	Rel. Ht. Gain W/m2	Tvis	Keff W/m-K	Layer 1 Keff W/m-K	Gap 1 Keff W/m-K	Layer 2 Keff W/m-K	Gap 2 Keff W/m-K	Layer 3 Keff W/m-K
1.744	0.709	0.617	462	0.703	0.1065	1.0000	0.0633	1.0000	0.0699	1.0000

Figure H61. The characteristic of the glazing system of option number 42 windows.

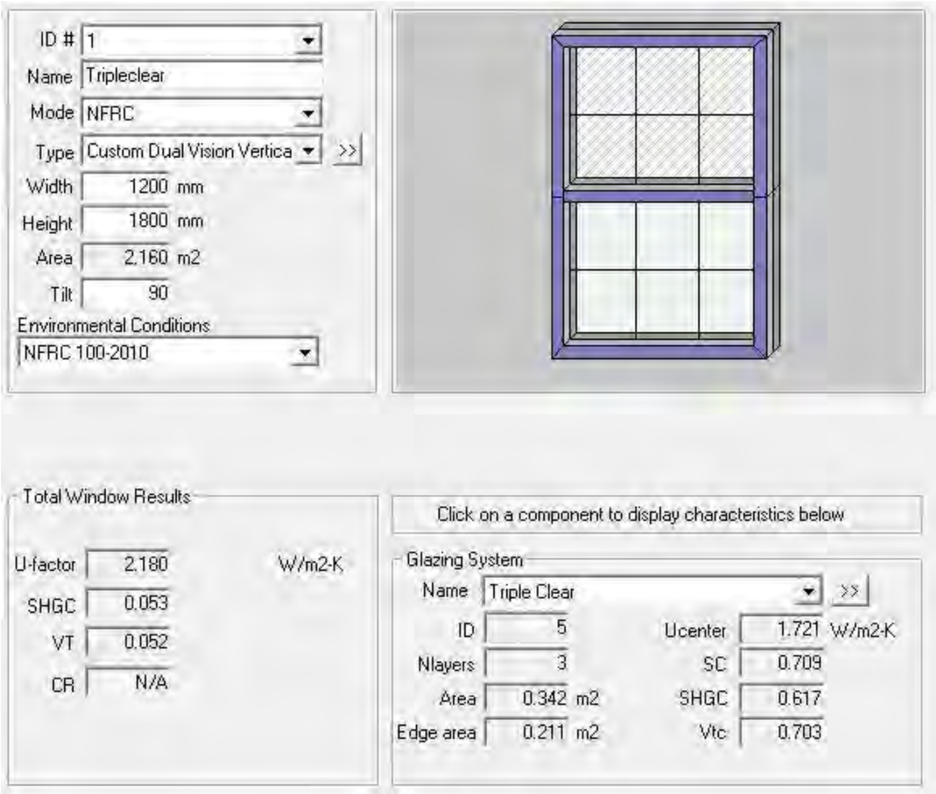
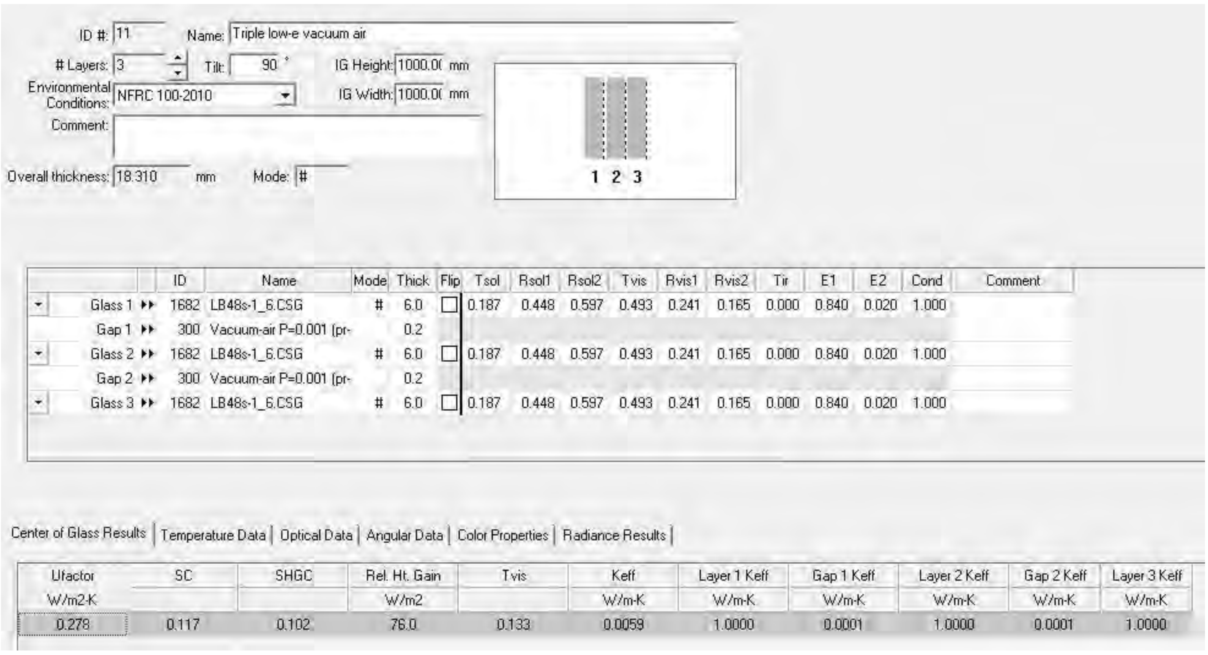


Figure H.62 Characteristic of option number 42 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1682	LB48s-1_6.CSG	#	6.0	☐	0.187	0.448	0.597	0.493	0.241	0.165	0.000	0.840	0.020	1.000	
Gap 1	300	Vacuum-air P=0.001 (pr-		0.2												
Glass 2	1682	LB48s-1_6.CSG	#	6.0	☐	0.187	0.448	0.597	0.493	0.241	0.165	0.000	0.840	0.020	1.000	
Gap 2	300	Vacuum-air P=0.001 (pr-		0.2												
Glass 3	1682	LB48s-1_6.CSG	#	6.0	☐	0.187	0.448	0.597	0.493	0.241	0.165	0.000	0.840	0.020	1.000	

Ufactor W/m2-K	SC	SHGC	Rel. Ht. Gain W/m2	Tvis	Keff W/m-K	Layer 1 Keff W/m-K	Gap 1 Keff W/m-K	Layer 2 Keff W/m-K	Gap 2 Keff W/m-K	Layer 3 Keff W/m-K
0.278	0.117	0.102	76.0	0.133	0.0059	1.0000	0.0001	1.0000	0.0001	1.0000

Figure H63. The characteristic of the glazing system of option number 43 windows.

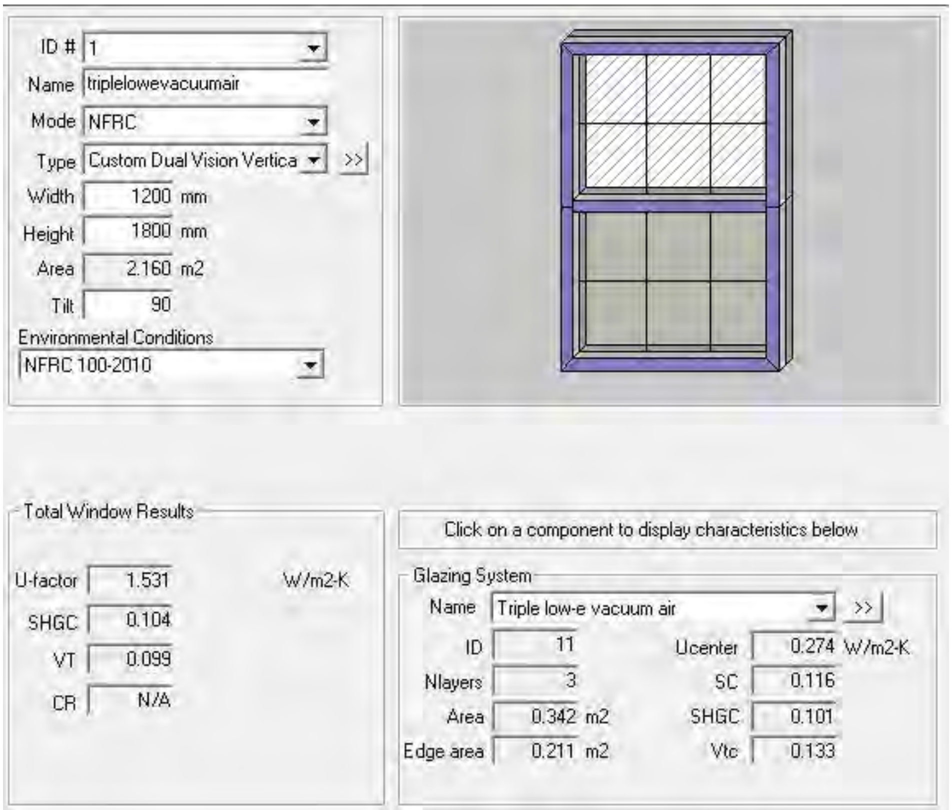
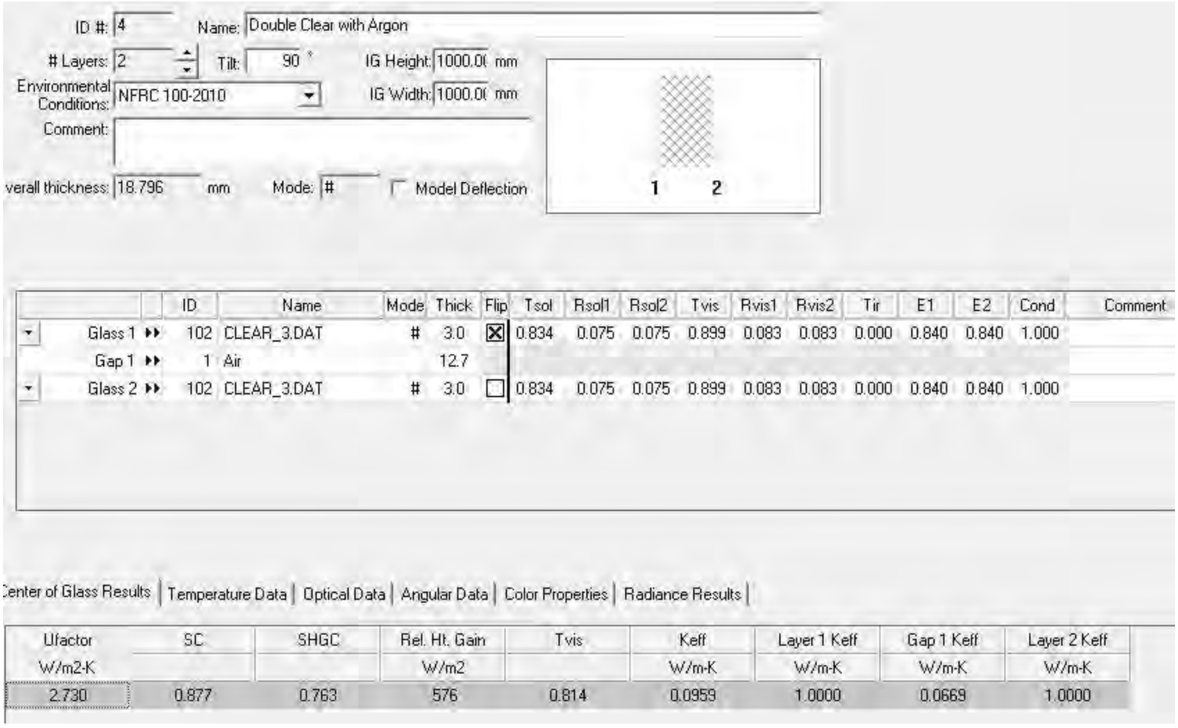


Figure H.64 Characteristic of option number 43 window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

H.2. Glazing System.

H.2.1. Gaps

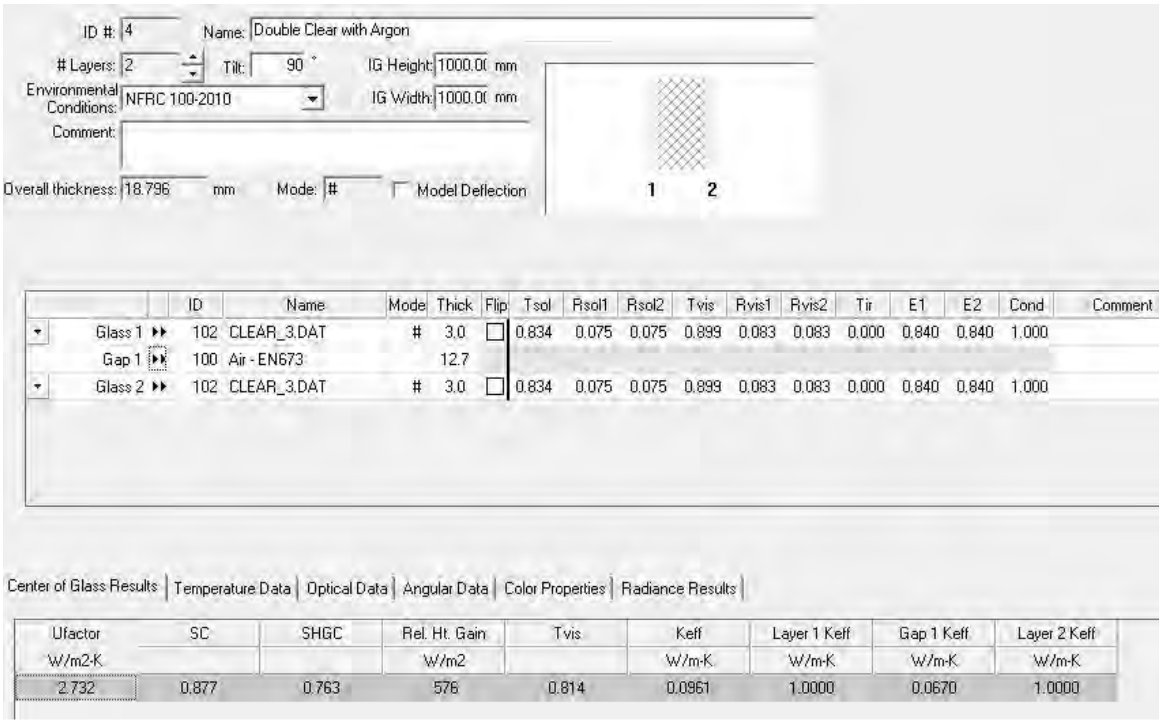
H.2.1.1 Kind of gap



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0	☒	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	1	Air		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.730	0.877	0.763	576	0.814	0.0959	1.0000	0.0669	1.0000

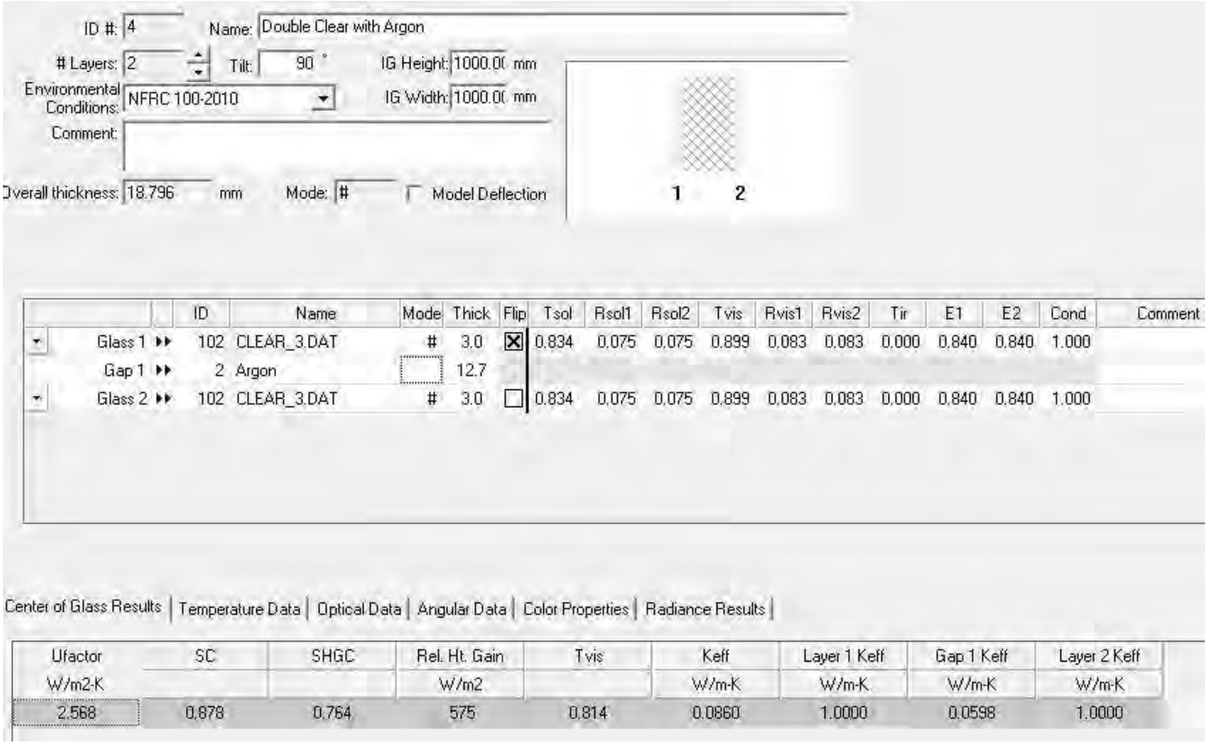
Figure H65. The characteristic of the glazing system of option number 44 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	100	Air - EN673		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.732	0.877	0.763	576	0.814	0.0961	1.0000	0.0670	1.0000

Figure H66. The characteristic of the glazing system of option number 45 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



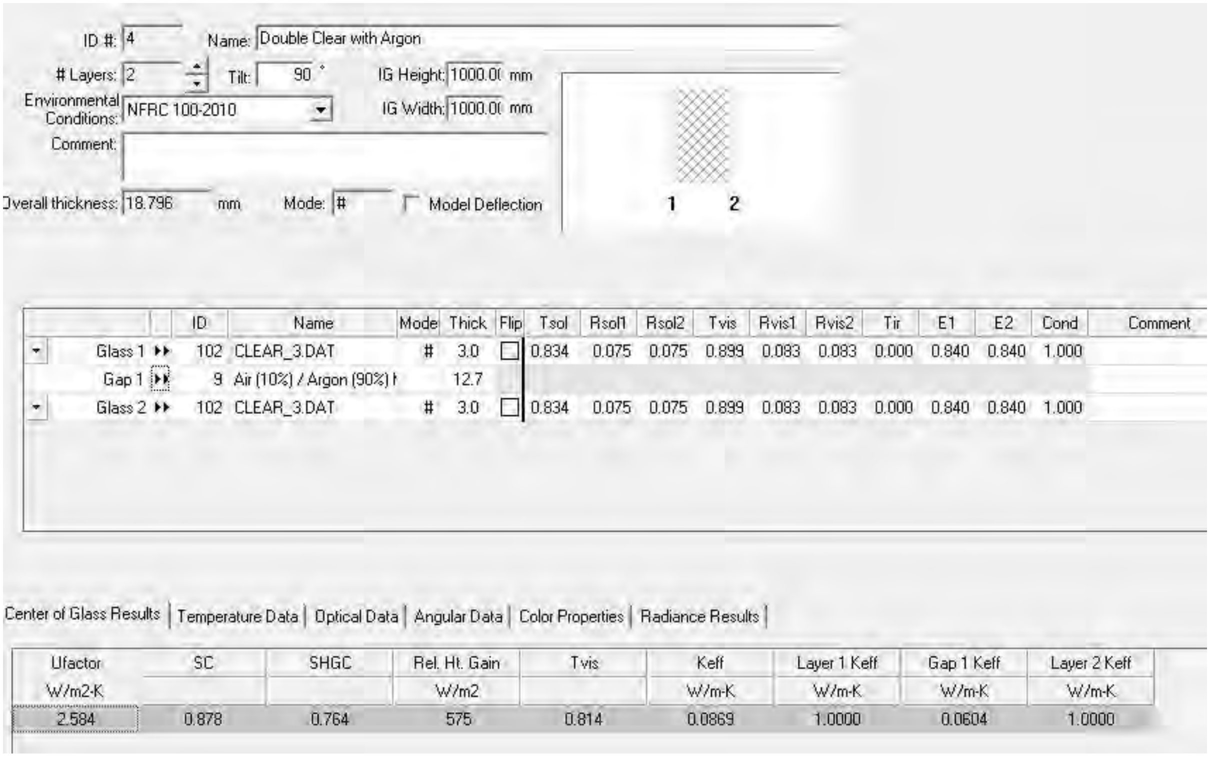
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.796 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0	☒	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	2	Argon		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.568	0.878	0.764	575	0.814	0.0860	1.0000	0.0598	1.0000

Figure H67. The characteristic of the glazing system of option number 46 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



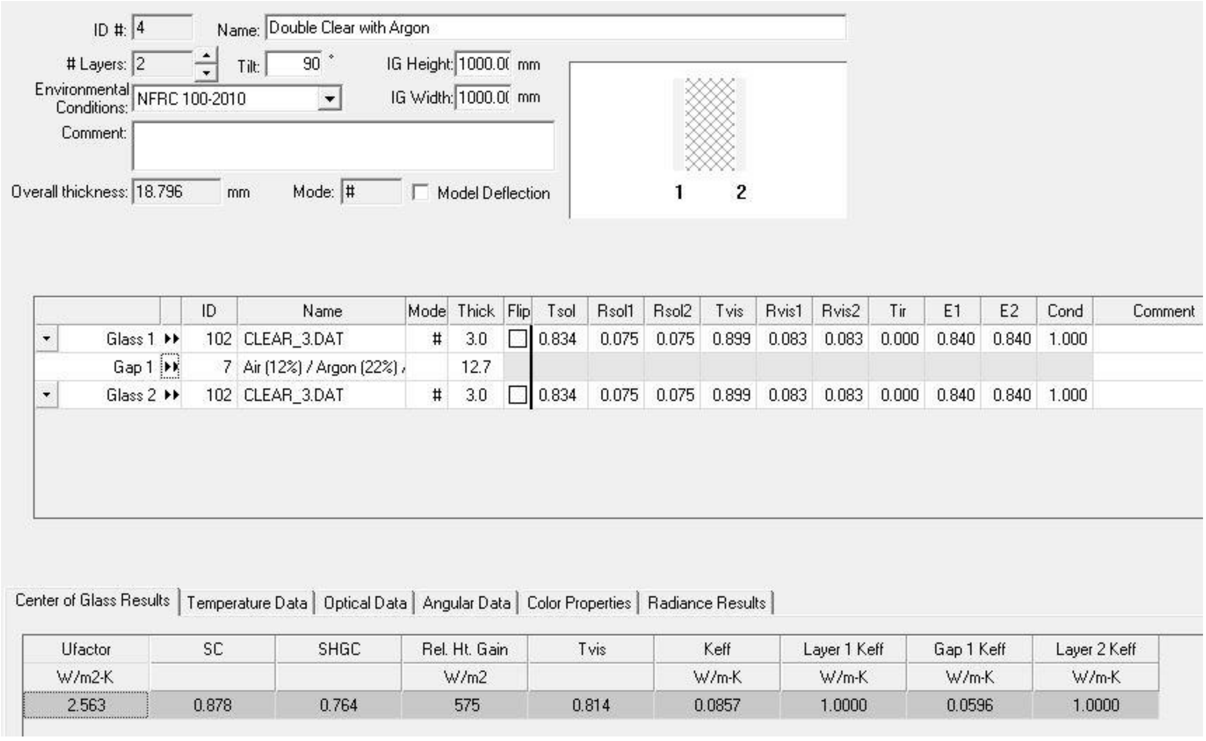
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.796 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	9	Air (10%) / Argon (90%) I		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.584	0.878	0.764	575	0.814	0.0869	1.0000	0.0604	1.0000

Figure H68. The characteristic of the glazing system of option number 47 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

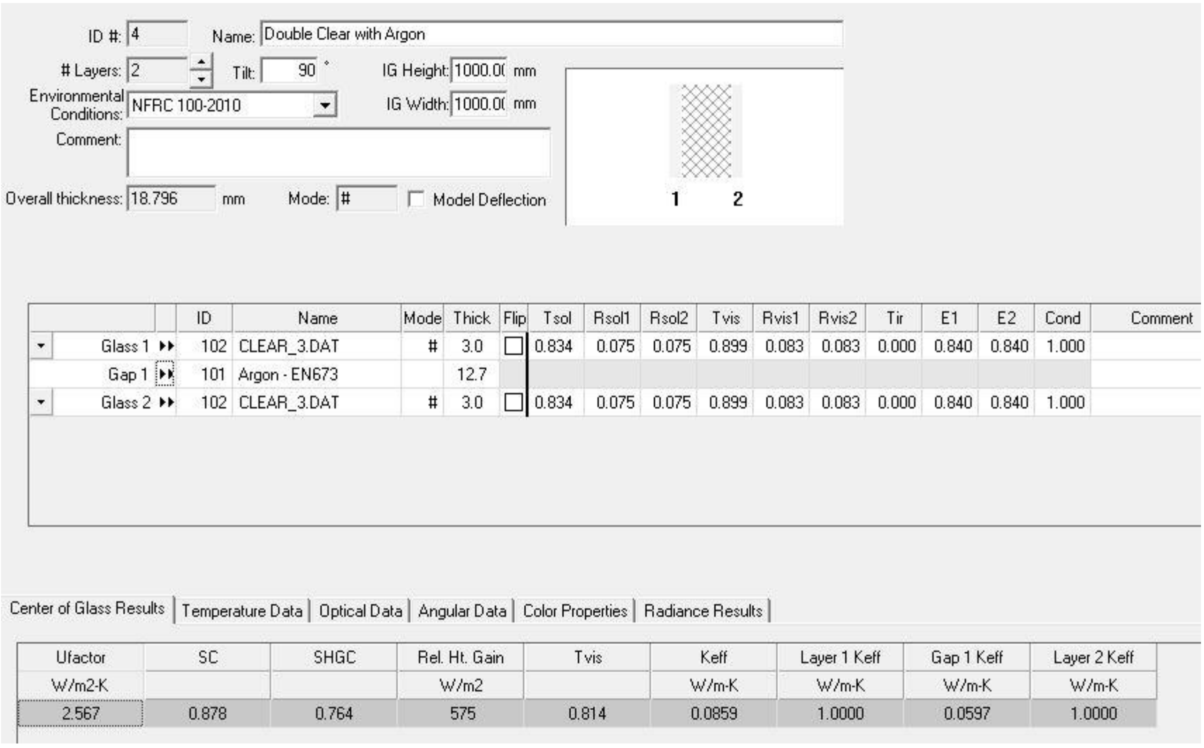
Overall thickness: 18.796 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	7	Air (12%) / Argon (22%) /		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.563	0.878	0.764	575	0.814	0.0857	1.0000	0.0596	1.0000

Figure H69. The characteristic of the glazing system of option number 48 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

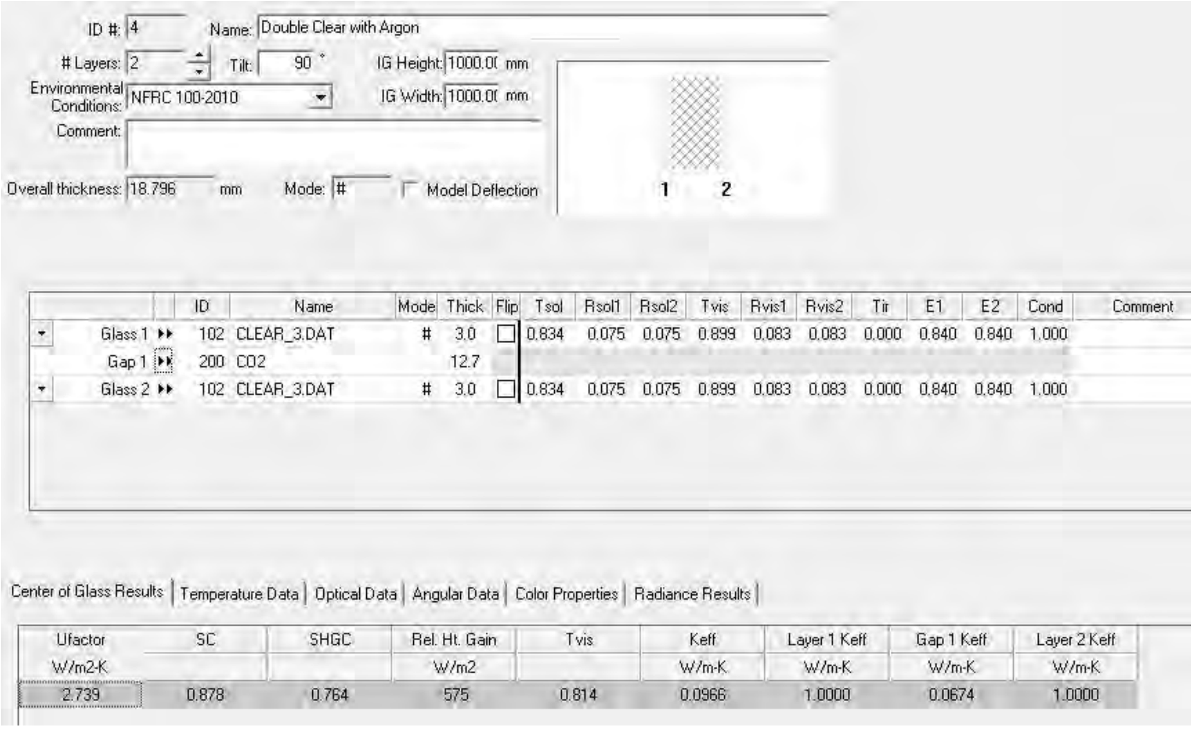
Overall thickness: 18.796 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	101	Argon - EN673		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.567	0.878	0.764	575	0.814	0.0859	1.0000	0.0597	1.0000

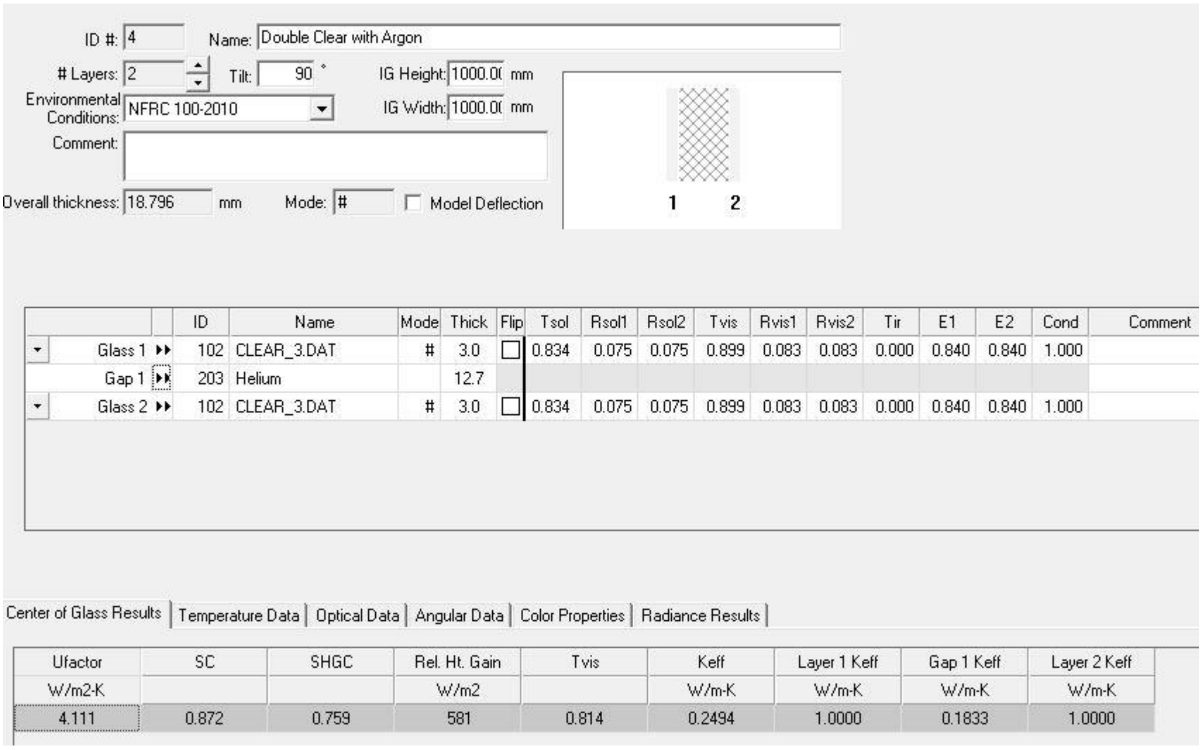
Figure H70. The characteristic of the glazing system of option number 49 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	200	CO2		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.739	0.878	0.764	575	0.814	0.0966	1.0000	0.0674	1.0000

Figure H71. The characteristic of the glazing system of option number 50 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	203	Helium		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
4.111	0.872	0.759	581	0.814	0.2494	1.0000	0.1833	1.0000

Figure H72. The characteristic of the glazing system of option number 51 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

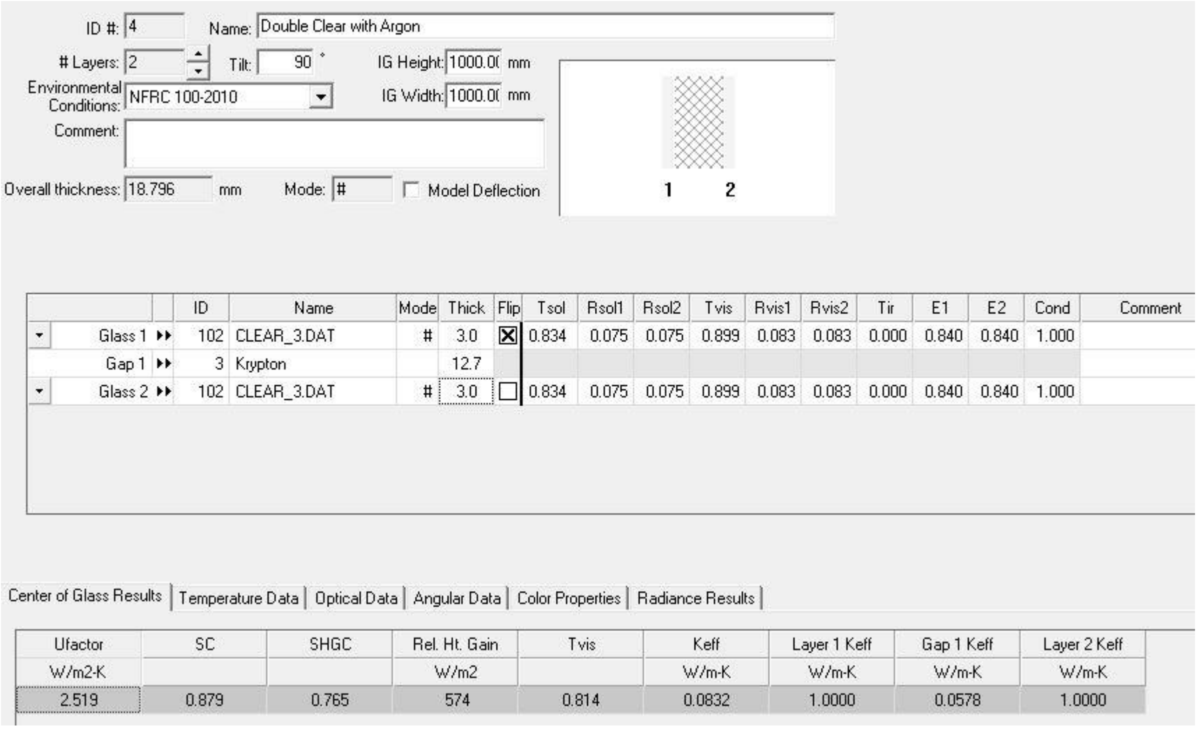


Figure H73. The characteristic of the glazing system of option number 52 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

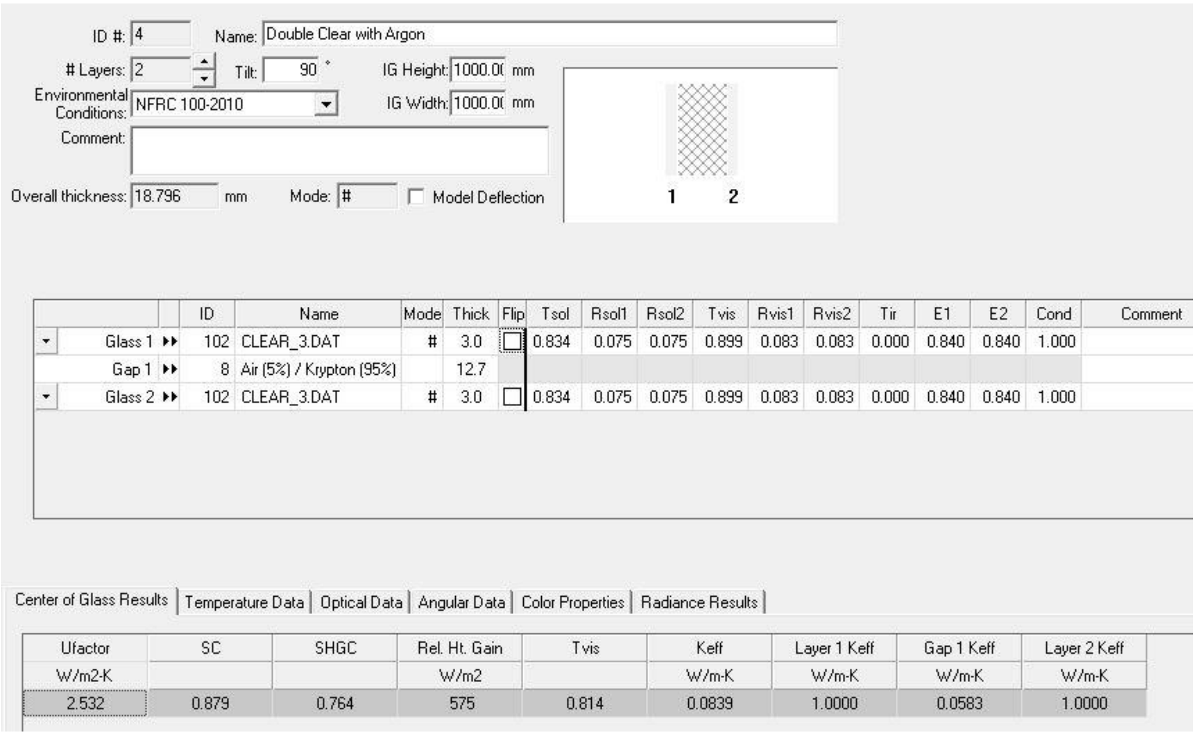
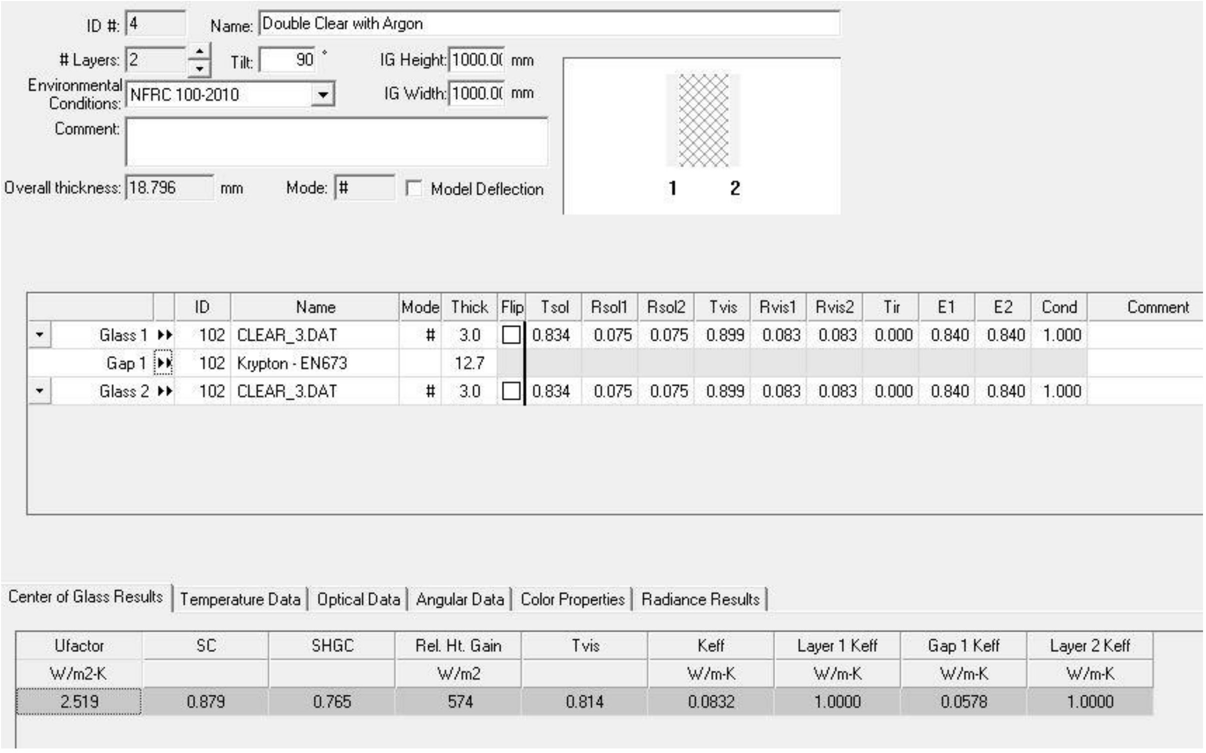


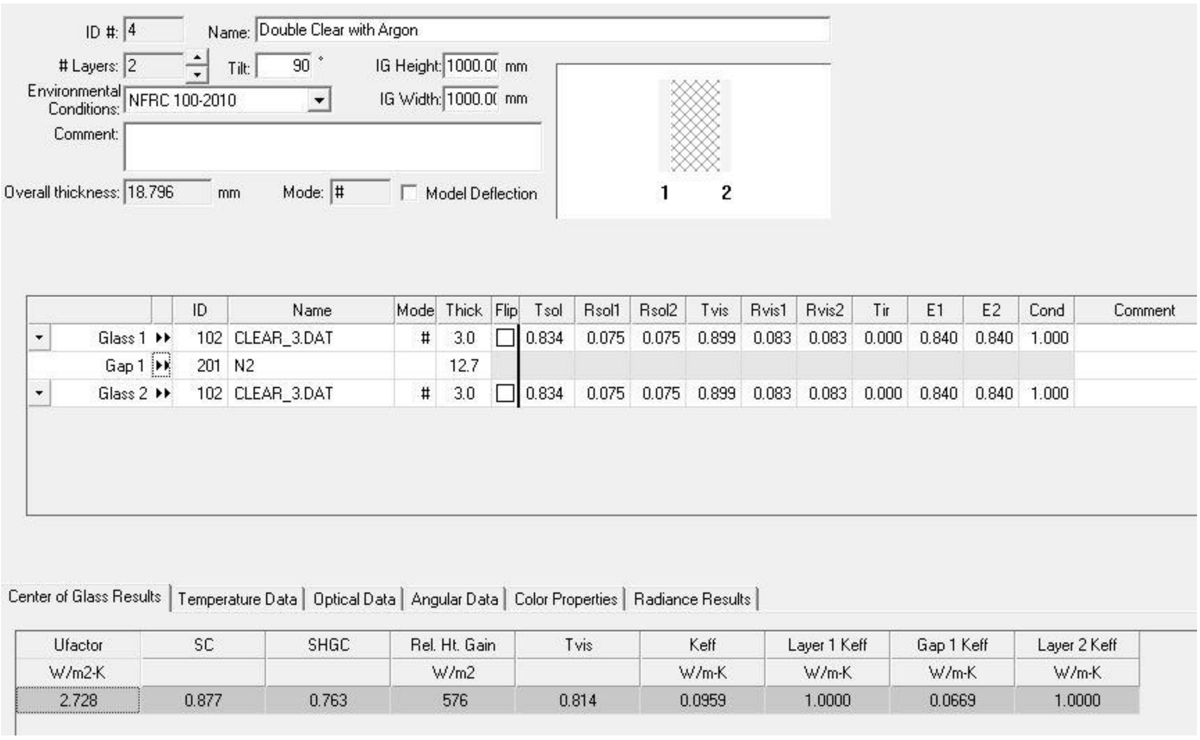
Figure H74. The characteristic of the glazing system of option number 53 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	102	Krypton - EN673		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.519	0.879	0.765	574	0.814	0.0832	1.0000	0.0578	1.0000

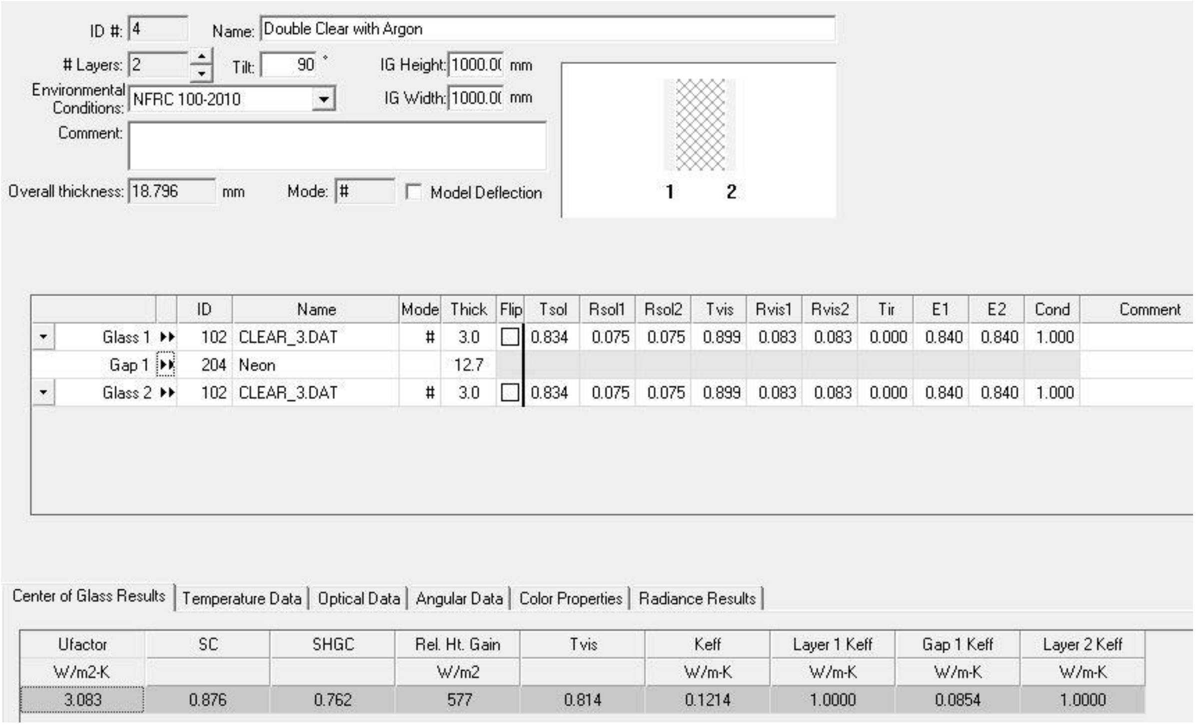
Figure H75. The characteristic of the glazing system of option number 54 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	201	N2		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.728	0.877	0.763	576	0.814	0.0959	1.0000	0.0669	1.0000

Figure H76. The characteristic of the glazing system of option number 55 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

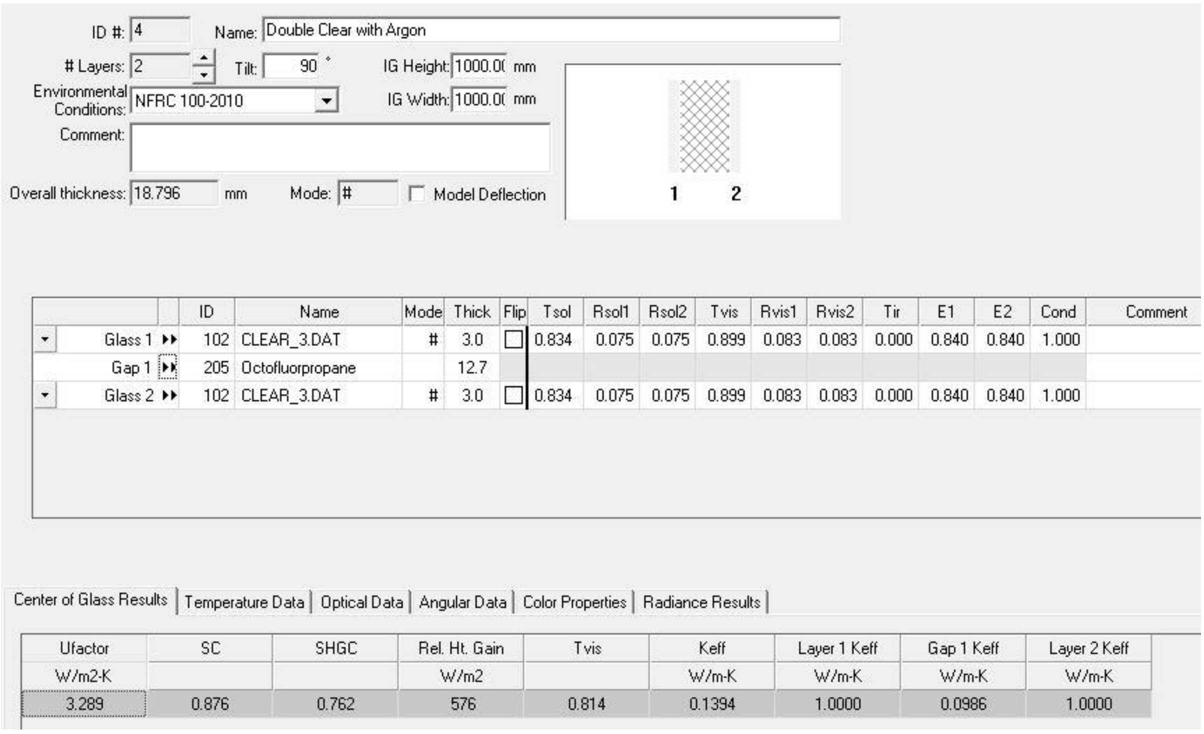

ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.796 mm Mode: # Model Deflection
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	204	Neon		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
3.083	0.876	0.762	577	0.814	0.1214	1.0000	0.0854	1.0000

Figure H77. The characteristic of the glazing system of option number 56 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

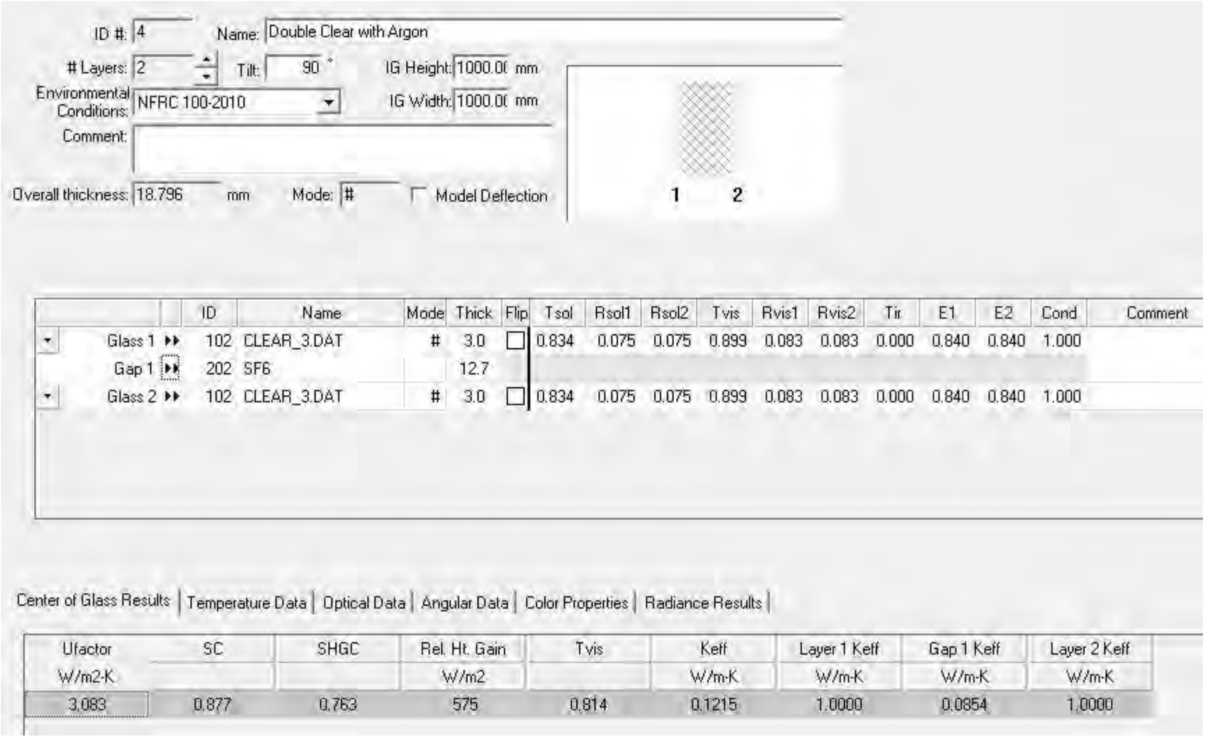

ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.796 mm Mode: # Model Deflection
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	205	Octofluorpropane		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
3.289	0.876	0.762	576	0.814	0.1394	1.0000	0.0986	1.0000

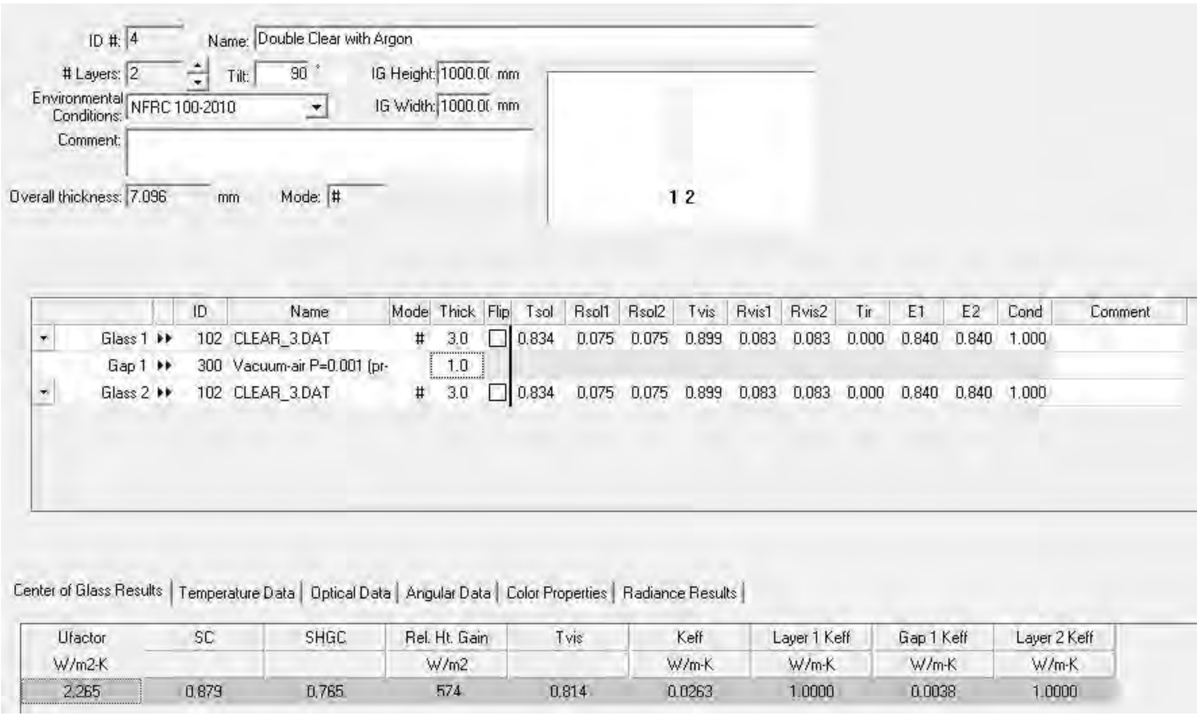
Figure H78. The characteristic of the glazing system of option number 57 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	202	SF6		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
3.083	0.877	0.763	575	0.814	0.1215	1.0000	0.0854	1.0000

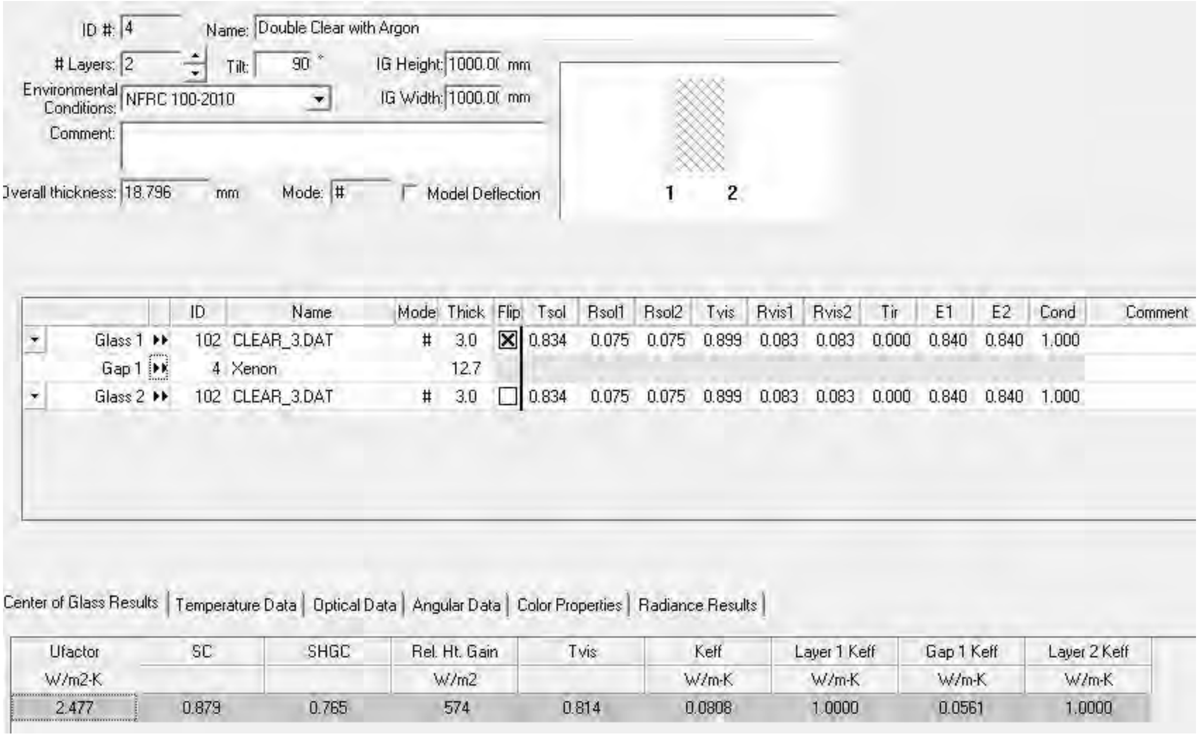
Figure H79. The characteristic of the glazing system of option number 58 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	300	Vacuum-air P=0.001 (pr-		1.0												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.265	0.879	0.765	574	0.814	0.0263	1.0000	0.0038	1.0000

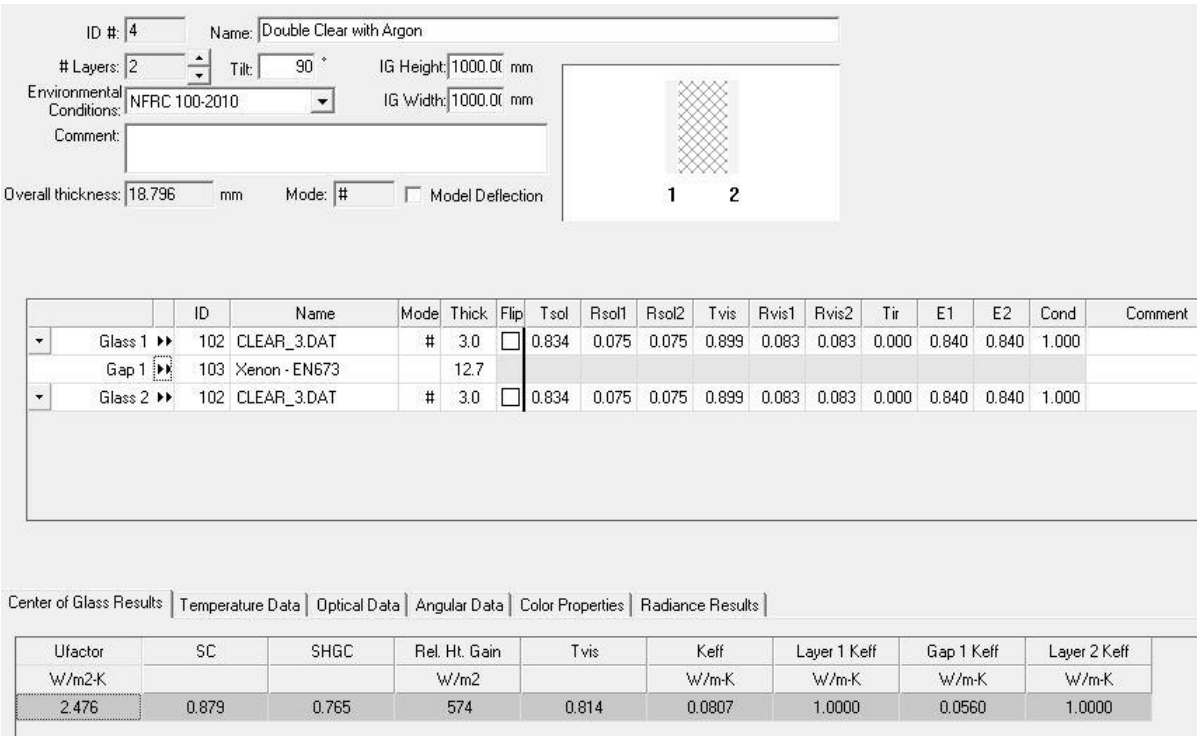
Figure H80. The characteristic of the glazing system of option number 59 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0	☒	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	4	Xenon		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.477	0.879	0.765	574	0.814	0.0808	1.0000	0.0561	1.0000

Figure H81. The characteristic of the glazing system of option number 60 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	103	Xenon - EN673		12.7												
Glass 2	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.476	0.879	0.765	574	0.814	0.0807	1.0000	0.0560	1.0000

Figure H82. The characteristic of the glazing system of option number 61 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

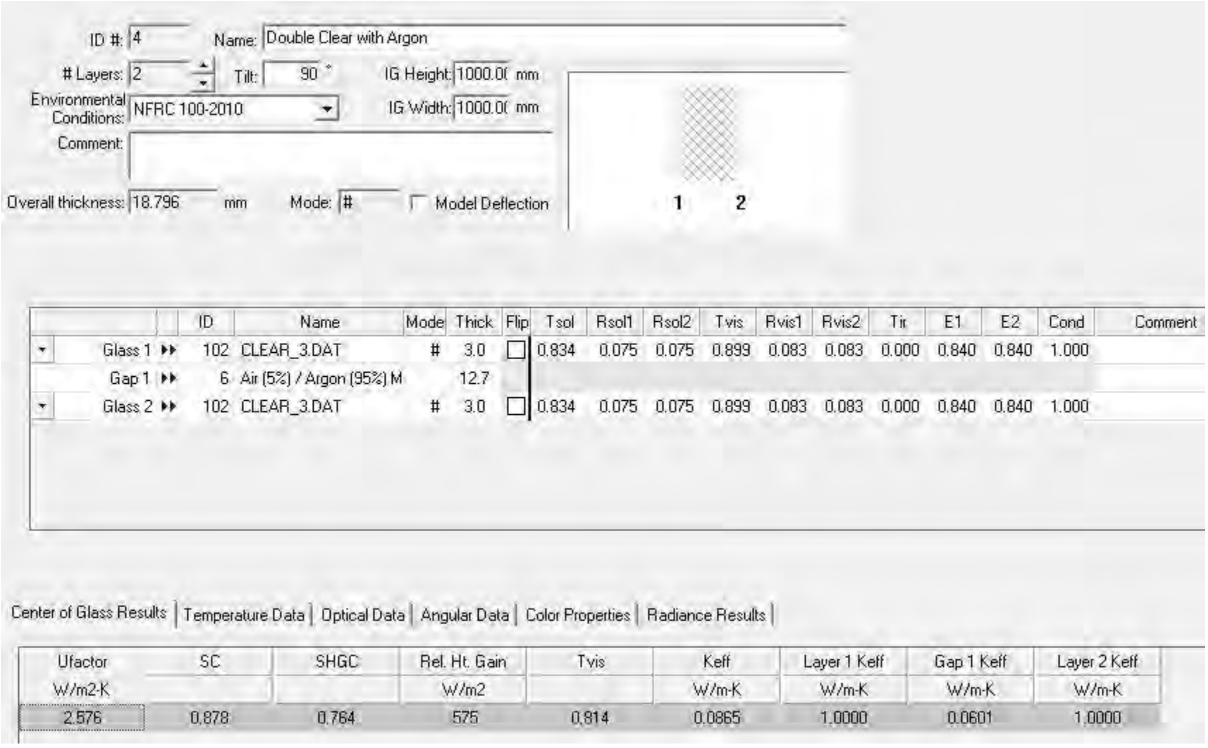


Figure H83. The characteristic of the glazing system of option number 62 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

H.2.1.2 The thickness of the gap

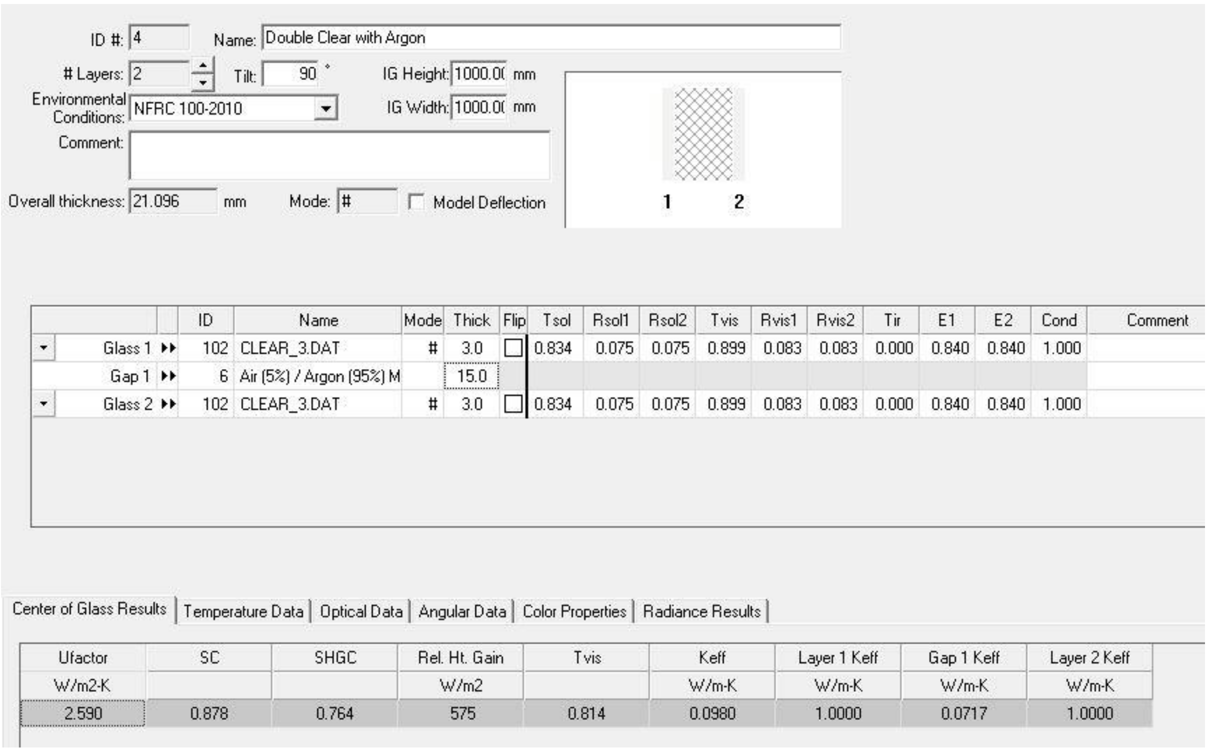
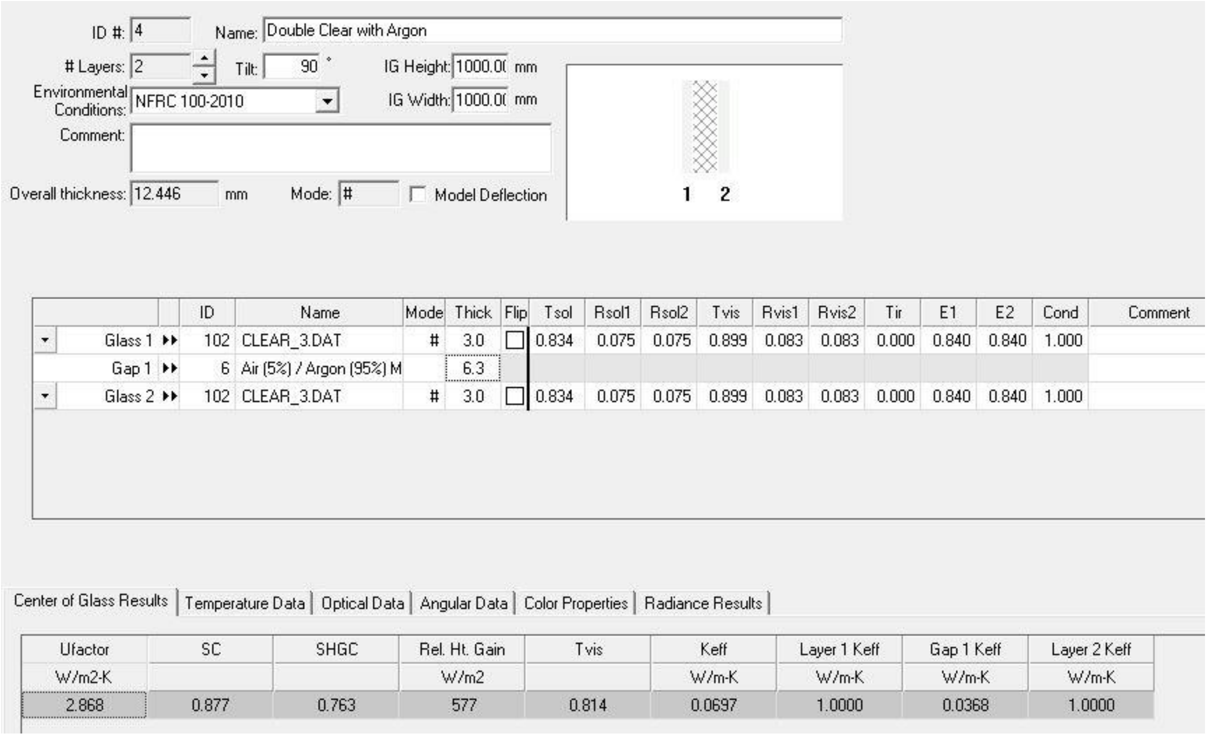


Figure H84. The characteristic of the glazing system of option number 63 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

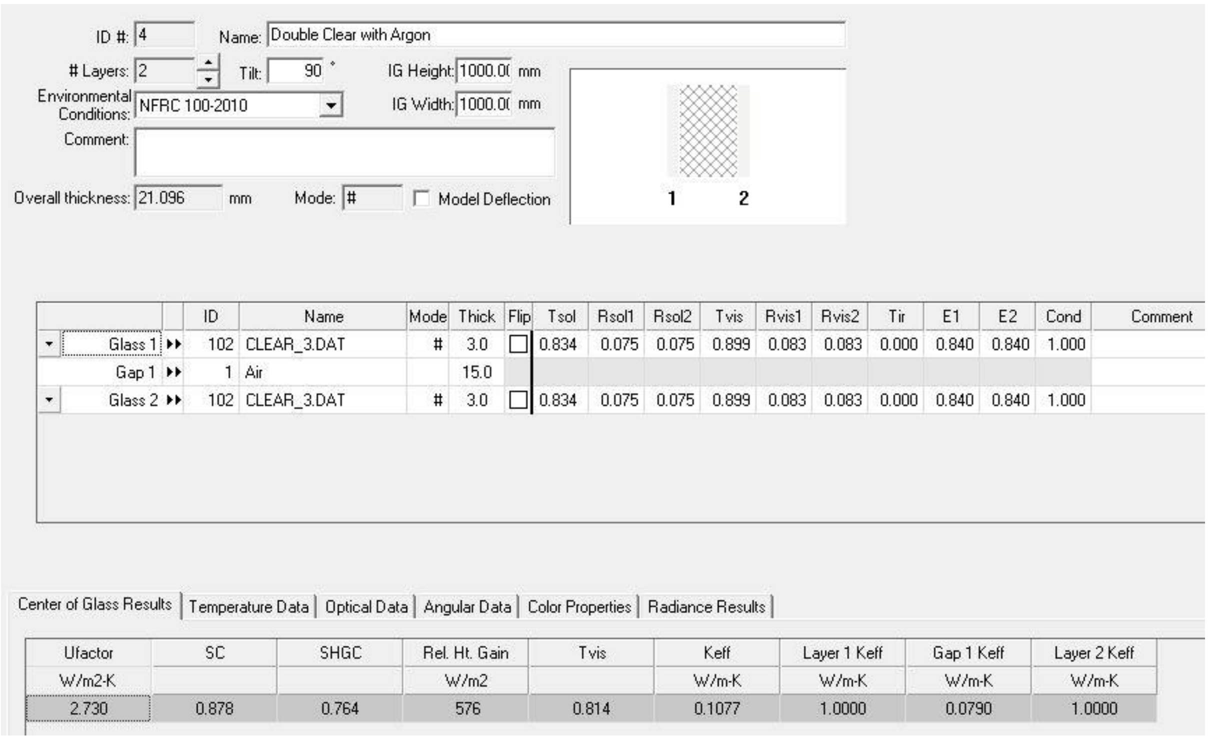

ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 12.446 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		6.3												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.868	0.877	0.763	577	0.814	0.0697	1.0000	0.0368	1.0000

Figure H85. The characteristic of the glazing system of option number 64 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

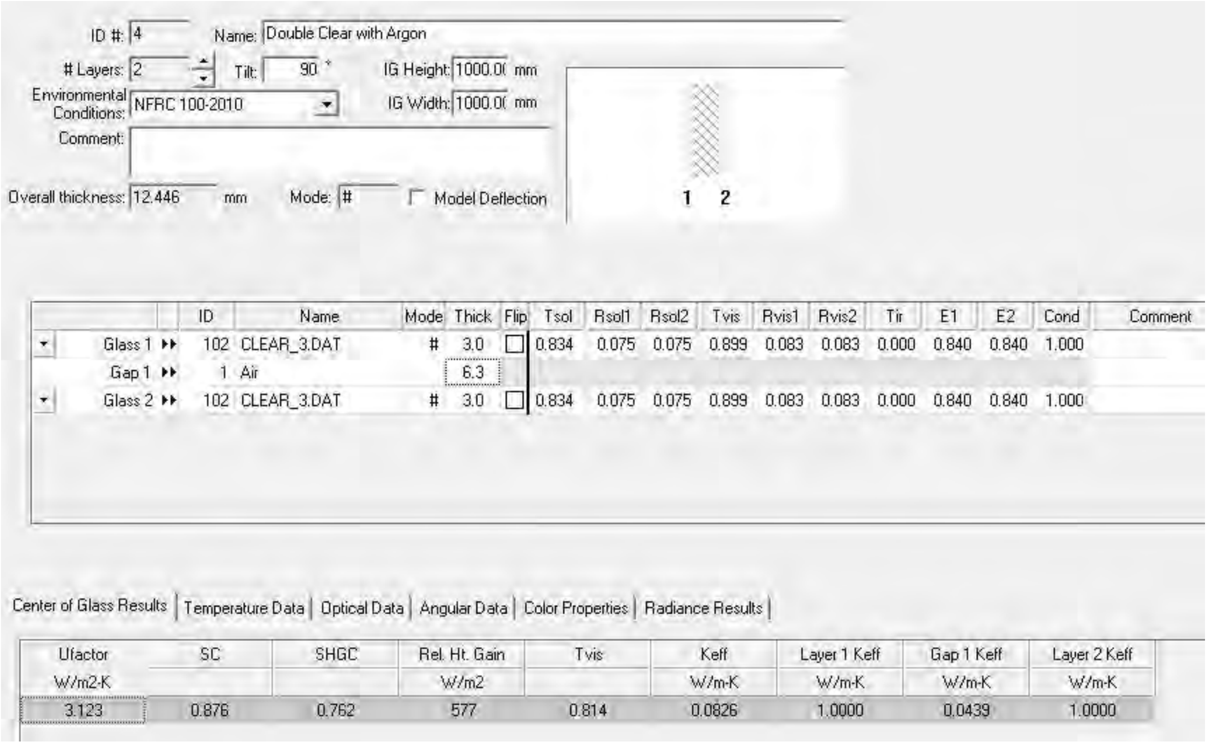

ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 21.096 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	1	Air		15.0												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.730	0.878	0.764	576	0.814	0.1077	1.0000	0.0790	1.0000

Figure H86. The characteristic of the glazing system of option number 65 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 12.446 mm Mode: # Model Deflection

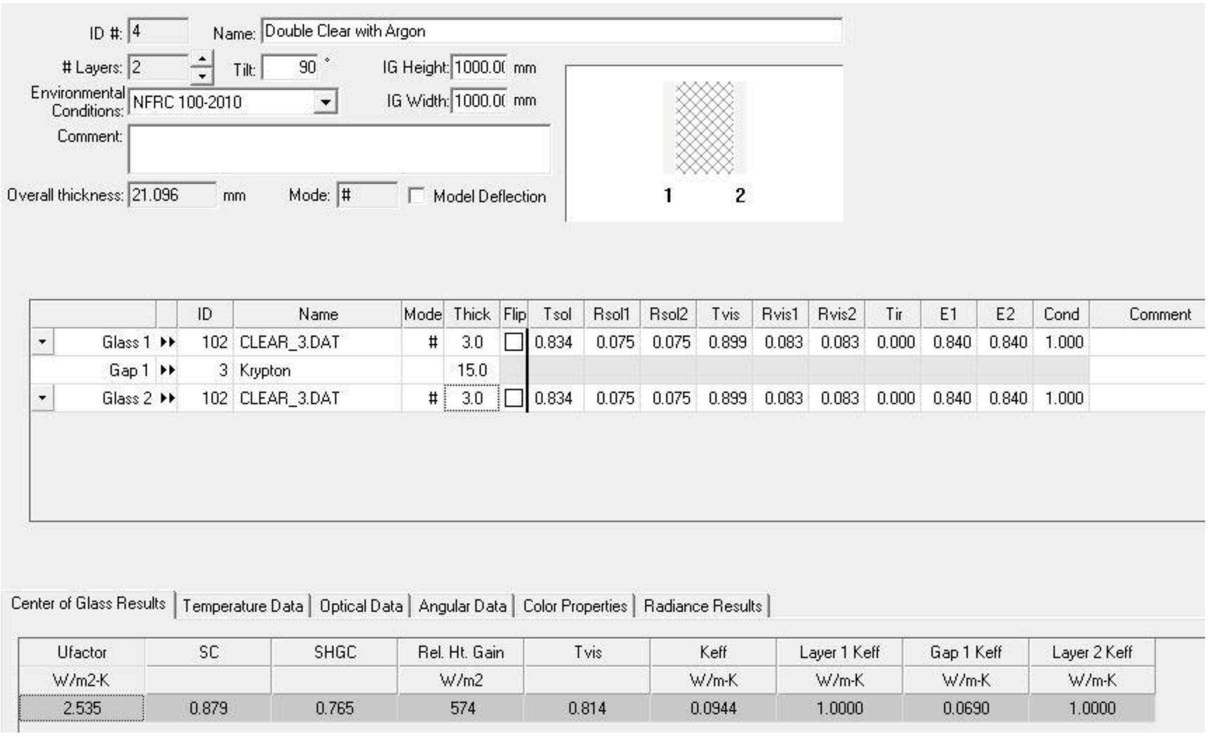
1 2

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	▸▸	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	▸▸	1	Air		6.3												
Glass 2	▸▸	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
3.123	0.876	0.762	577	0.814	0.0826	1.0000	0.0439	1.0000

Figure H87. The characteristic of the glazing system of option number 66 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 21.096 mm Mode: # Model Deflection

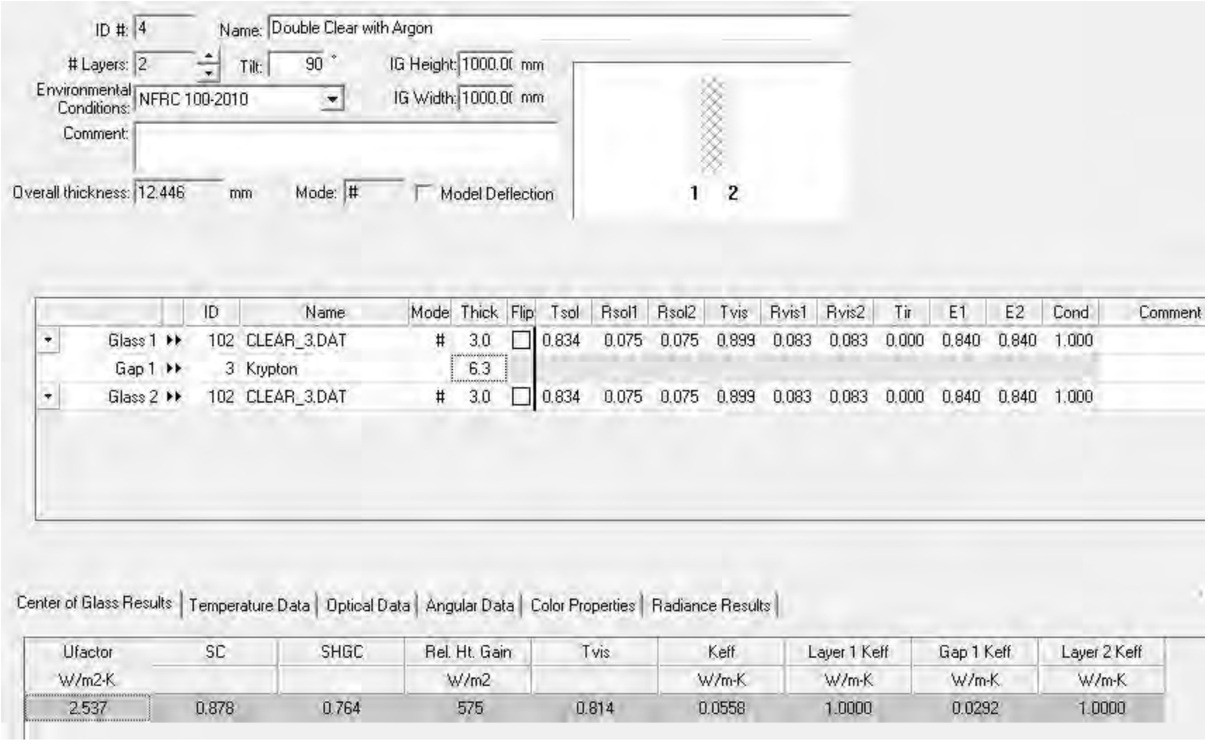
1 2

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	▸▸	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	▸▸	3	Krypton		15.0												
Glass 2	▸▸	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.535	0.879	0.765	574	0.814	0.0944	1.0000	0.0690	1.0000

Figure H88. The characteristic of the glazing system of option number 67 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

Overall thickness: 12.446 mm Mode: # Model Deflection

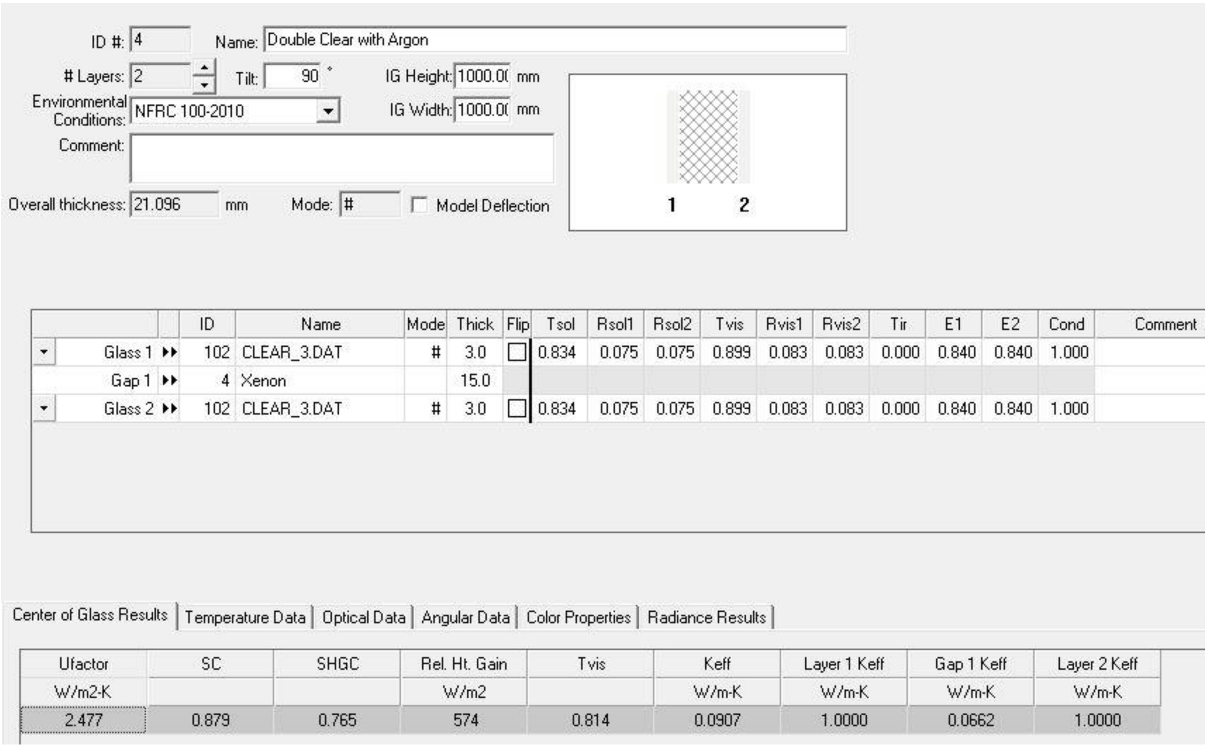
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	3	Krypton		6.3												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.537	0.878	0.764	575	0.814	0.0558	1.0000	0.0292	1.0000

Figure H89. The characteristic of the glazing system of option number 68 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

Overall thickness: 21.096 mm Mode: # Model Deflection

1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	4	Xenon		15.0												
Glass 2	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.477	0.879	0.765	574	0.814	0.0907	1.0000	0.0662	1.0000

Figure H90. The characteristic of the glazing system of option number 69 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

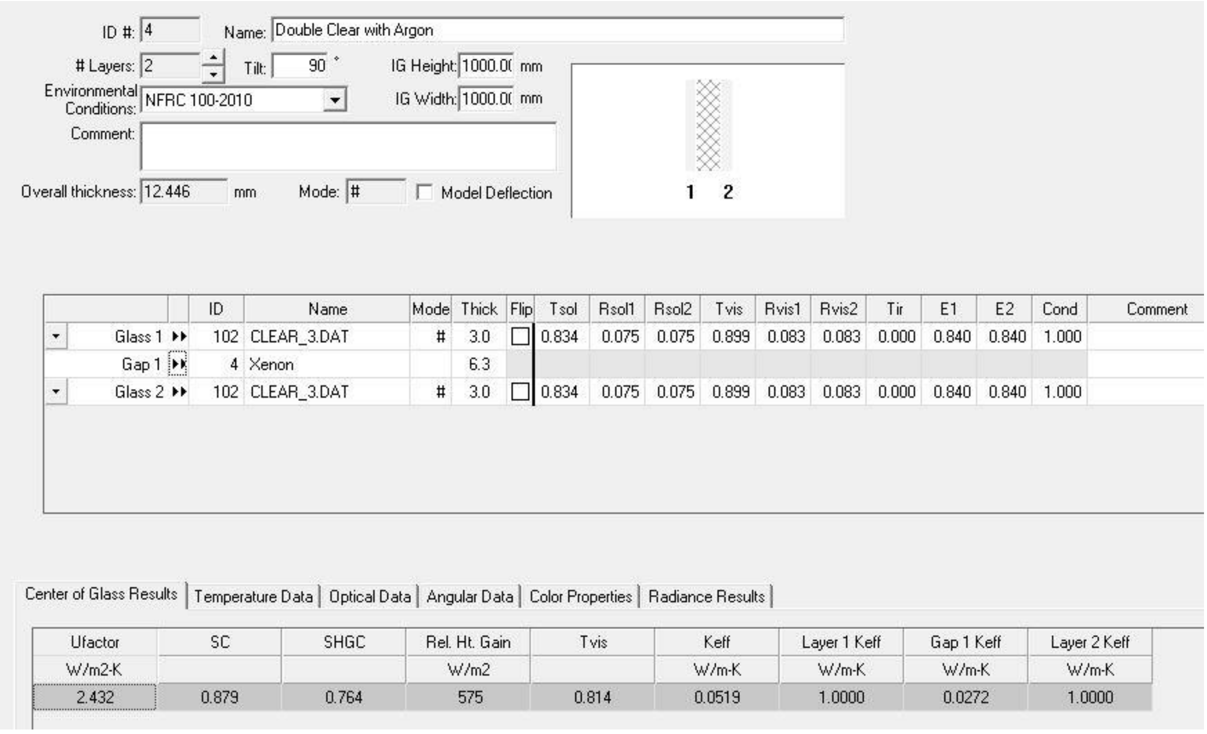


Figure H91. The characteristic of the glazing system of option number 70 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

H.2.2. Glass

H.2.2.1 Kind of glass

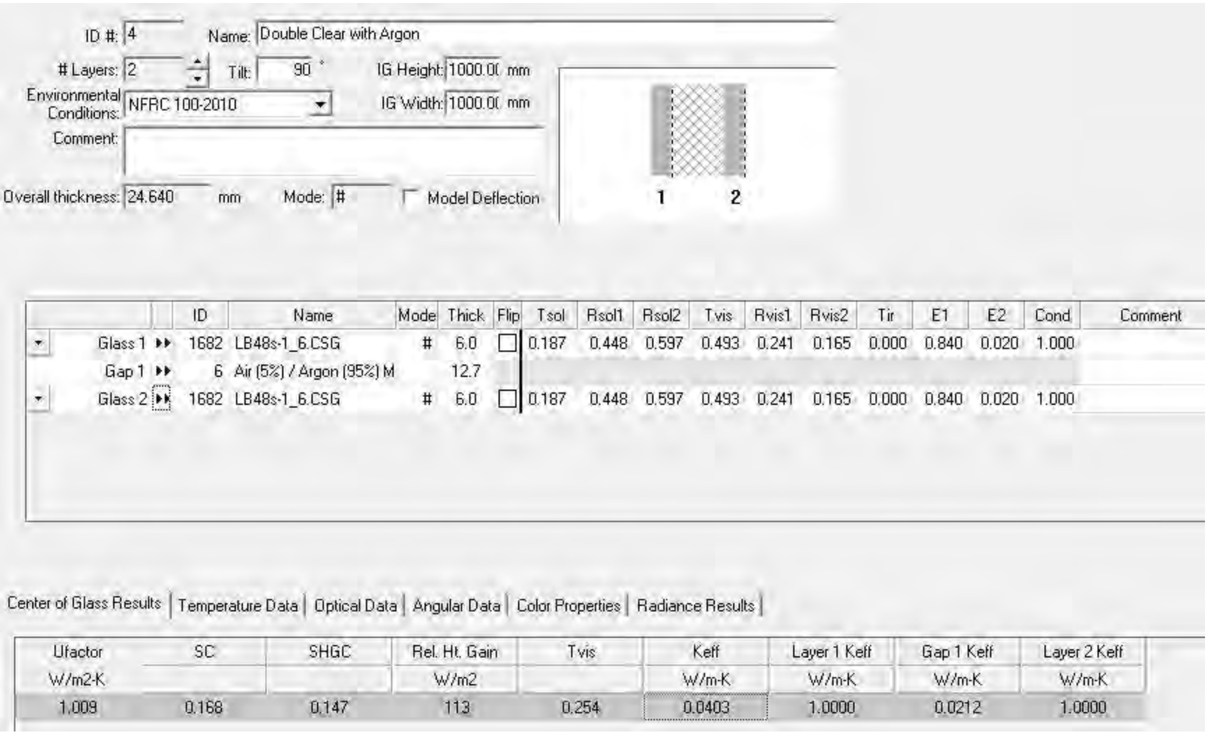
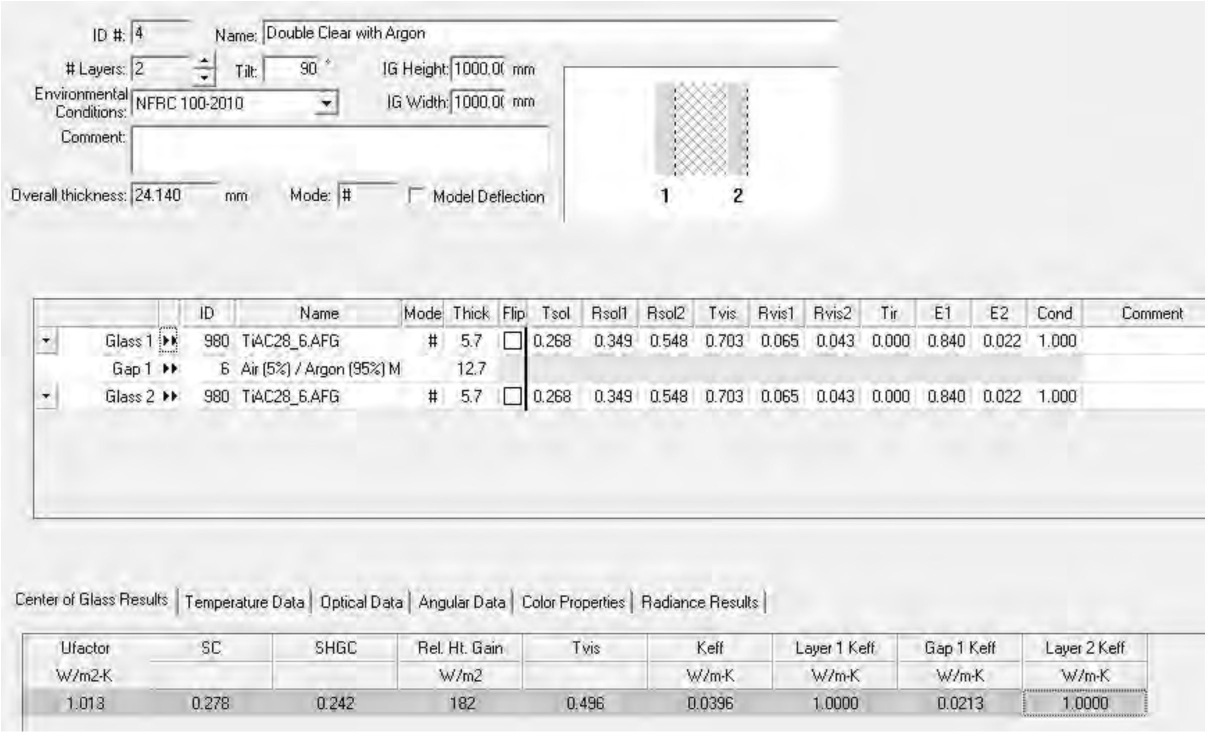


Figure H92. The characteristic of the glazing system of option number 71 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



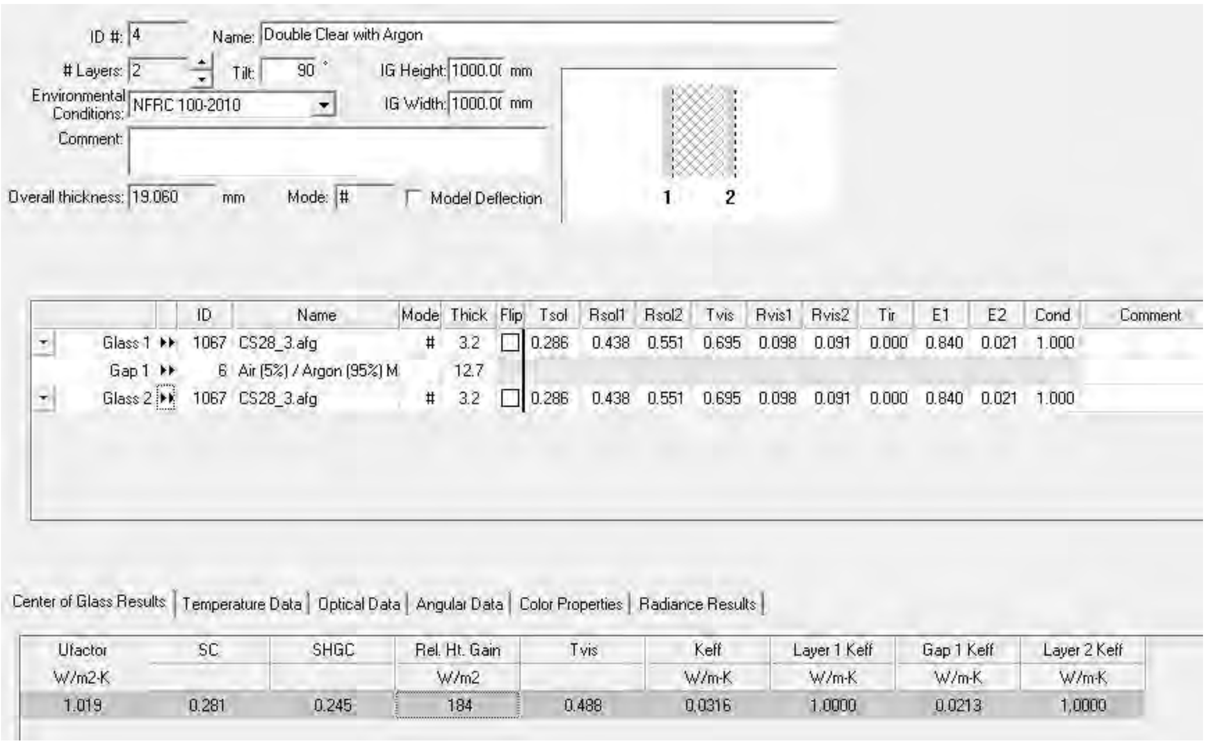
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 24.140 mm Mode: # Model Deflection
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	980	TiAC28_6.AFG	#	5.7		0.268	0.349	0.548	0.703	0.065	0.043	0.000	0.840	0.022	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	980	TiAC28_6.AFG	#	5.7		0.268	0.349	0.548	0.703	0.065	0.043	0.000	0.840	0.022	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.013	0.278	0.242	182	0.496	0.0396	1.0000	0.0213	1.0000

Figure H93. The characteristic of the glazing system of option number 72 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



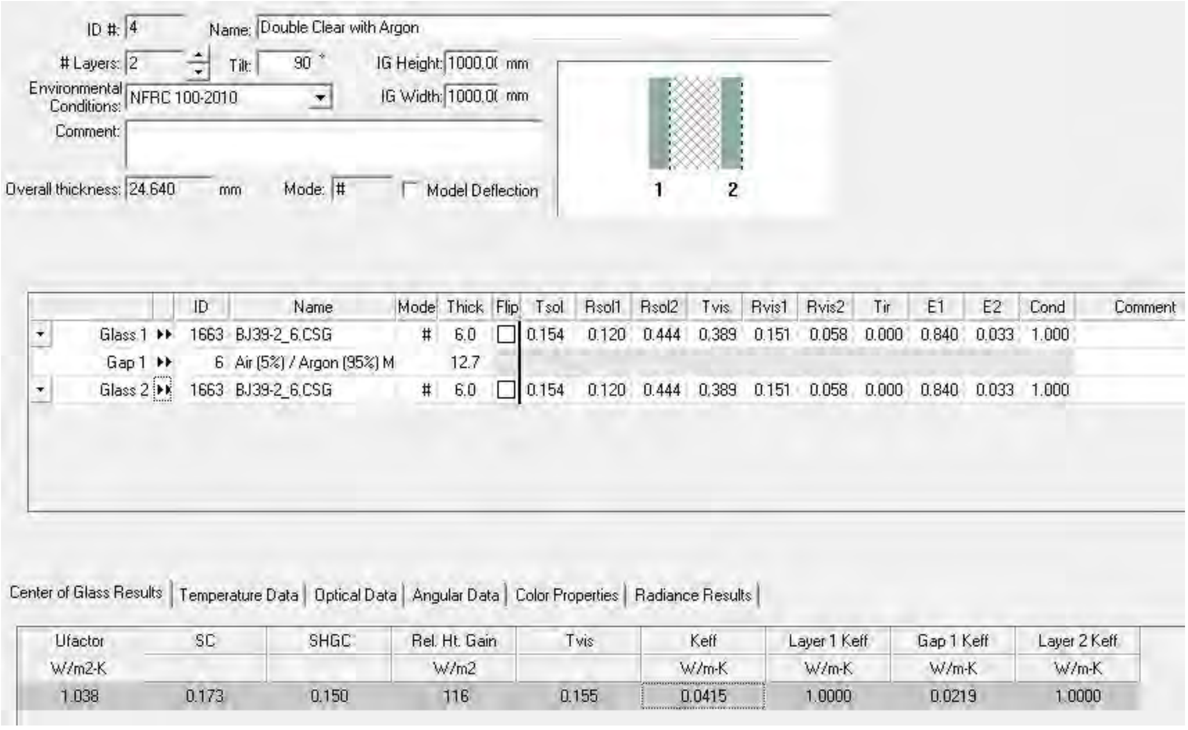
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 19.060 mm Mode: # Model Deflection
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1067	CS28_3.afg	#	3.2		0.286	0.438	0.551	0.695	0.098	0.091	0.000	0.840	0.021	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	1067	CS28_3.afg	#	3.2		0.286	0.438	0.551	0.695	0.098	0.091	0.000	0.840	0.021	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.019	0.281	0.245	184	0.488	0.0316	1.0000	0.0213	1.0000

Figure H94. The characteristic of the glazing system of option number 73 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

Overall thickness: 24.640 mm Mode: # Model Deflection

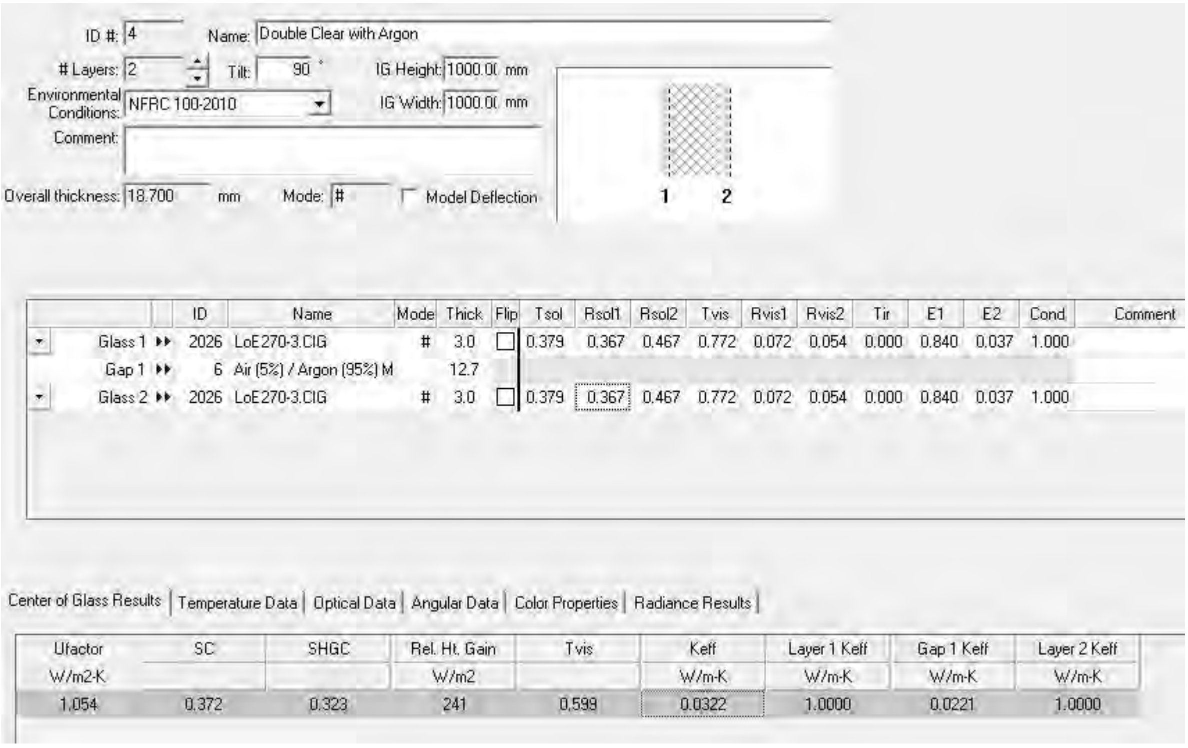
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1663	BJ39-2_6.CSG	#	6.0	☐	0.154	0.120	0.444	0.389	0.151	0.058	0.000	0.840	0.033	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	1663	BJ39-2_6.CSG	#	6.0	☐	0.154	0.120	0.444	0.389	0.151	0.058	0.000	0.840	0.033	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.038	0.173	0.150	116	0.155	0.0415	1.0000	0.0219	1.0000

Figure H95. The characteristic of the glazing system of option number 74 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

Overall thickness: 18.700 mm Mode: # Model Deflection

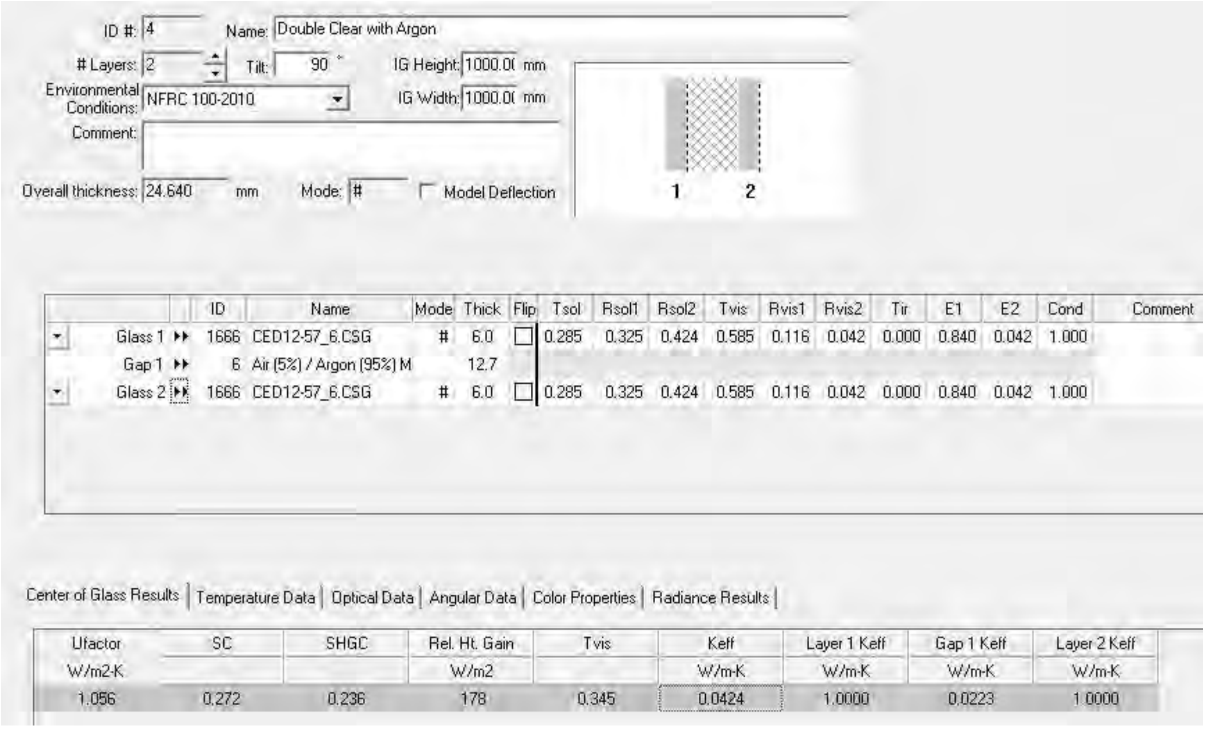
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	2026	LoE270-3.CIG	#	3.0	☐	0.379	0.367	0.467	0.772	0.072	0.054	0.000	0.840	0.037	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	2026	LoE270-3.CIG	#	3.0	☐	0.379	0.367	0.467	0.772	0.072	0.054	0.000	0.840	0.037	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.054	0.372	0.323	241	0.599	0.0322	1.0000	0.0221	1.0000

Figure H96. The characteristic of the glazing system of option number 75 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



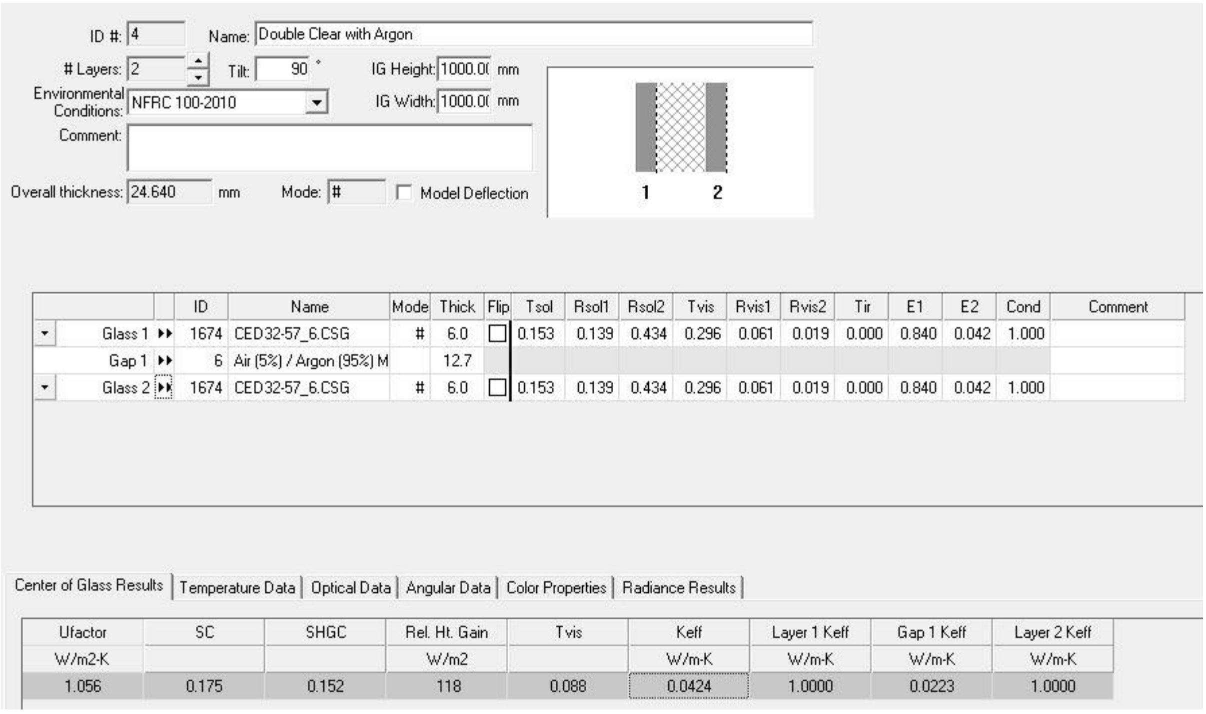
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 24.640 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1666	CED12-57_6.CSG	#	6.0		0.285	0.325	0.424	0.585	0.116	0.042	0.000	0.840	0.042	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	1666	CED12-57_6.CSG	#	6.0		0.285	0.325	0.424	0.585	0.116	0.042	0.000	0.840	0.042	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.056	0.272	0.236	178	0.345	0.0424	1.0000	0.0223	1.0000

Figure H97. The characteristic of the glazing system of option number 76 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



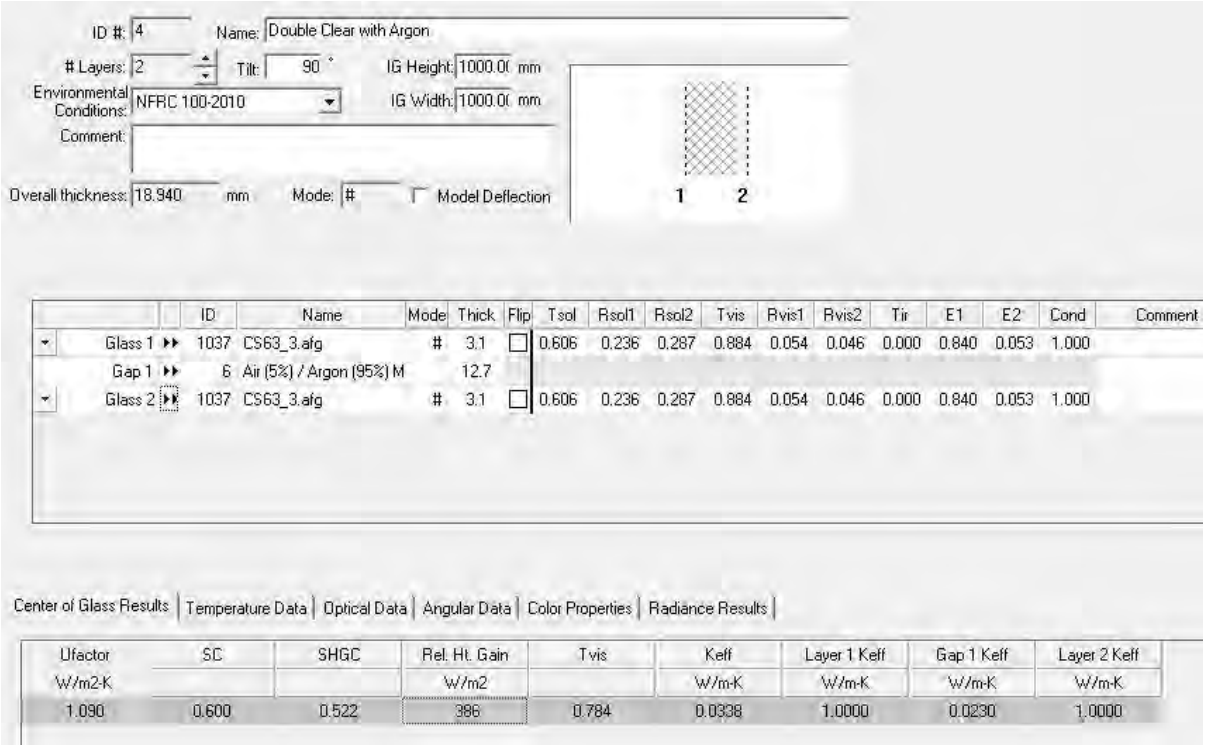
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 24.640 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1674	CED32-57_6.CSG	#	6.0		0.153	0.139	0.434	0.296	0.061	0.019	0.000	0.840	0.042	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	1674	CED32-57_6.CSG	#	6.0		0.153	0.139	0.434	0.296	0.061	0.019	0.000	0.840	0.042	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.056	0.175	0.152	118	0.088	0.0424	1.0000	0.0223	1.0000

Figure H98. The characteristic of the glazing system of option number 77 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



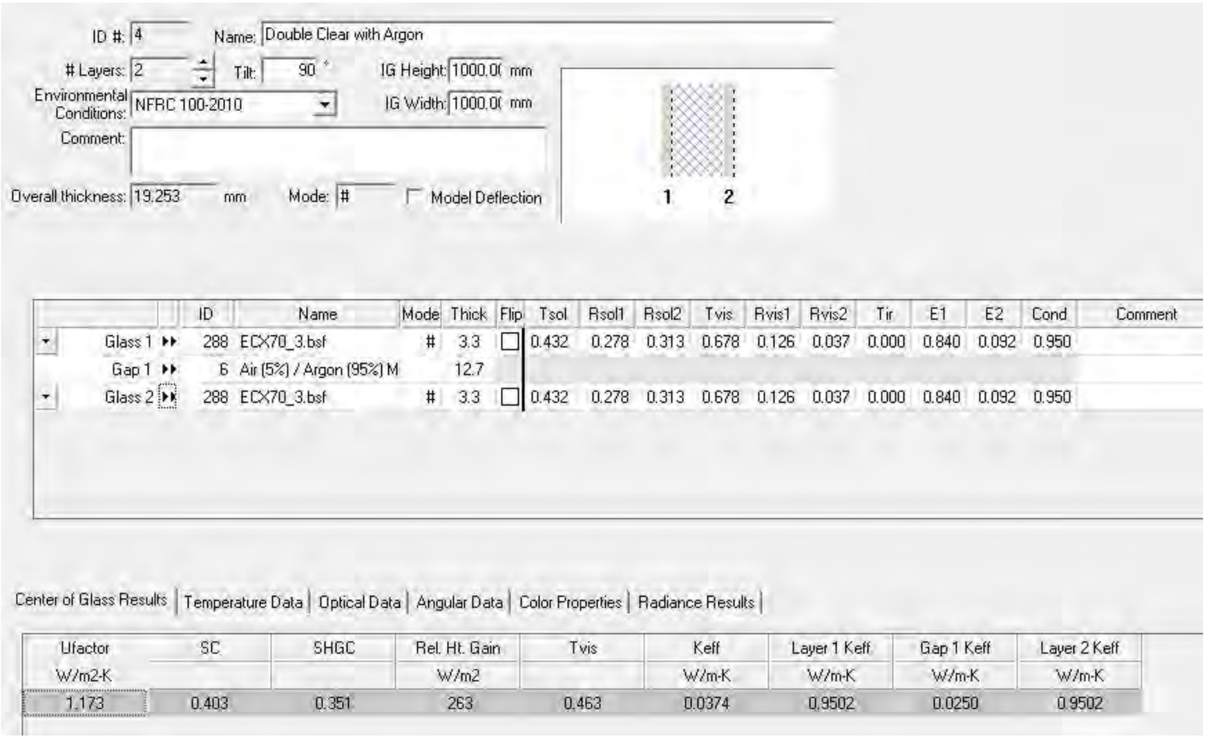
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.940 mm Mode: # Model Deflection
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1037	CS63_3.afg	#	3.1		0.606	0.236	0.287	0.884	0.054	0.046	0.000	0.840	0.053	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	1037	CS63_3.afg	#	3.1		0.606	0.236	0.287	0.884	0.054	0.046	0.000	0.840	0.053	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results |

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.090	0.600	0.522	386	0.784	0.0338	1.0000	0.0230	1.0000

Figure H99. The characteristic of the glazing system of option number 78 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 19.253 mm Mode: # Model Deflection
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	288	ECX70_3.bsf	#	3.3		0.432	0.278	0.313	0.678	0.126	0.037	0.000	0.840	0.092	0.950	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	288	ECX70_3.bsf	#	3.3		0.432	0.278	0.313	0.678	0.126	0.037	0.000	0.840	0.092	0.950	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results |

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.173	0.403	0.351	263	0.463	0.0374	0.9502	0.0250	0.9502

Figure H100. The characteristic of the glazing system of option number 79 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

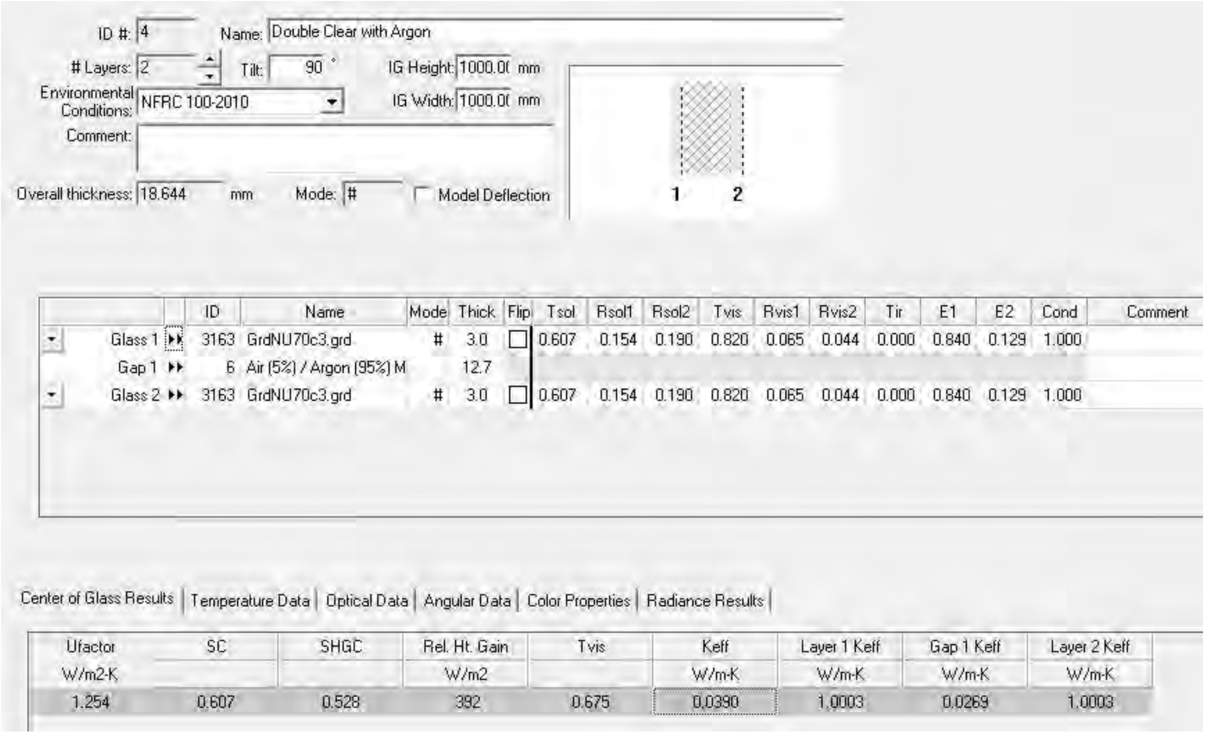


Figure H101. The characteristic of the glazing system of option number 80 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

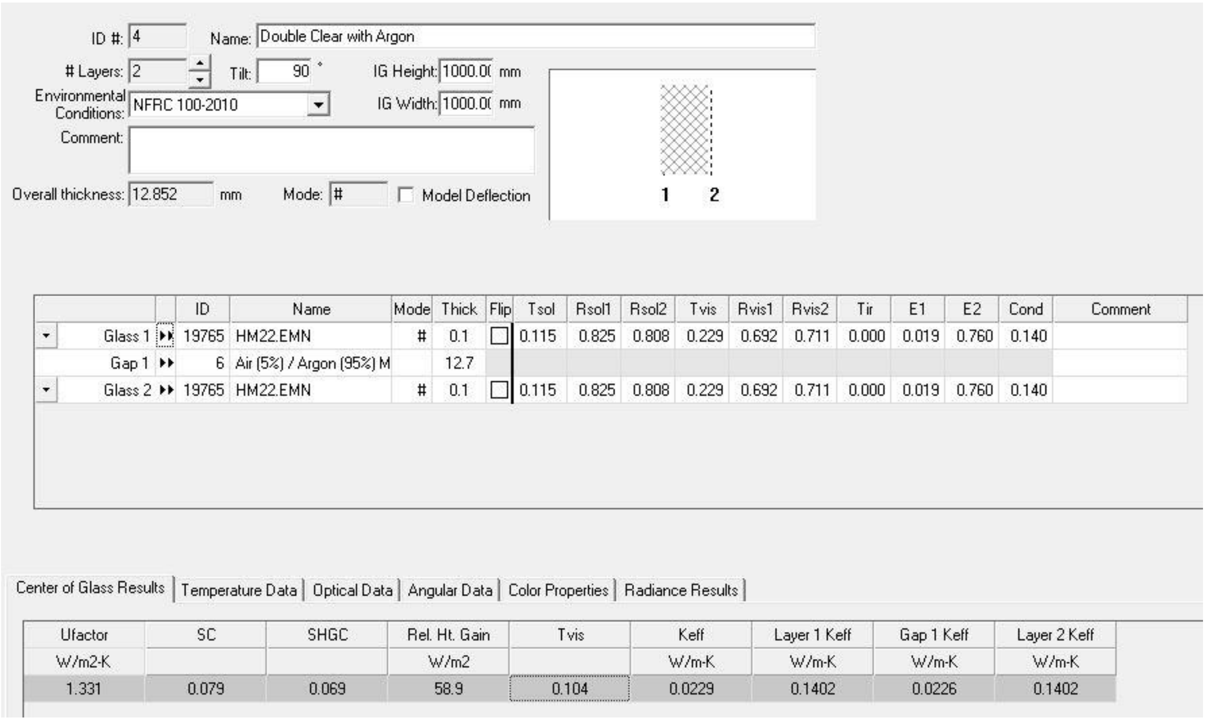


Figure H102. The characteristic of the glazing system of option number 81 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

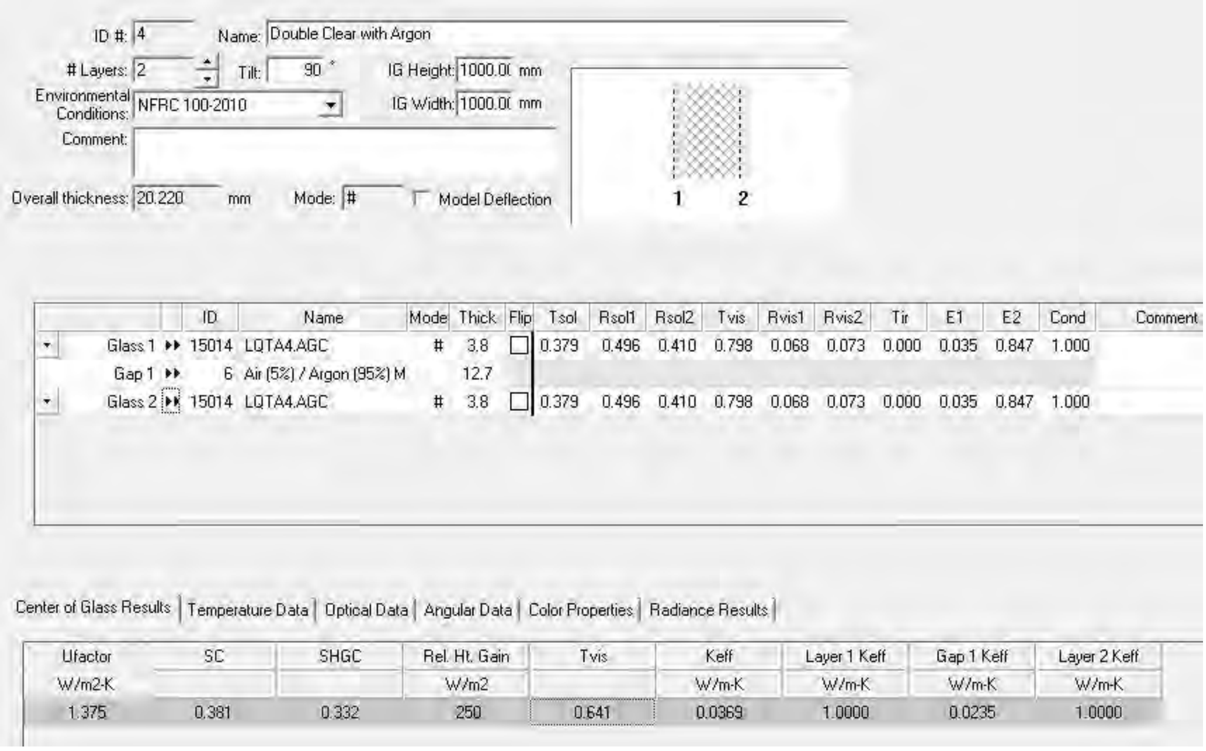


Figure H103. The characteristic of the glazing system of option number 82 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

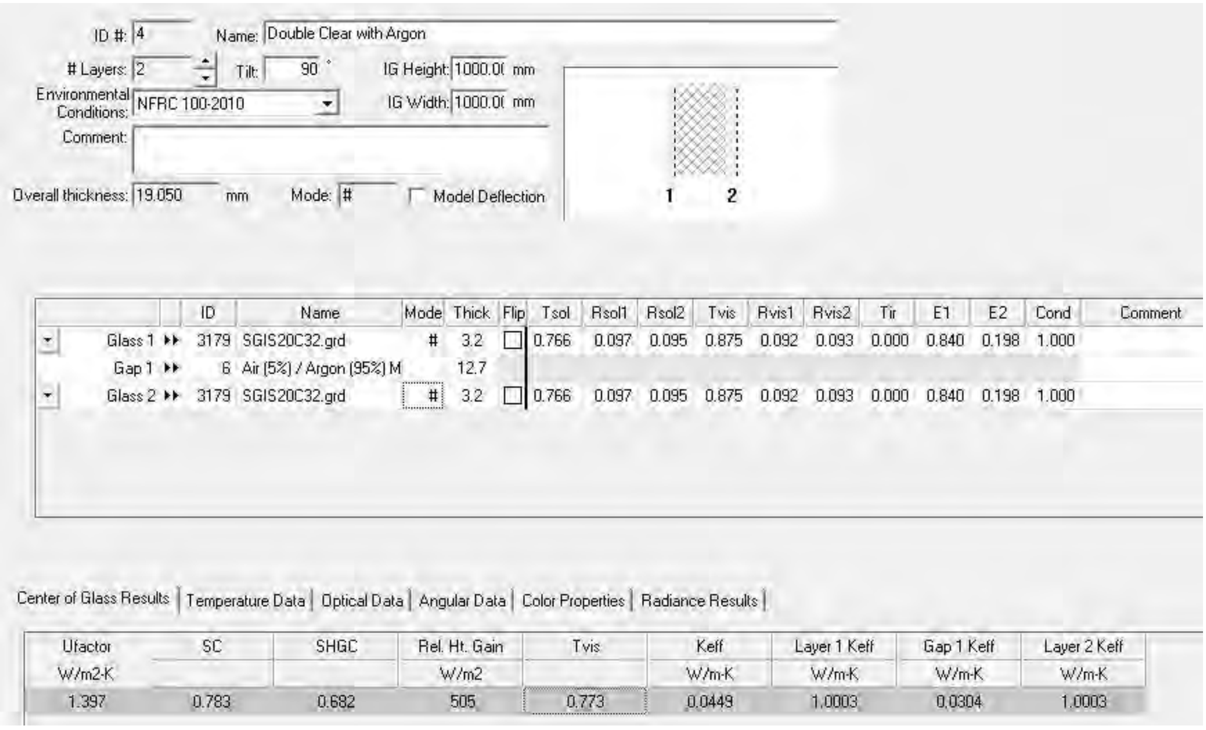


Figure H104. The characteristic of the glazing system of option number 83 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

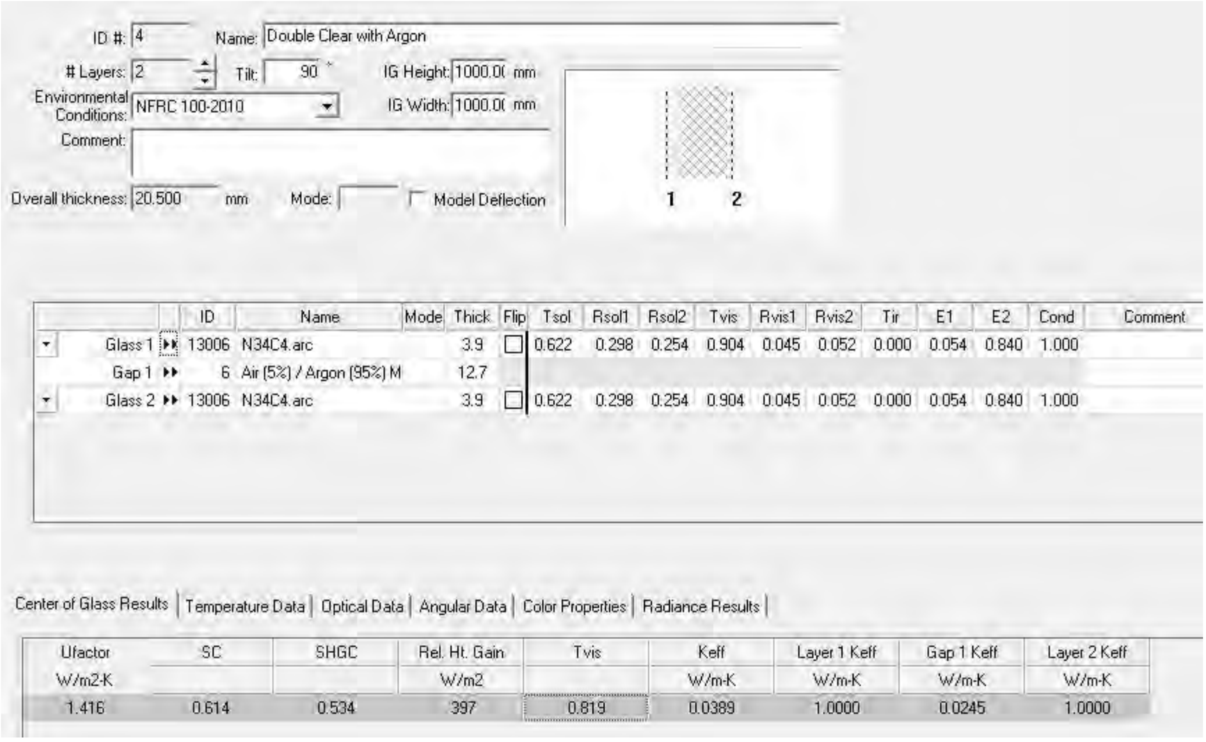


Figure H105. The characteristic of the glazing system of option number 84 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

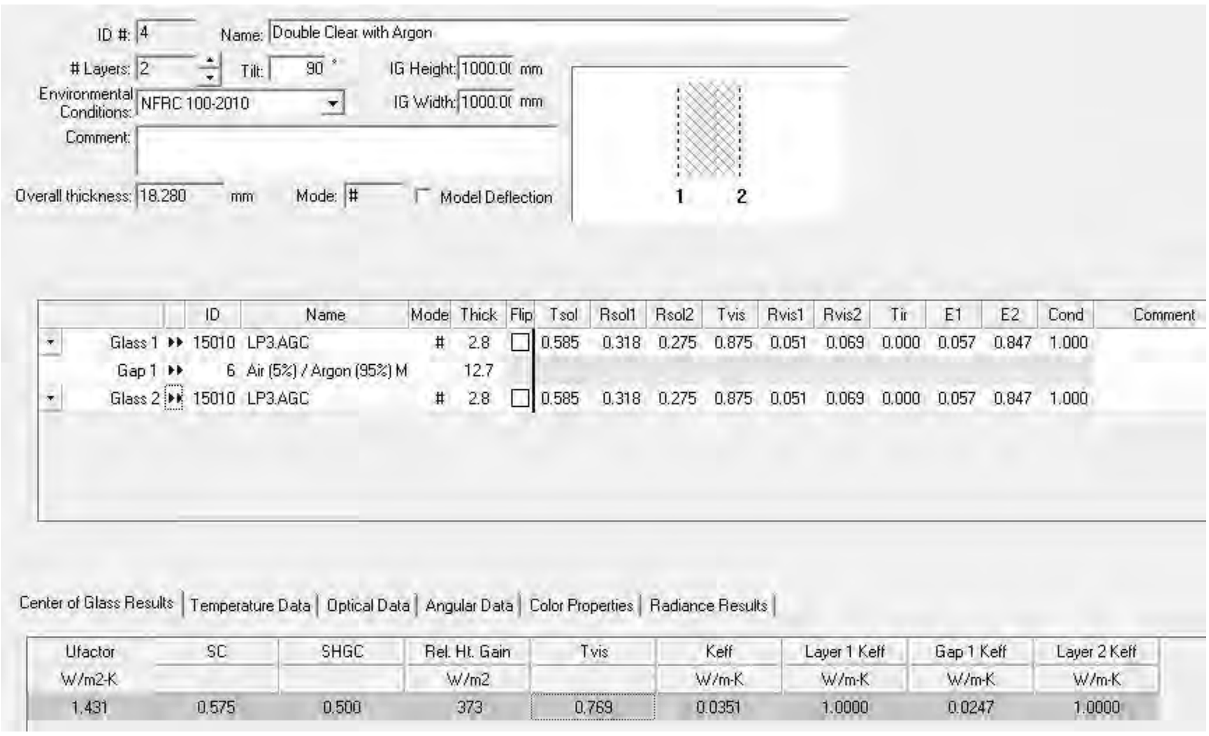
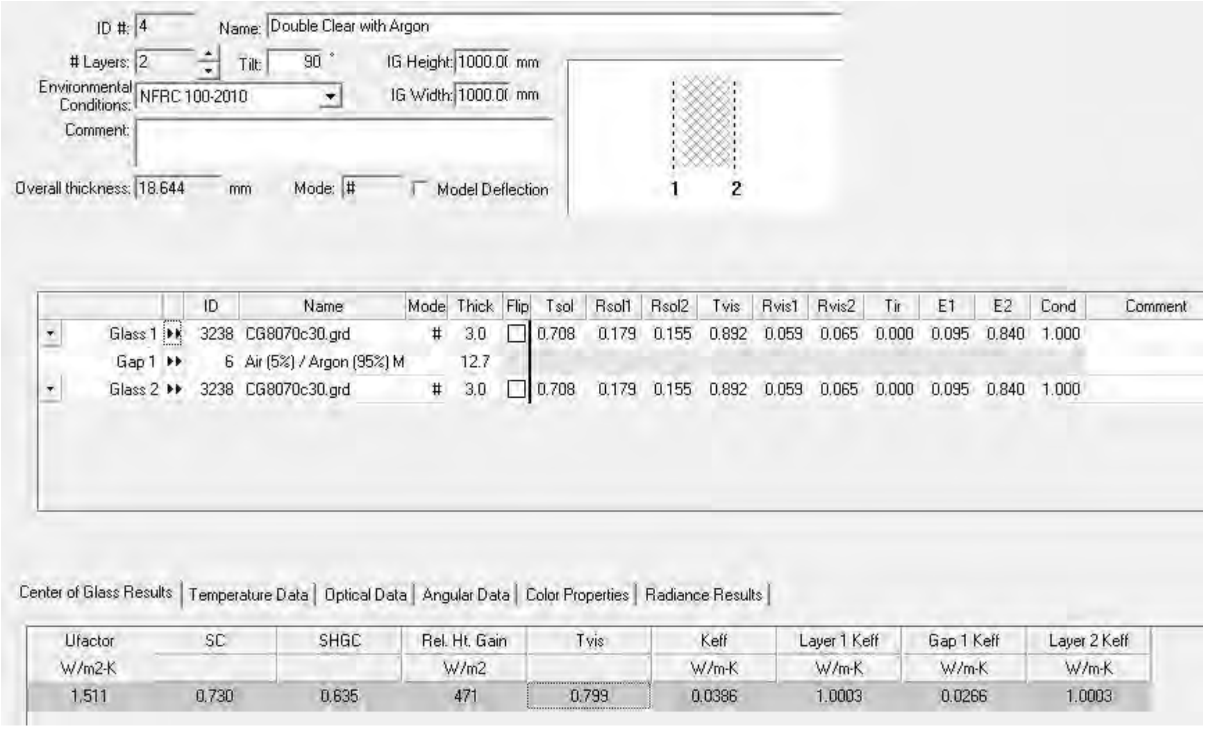


Figure H105. The characteristic of the glazing system of option number 85 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



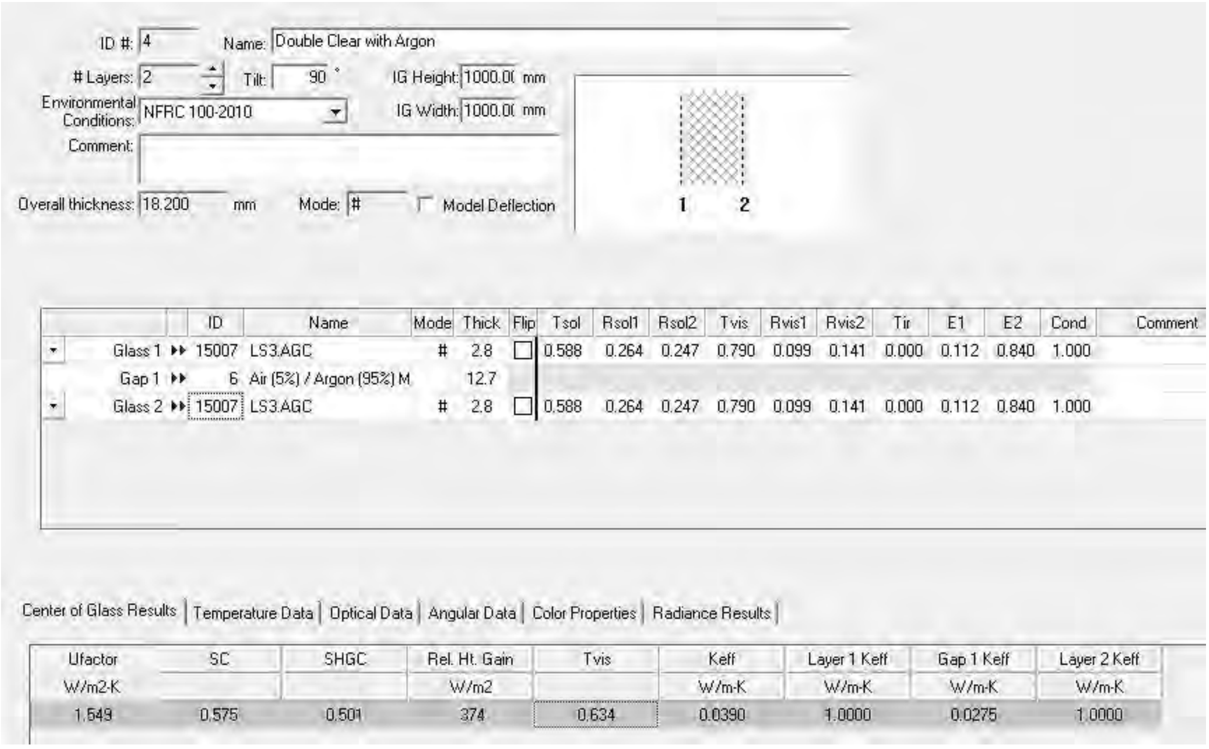
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.644 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	3238	CG8070c30.grd	#	3.0		0.708	0.179	0.155	0.892	0.059	0.065	0.000	0.095	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	3238	CG8070c30.grd	#	3.0		0.708	0.179	0.155	0.892	0.059	0.065	0.000	0.095	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.511	0.730	0.635	471	0.799	0.0386	1.0003	0.0266	1.0003

Figure H107. The characteristic of the glazing system of option number 86 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.200 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	15007	LS3.AGC	#	2.8		0.588	0.264	0.247	0.790	0.099	0.141	0.000	0.112	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	15007	LS3.AGC	#	2.8		0.588	0.264	0.247	0.790	0.099	0.141	0.000	0.112	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.549	0.575	0.501	374	0.634	0.0390	1.0000	0.0275	1.0000

Figure H108. The characteristic of the glazing system of option number 87 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

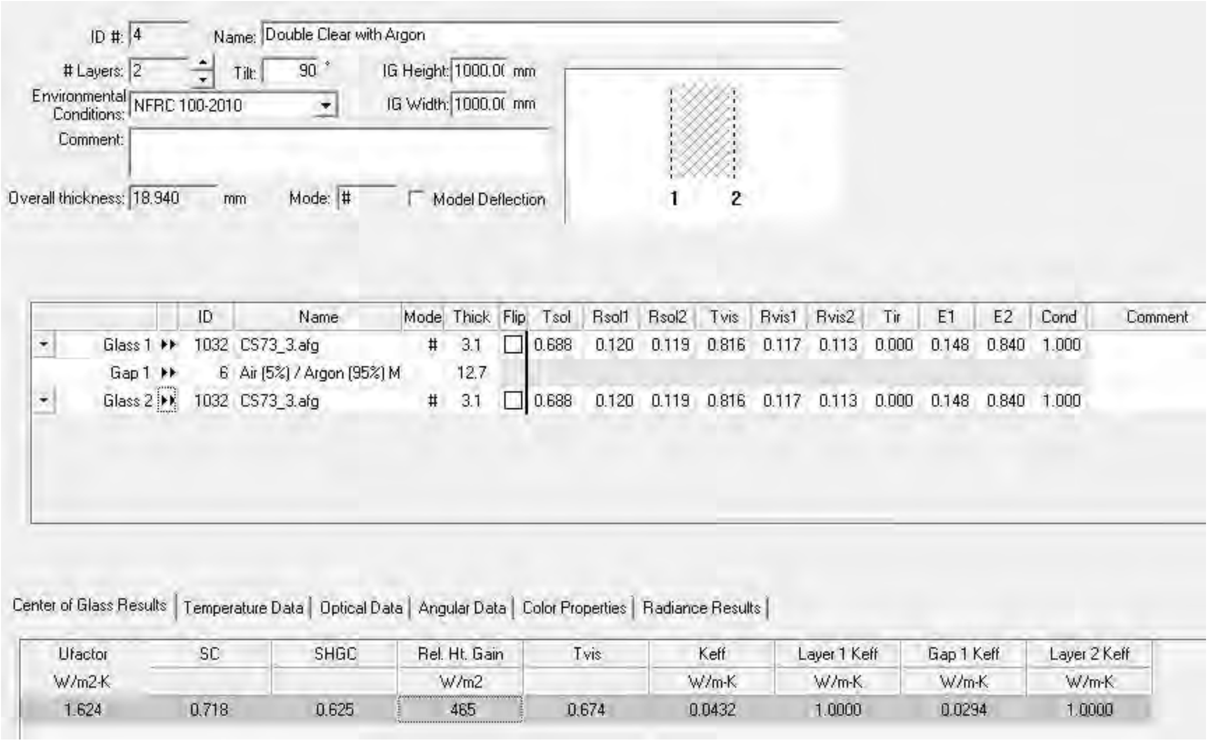


Figure H109. The characteristic of the glazing system of option number 88 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

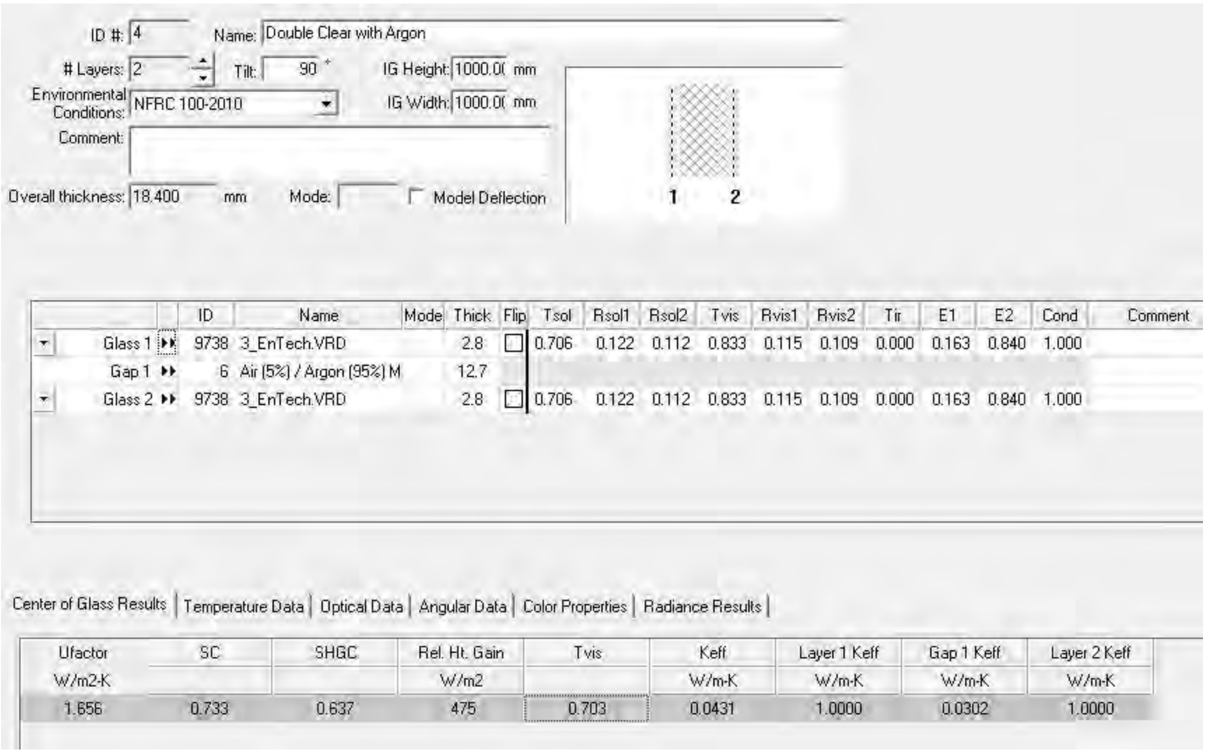
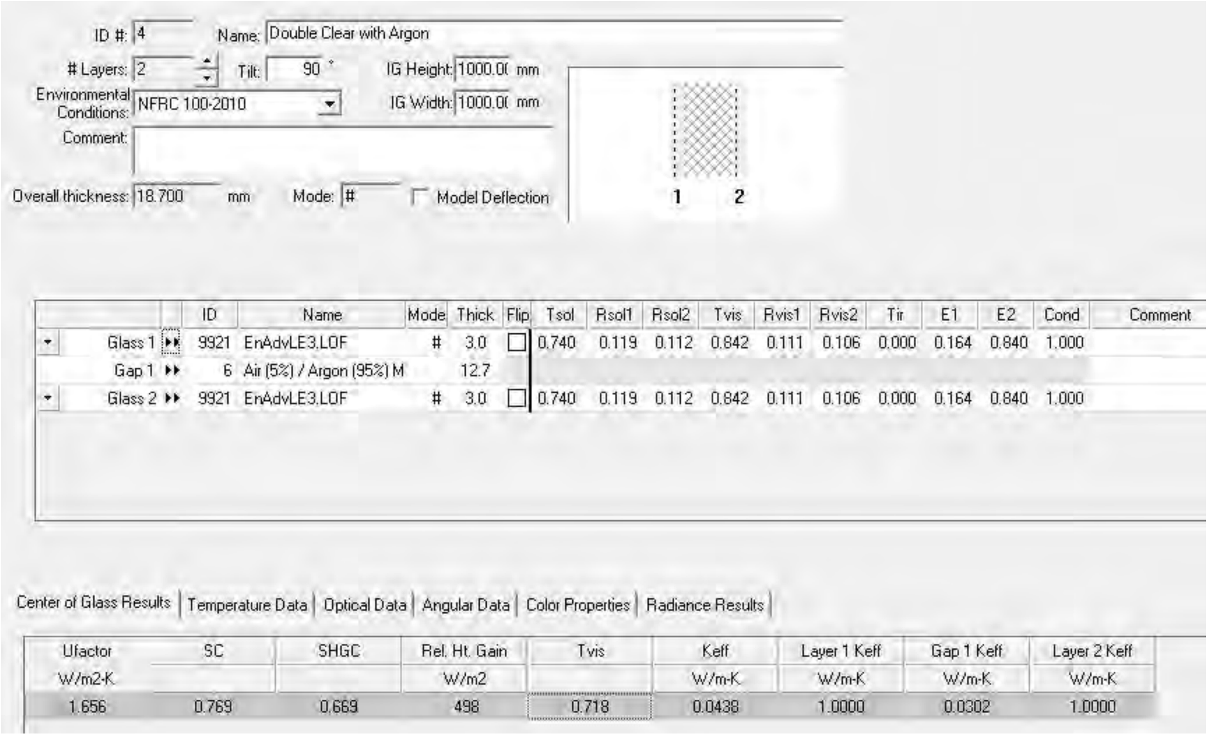


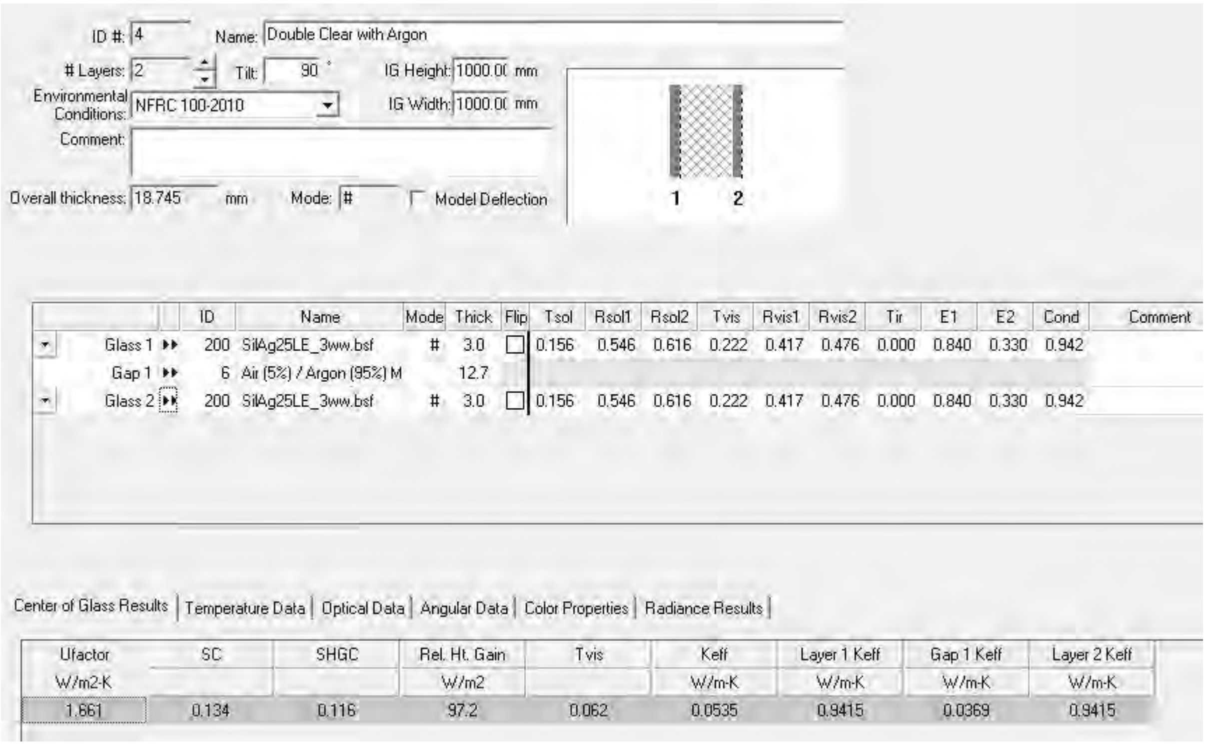
Figure H110. The characteristic of the glazing system of option number 89 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	9921	EnAdvLE3.LOF	#	3.0		0.740	0.119	0.112	0.842	0.111	0.106	0.000	0.164	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	9921	EnAdvLE3.LOF	#	3.0		0.740	0.119	0.112	0.842	0.111	0.106	0.000	0.164	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.656	0.769	0.669	498	0.718	0.0438	1.0000	0.0302	1.0000

Figure H111. The characteristic of the glazing system of option number 90 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	200	SilAg25LE_3ww.bsf	#	3.0		0.156	0.546	0.616	0.222	0.417	0.476	0.000	0.840	0.330	0.942	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	200	SilAg25LE_3ww.bsf	#	3.0		0.156	0.546	0.616	0.222	0.417	0.476	0.000	0.840	0.330	0.942	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.661	0.134	0.116	97.2	0.062	0.0535	0.9415	0.0369	0.9415

Figure H112. The characteristic of the glazing system of option number 91 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

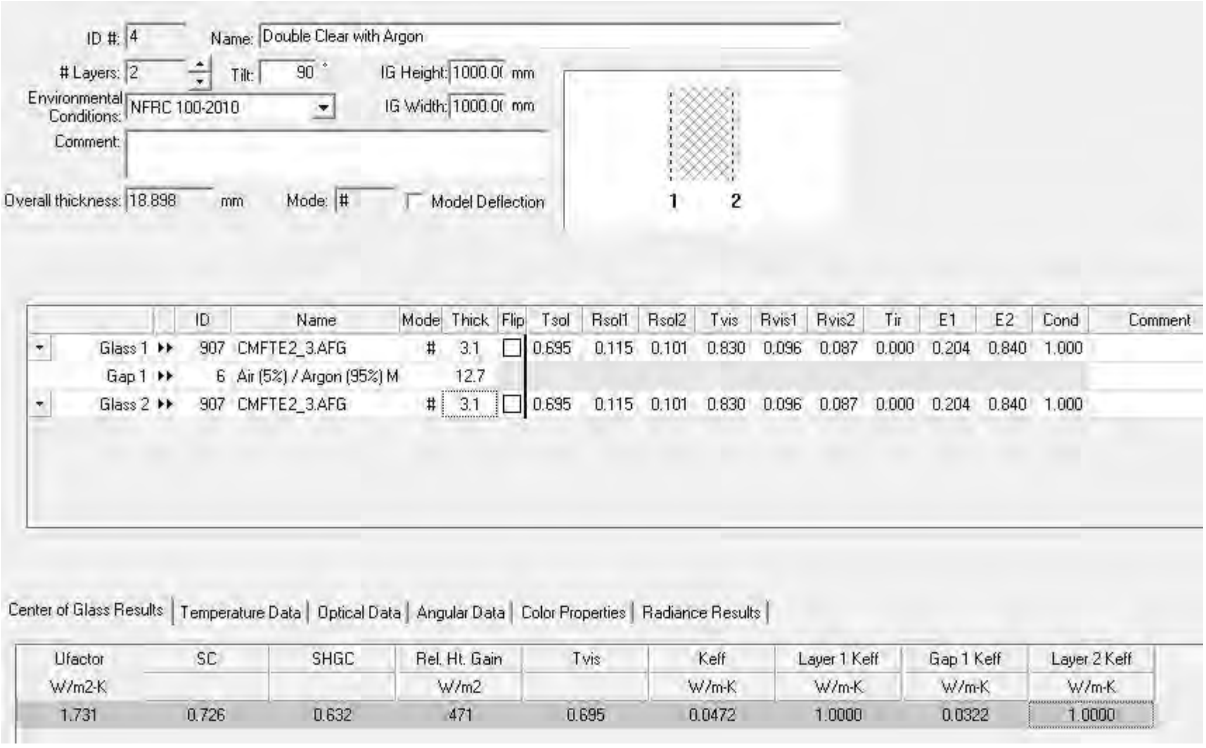


Figure H113. The characteristic of the glazing system of option number 92 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

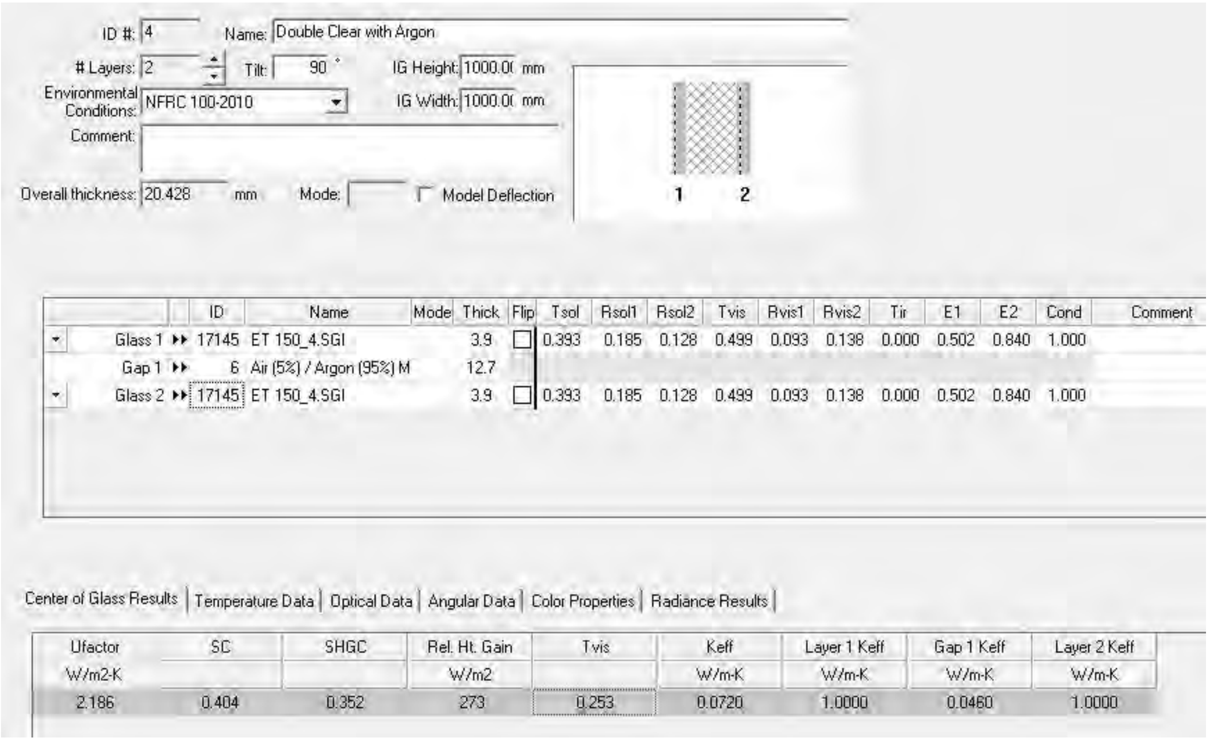


Figure H114. The characteristic of the glazing system of option number 93 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

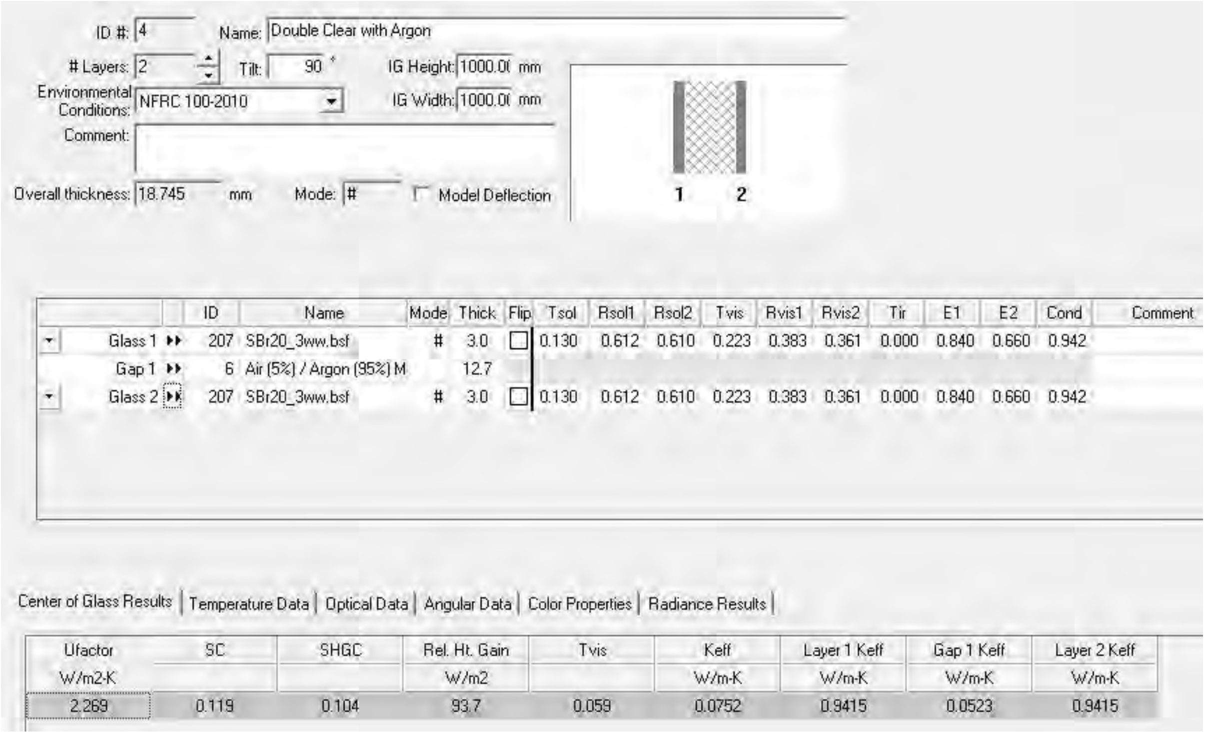


Figure H115. The characteristic of the glazing system of option number 94 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

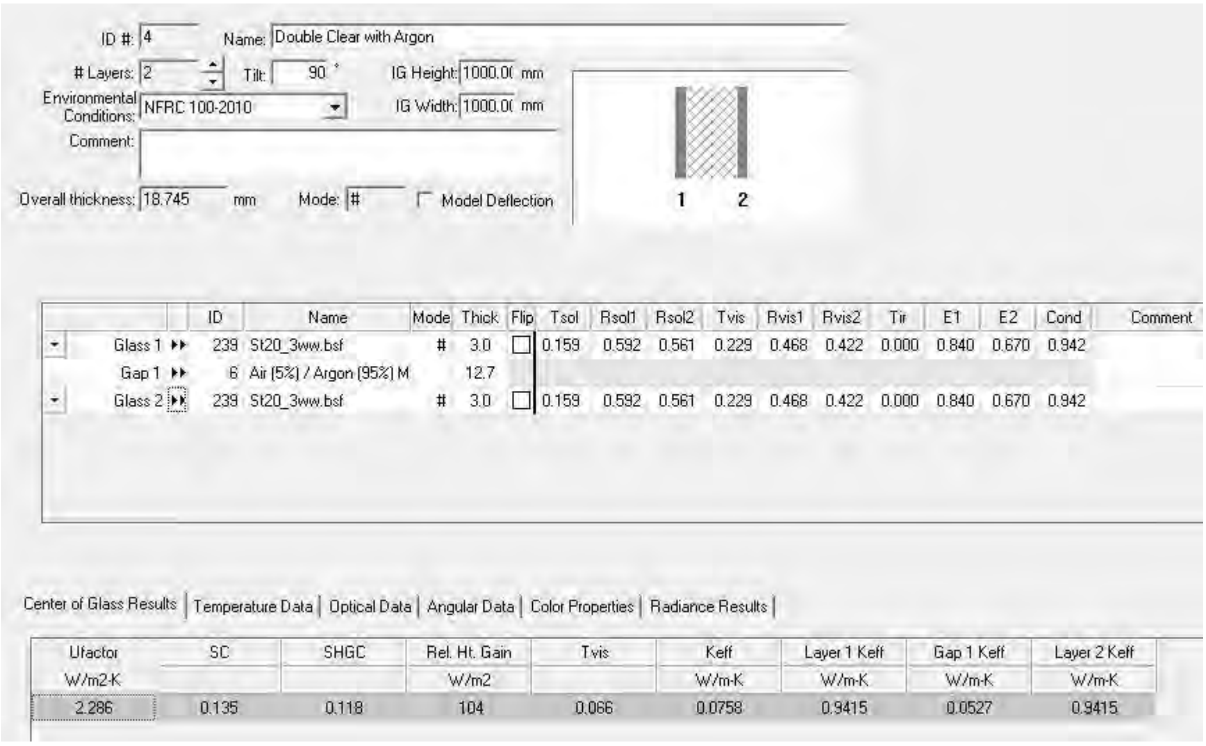
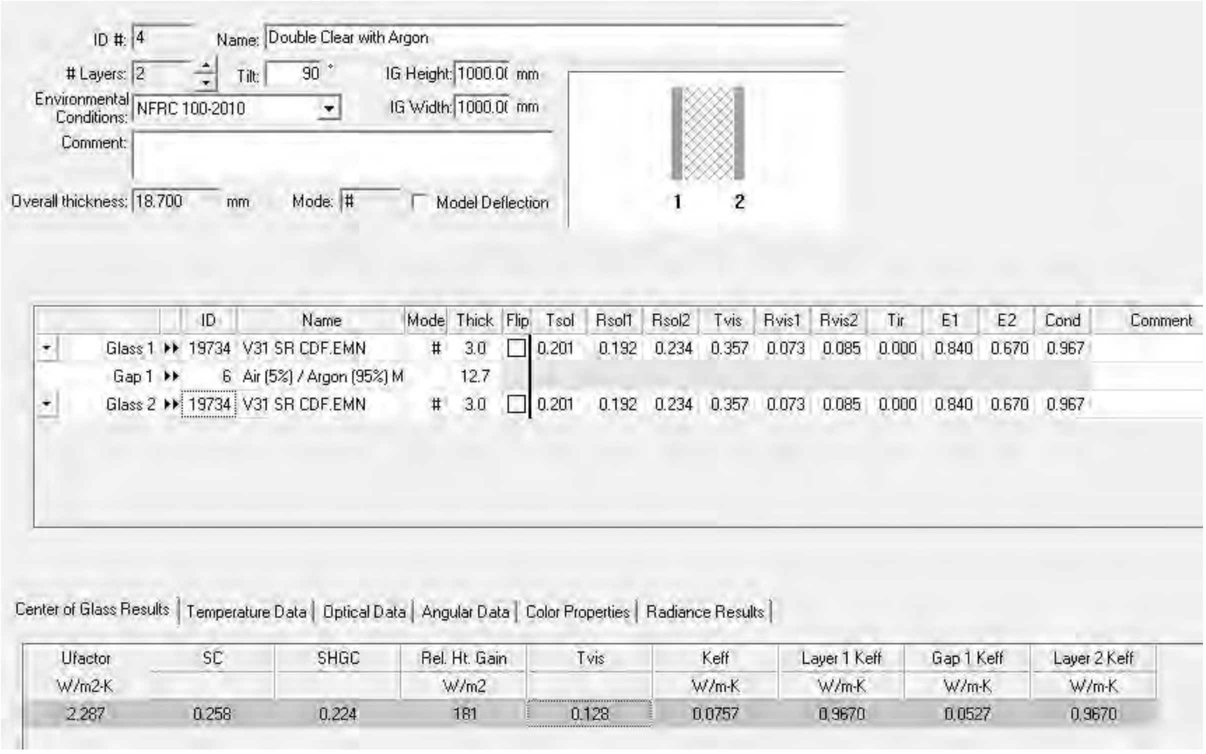


Figure H116. The characteristic of the glazing system of option number 95 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

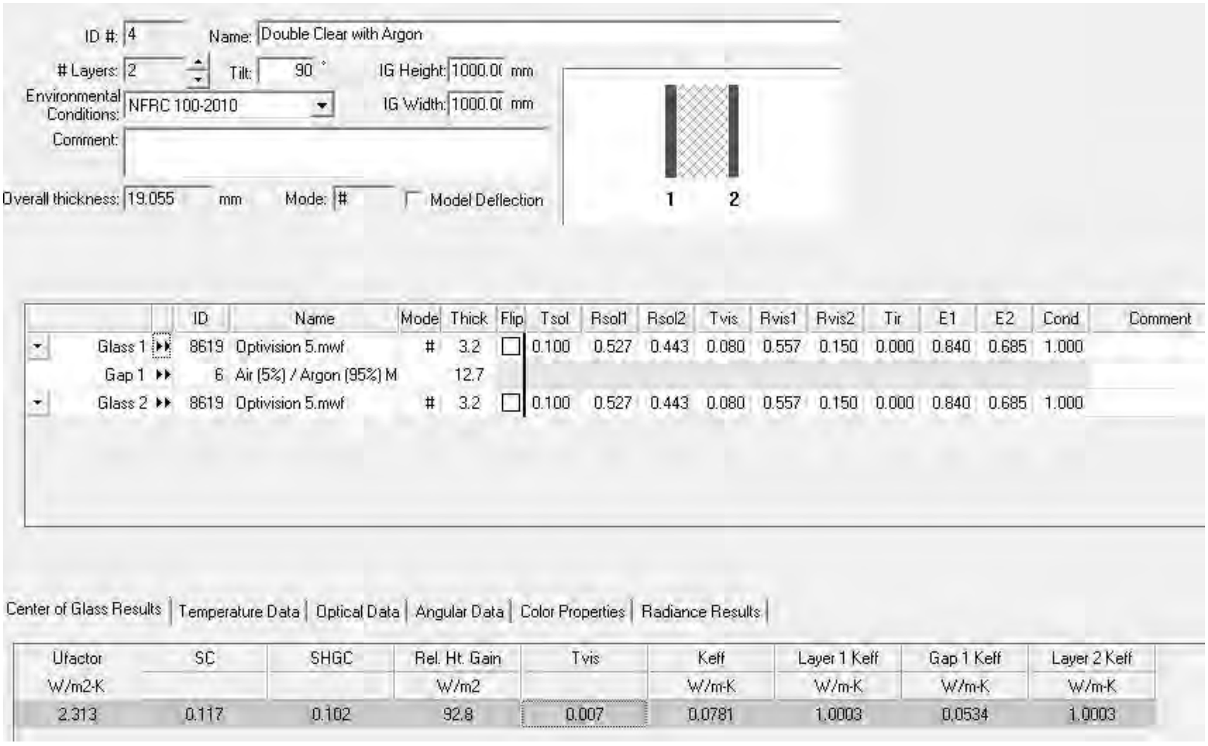
Overall thickness: 18.700 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	19734	V31 SR CDF.EMN	#	3.0		0.201	0.192	0.234	0.357	0.073	0.085	0.000	0.840	0.670	0.967	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	19734	V31 SR CDF.EMN	#	3.0		0.201	0.192	0.234	0.357	0.073	0.085	0.000	0.840	0.670	0.967	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results |

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.287	0.258	0.224	181	0.128	0.0757	0.9670	0.0527	0.9670

Figure H117. The characteristic of the glazing system of option number 96 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

Overall thickness: 19.055 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	8619	Optivision 5.mwf	#	3.2		0.100	0.527	0.443	0.080	0.557	0.150	0.000	0.840	0.685	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	8619	Optivision 5.mwf	#	3.2		0.100	0.527	0.443	0.080	0.557	0.150	0.000	0.840	0.685	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results |

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.313	0.117	0.102	92.8	0.007	0.0781	1.0003	0.0534	1.0003

Figure H118. The characteristic of the glazing system of option number 97 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

Figure H119. The characteristic of the glazing system of option number 98 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

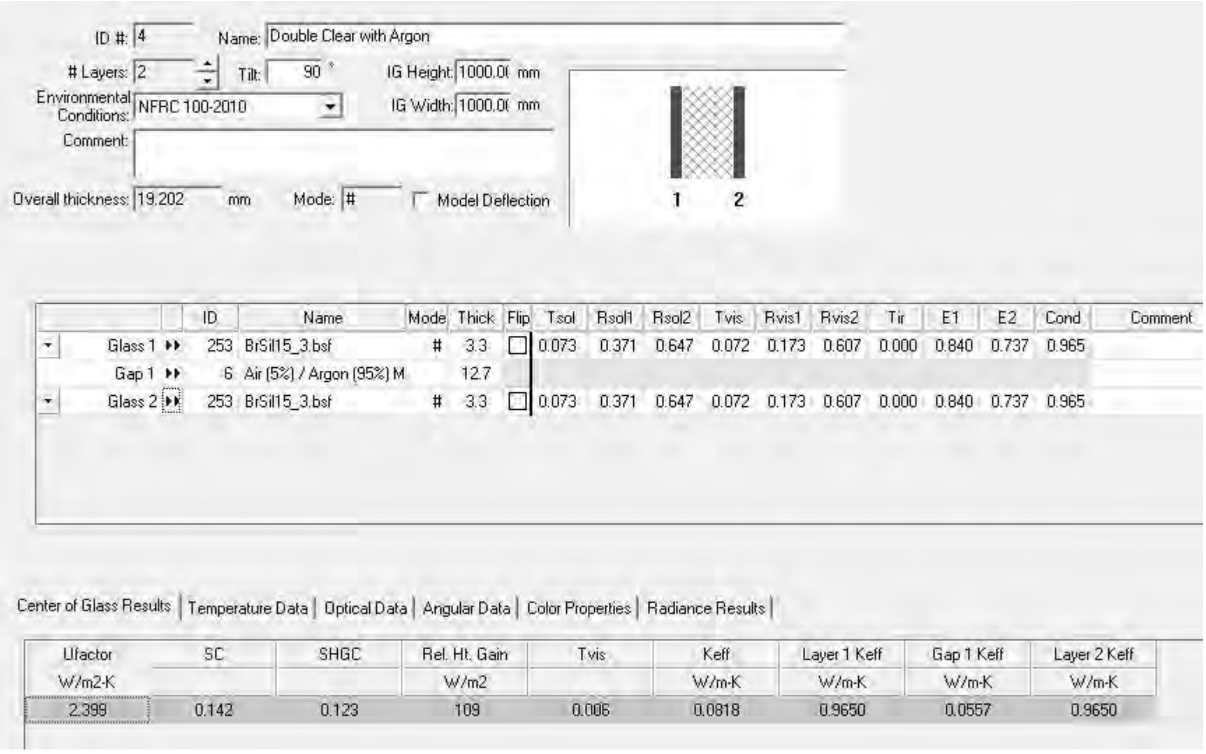


Figure H120. The characteristic of the glazing system of option number 99 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

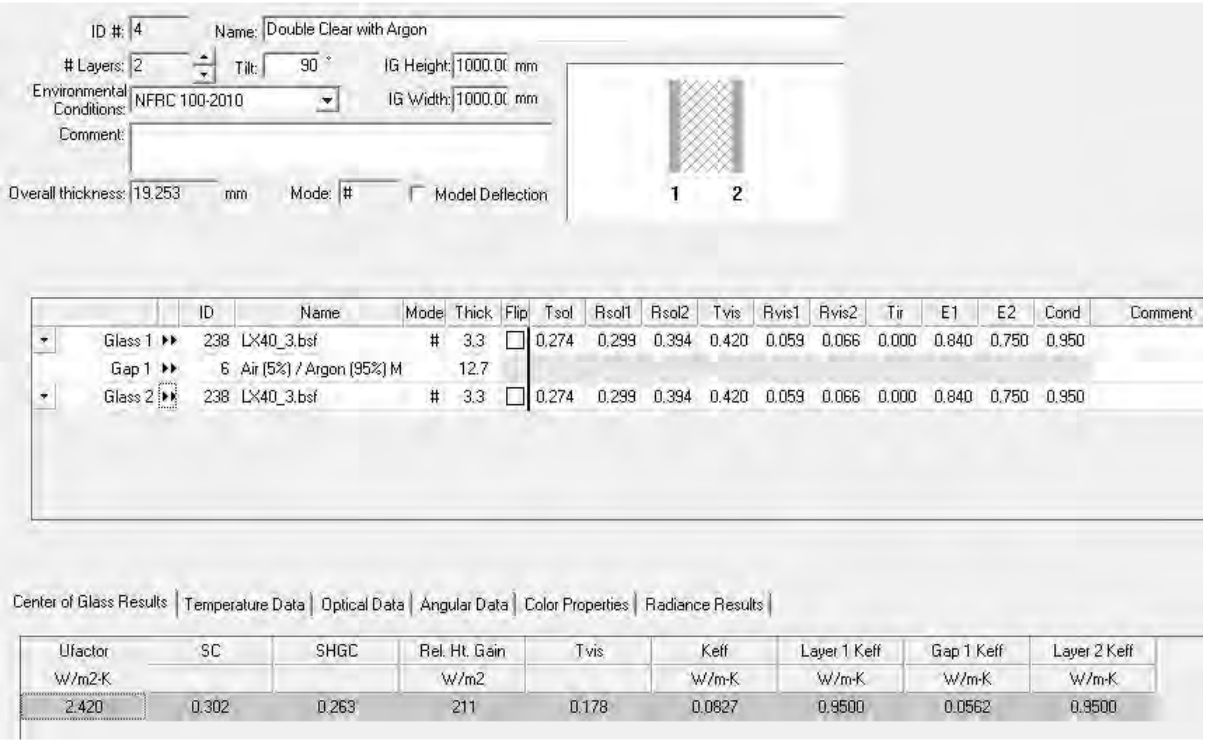
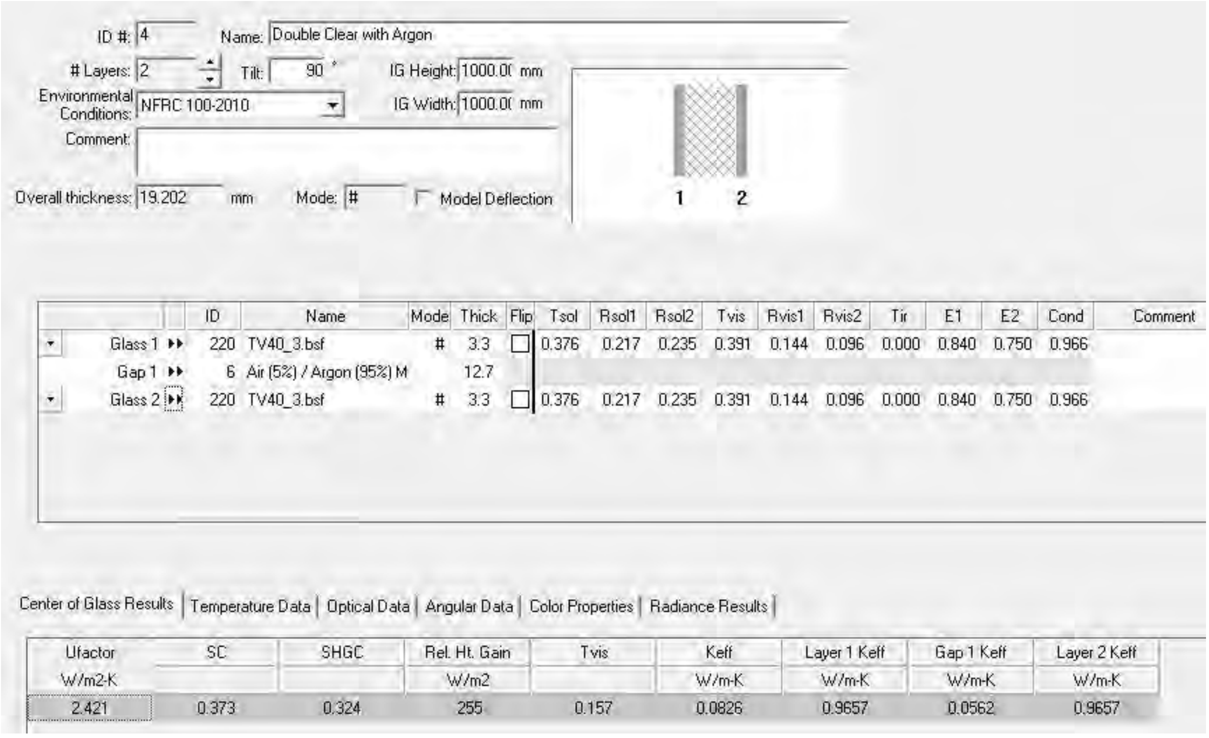


Figure H121. The characteristic of the glazing system of option number 100 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

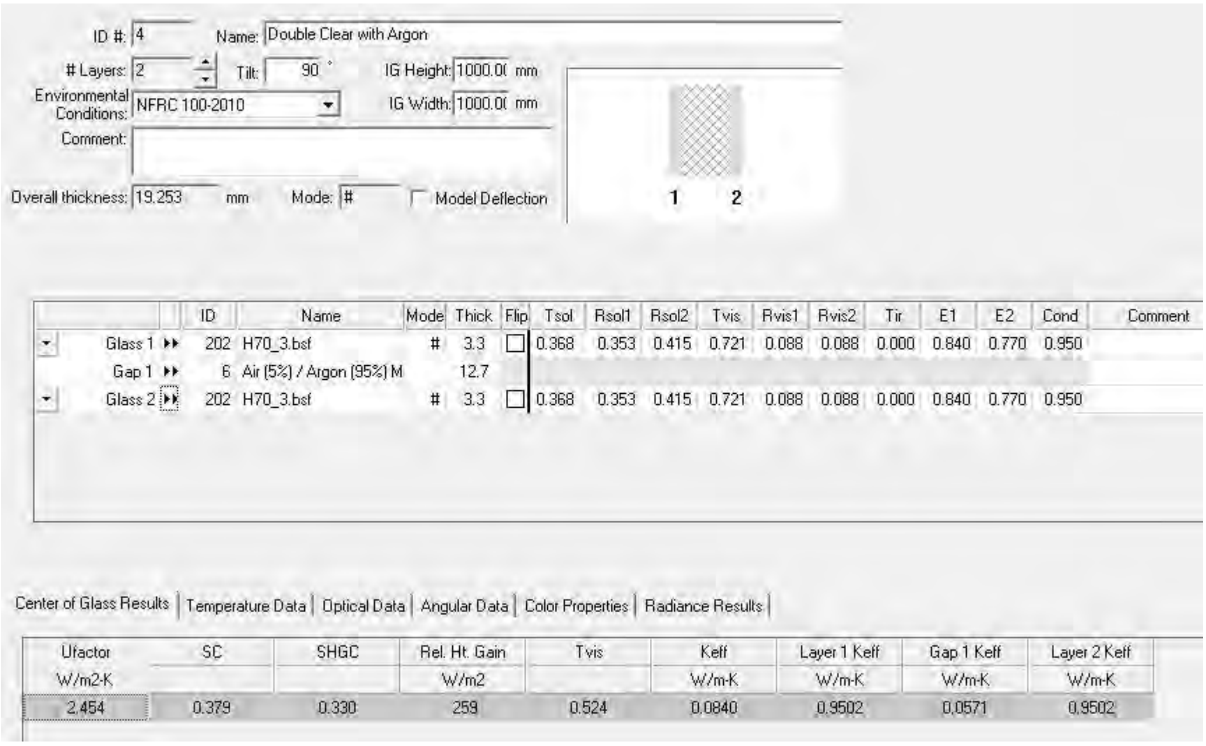

ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 19.202 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	220	TV40_3.bsf	#	3.3		0.376	0.217	0.235	0.391	0.144	0.096	0.000	0.840	0.750	0.966	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	220	TV40_3.bsf	#	3.3		0.376	0.217	0.235	0.391	0.144	0.096	0.000	0.840	0.750	0.966	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.421	0.373	0.324	255	0.157	0.0826	0.9657	0.0562	0.9657

Figure H122. The characteristic of the glazing system of option number 101 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.


ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 19.253 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	202	H70_3.bsf	#	3.3		0.368	0.353	0.415	0.721	0.088	0.088	0.000	0.840	0.770	0.950	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	202	H70_3.bsf	#	3.3		0.368	0.353	0.415	0.721	0.088	0.088	0.000	0.840	0.770	0.950	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.454	0.379	0.330	259	0.524	0.0840	0.9502	0.0571	0.9502

Figure H123. The characteristic of the glazing system of option number 102 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

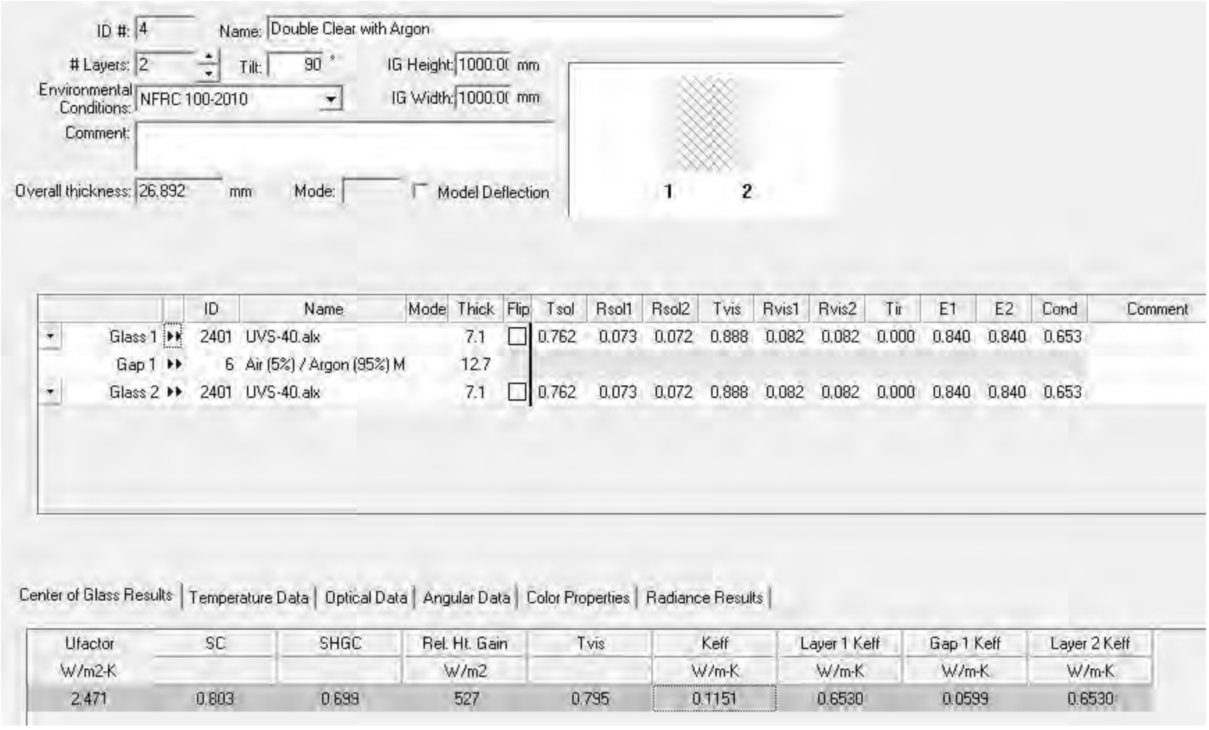


Figure H124. The characteristic of the glazing system of option number 103 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

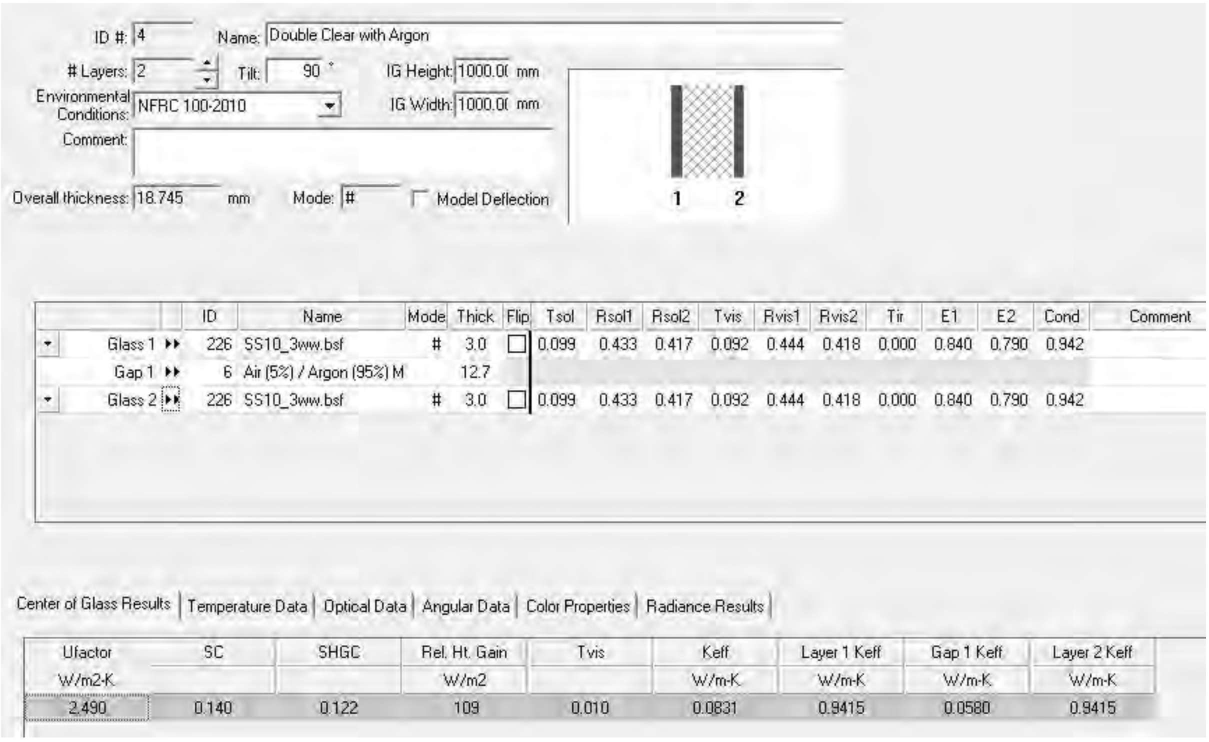
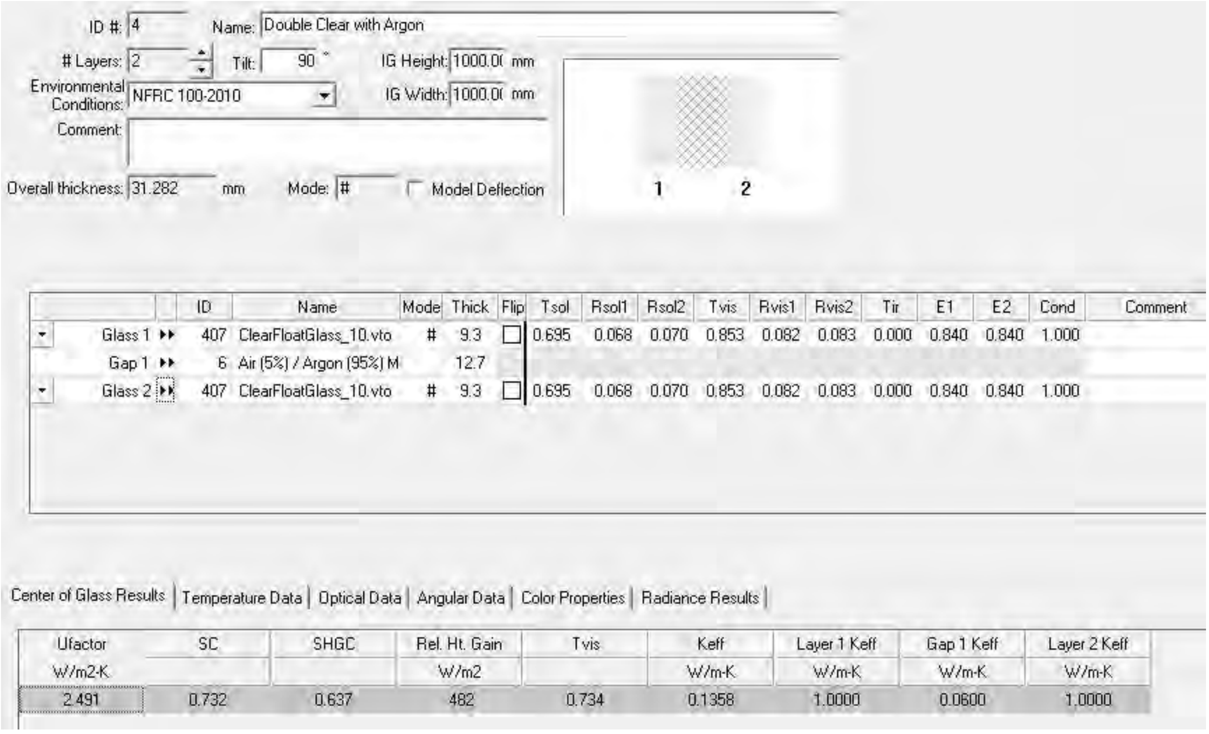


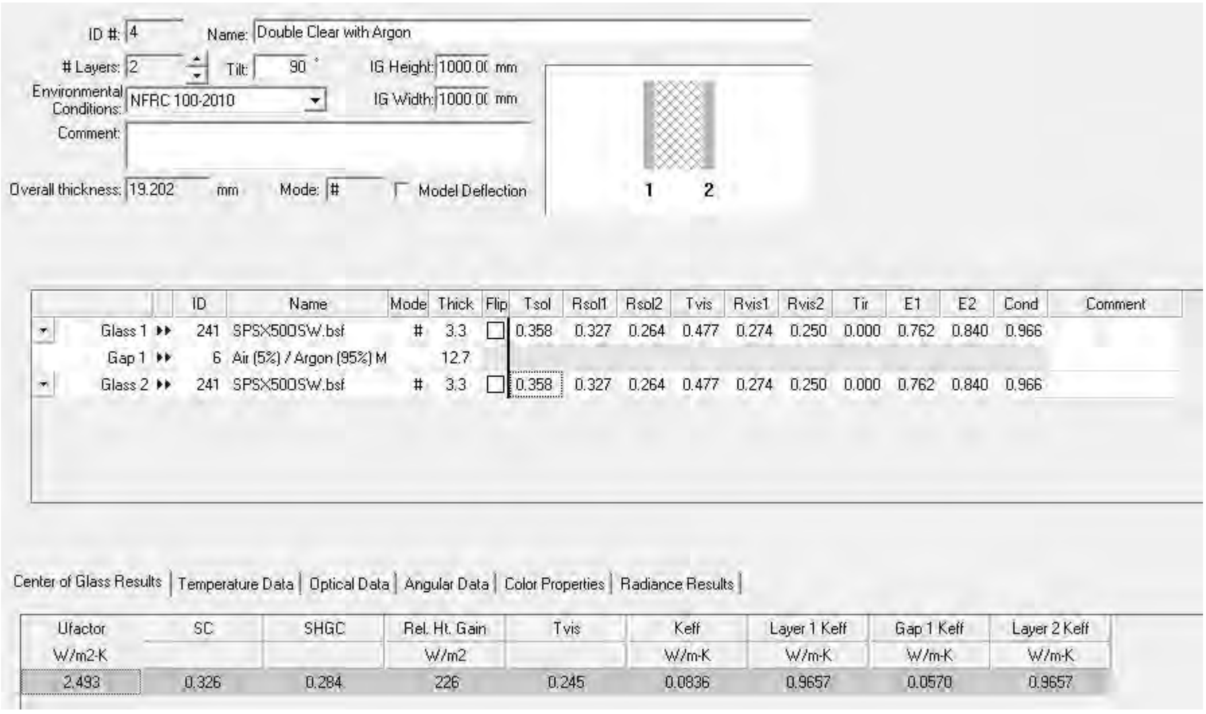
Figure H125. The characteristic of the glazing system of option number 104 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	407	ClearFloatGlass_10.vto	#	9.3	☐	0.695	0.068	0.070	0.853	0.082	0.083	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	407	ClearFloatGlass_10.vto	#	9.3	☐	0.695	0.068	0.070	0.853	0.082	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.491	0.732	0.637	482	0.734	0.1358	1.0000	0.0600	1.0000

Figure H126. The characteristic of the glazing system of option number 105 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	241	SPSX500SW.bsf	#	3.3	☐	0.358	0.327	0.264	0.477	0.274	0.250	0.000	0.762	0.840	0.966	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	241	SPSX500SW.bsf	#	3.3	☐	0.358	0.327	0.264	0.477	0.274	0.250	0.000	0.762	0.840	0.966	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.493	0.326	0.284	226	0.245	0.0836	0.9657	0.0570	0.9657

Figure H127. The characteristic of the glazing system of option number 106 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

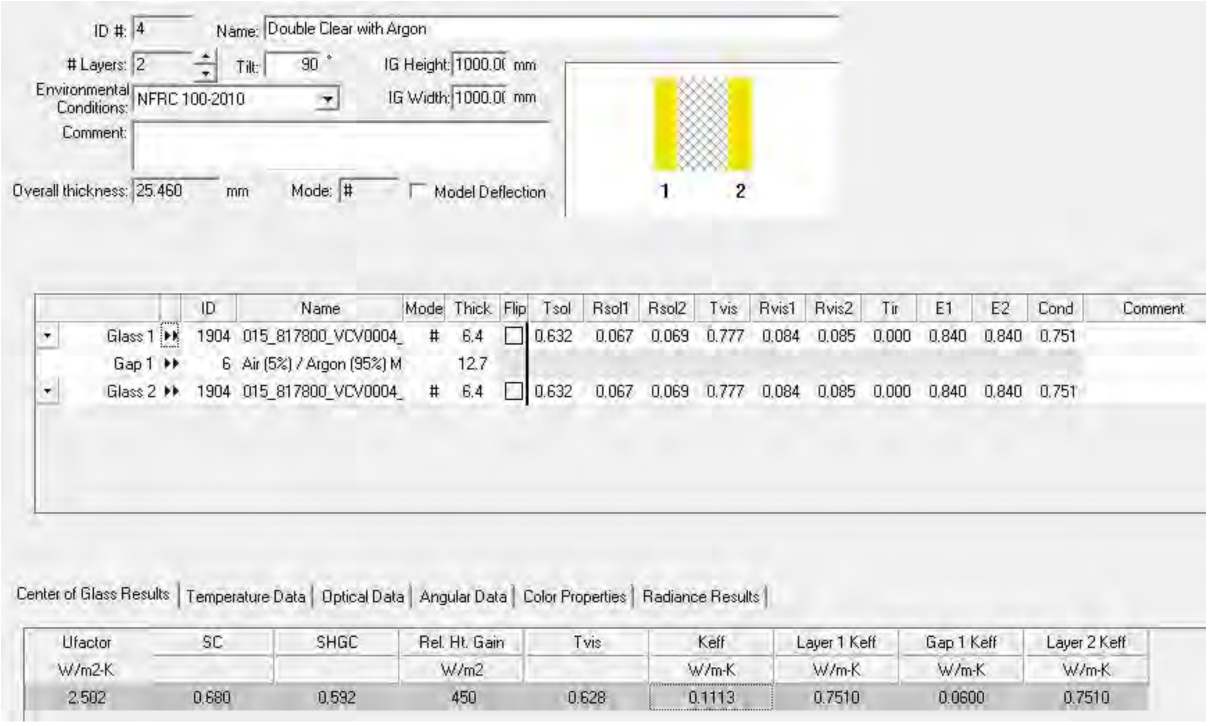


Figure H128. The characteristic of the glazing system of option number 107 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

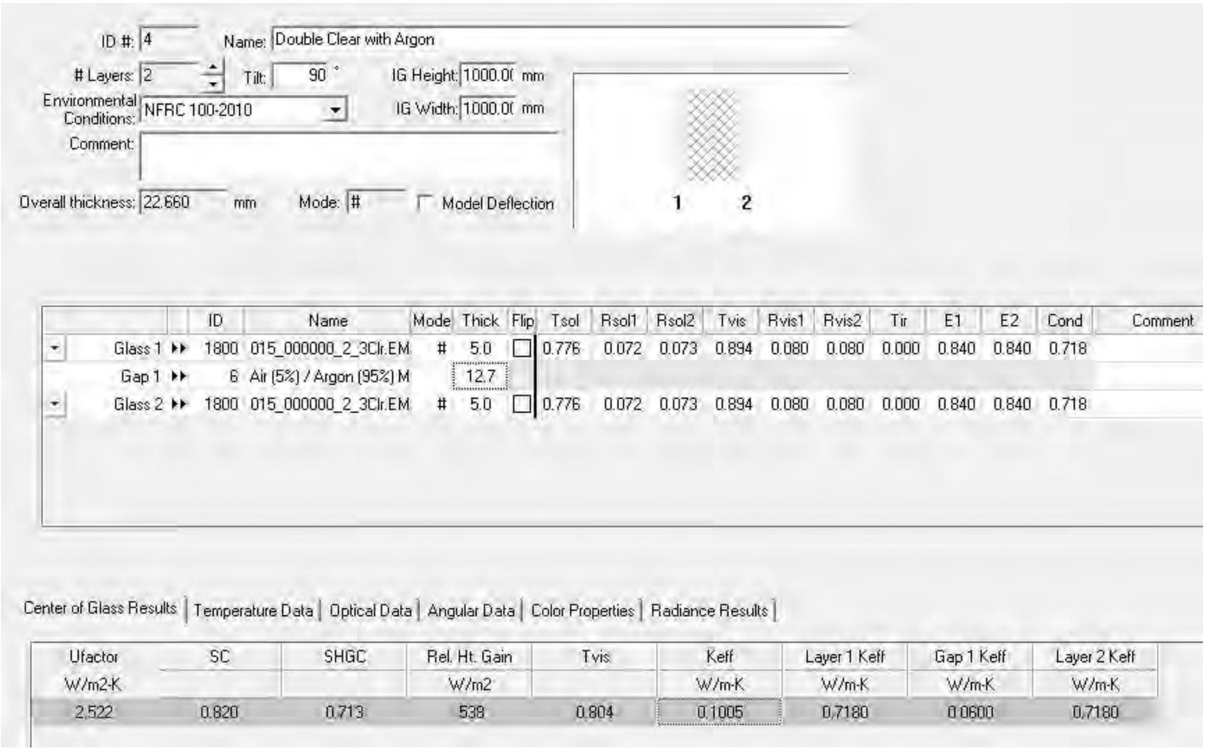
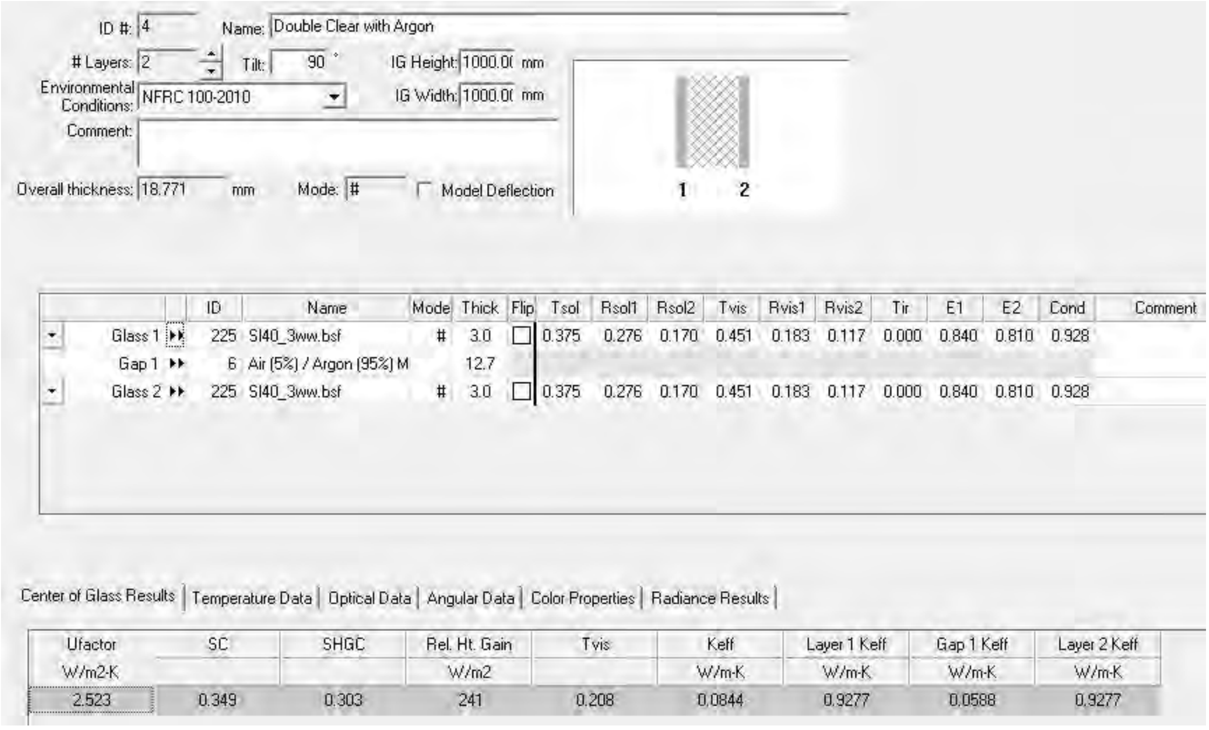


Figure H129. The characteristic of the glazing system of option number 108 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

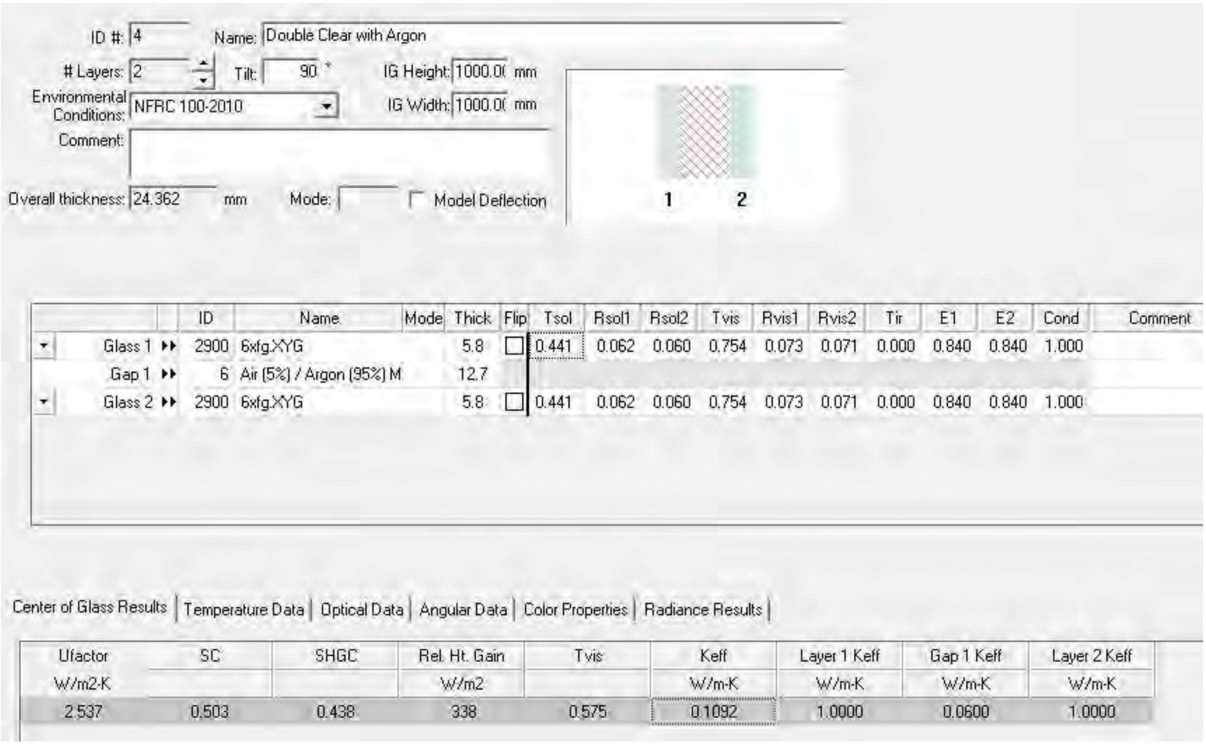


	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	225	SI40_3ww.bsf	#	3.0		0.375	0.276	0.170	0.451	0.183	0.117	0.000	0.840	0.810	0.928	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	225	SI40_3ww.bsf	#	3.0		0.375	0.276	0.170	0.451	0.183	0.117	0.000	0.840	0.810	0.928	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.523	0.349	0.303	241	0.208	0.0844	0.9277	0.0588	0.9277

Figure H130. The characteristic of the glazing system of option number 109 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	2900	6xfg.XYG		5.8		0.441	0.062	0.060	0.754	0.073	0.071	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	2900	6xfg.XYG		5.8		0.441	0.062	0.060	0.754	0.073	0.071	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.537	0.503	0.438	338	0.575	0.1092	1.0000	0.0600	1.0000

Figure H131. The characteristic of the glazing system of option number 110 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

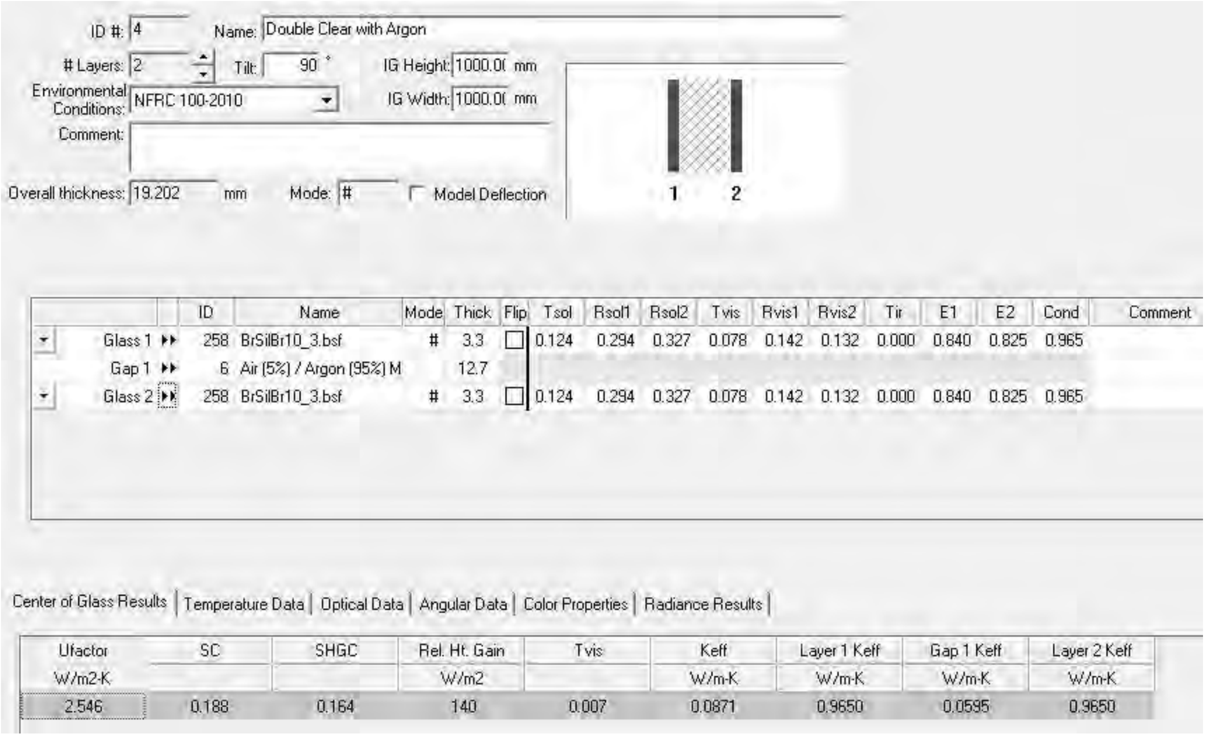


Figure H132. The characteristic of the glazing system of option number 111 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

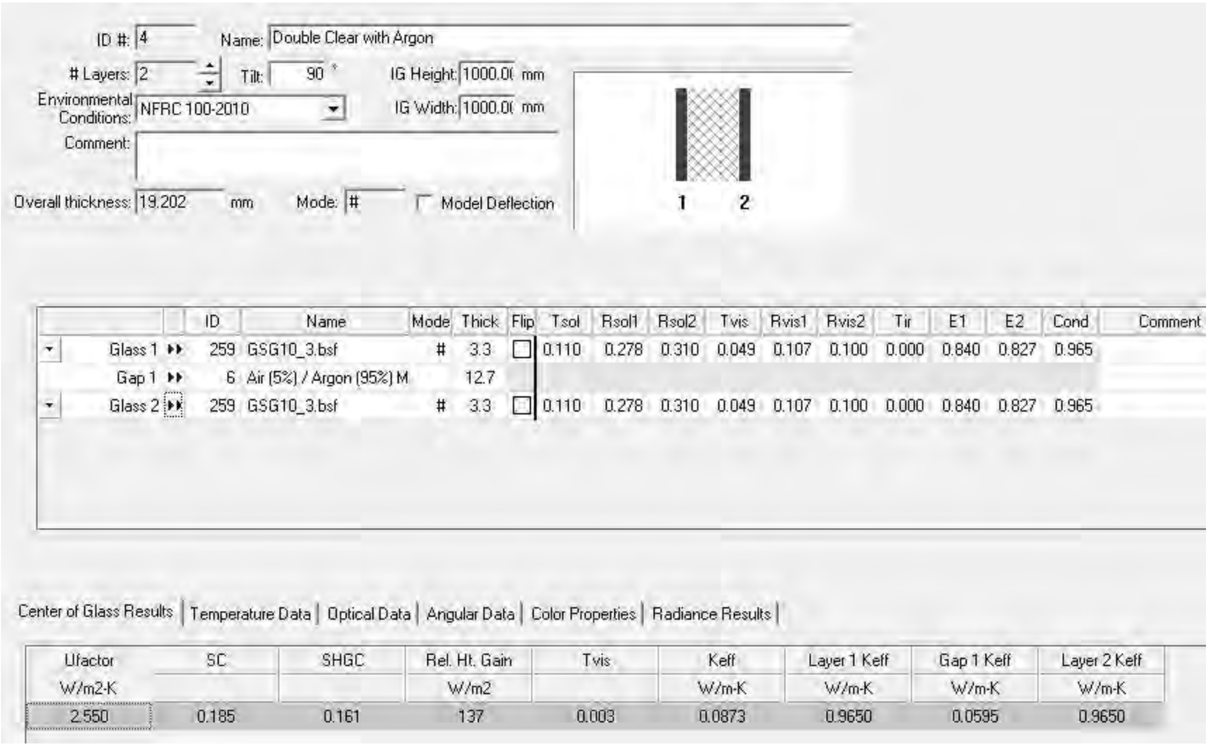
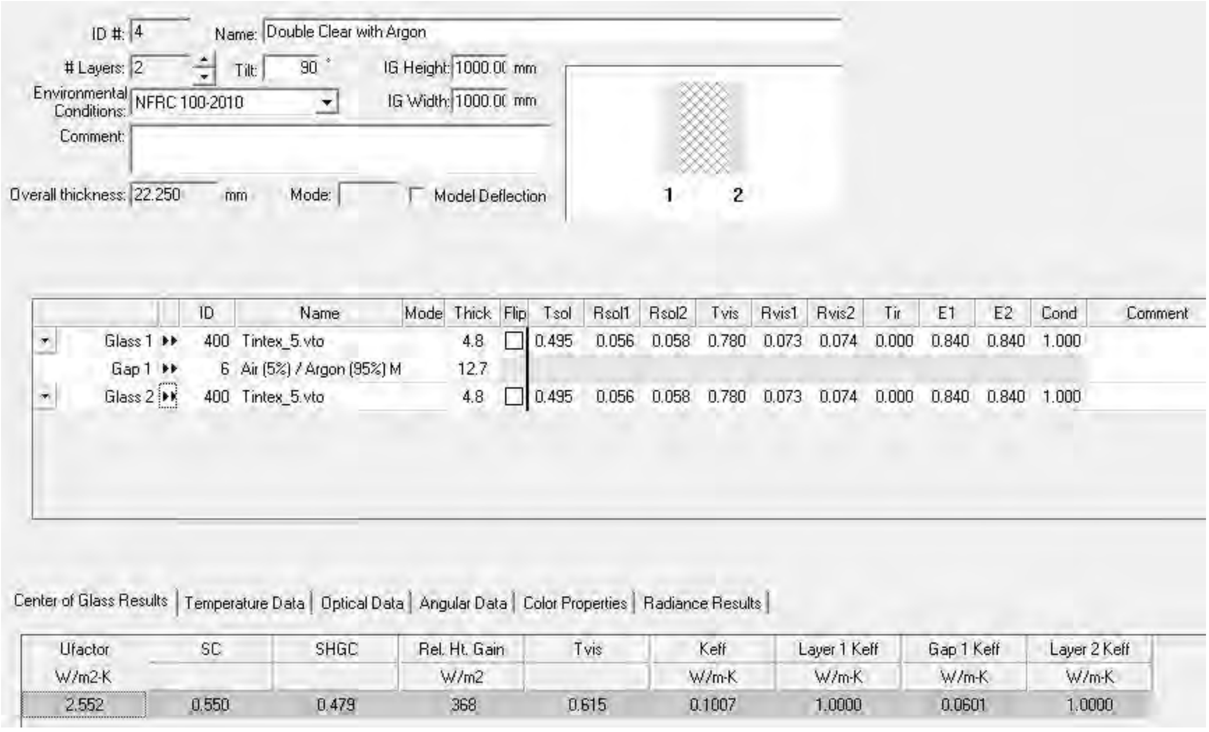


Figure H133. The characteristic of the glazing system of option number 112 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

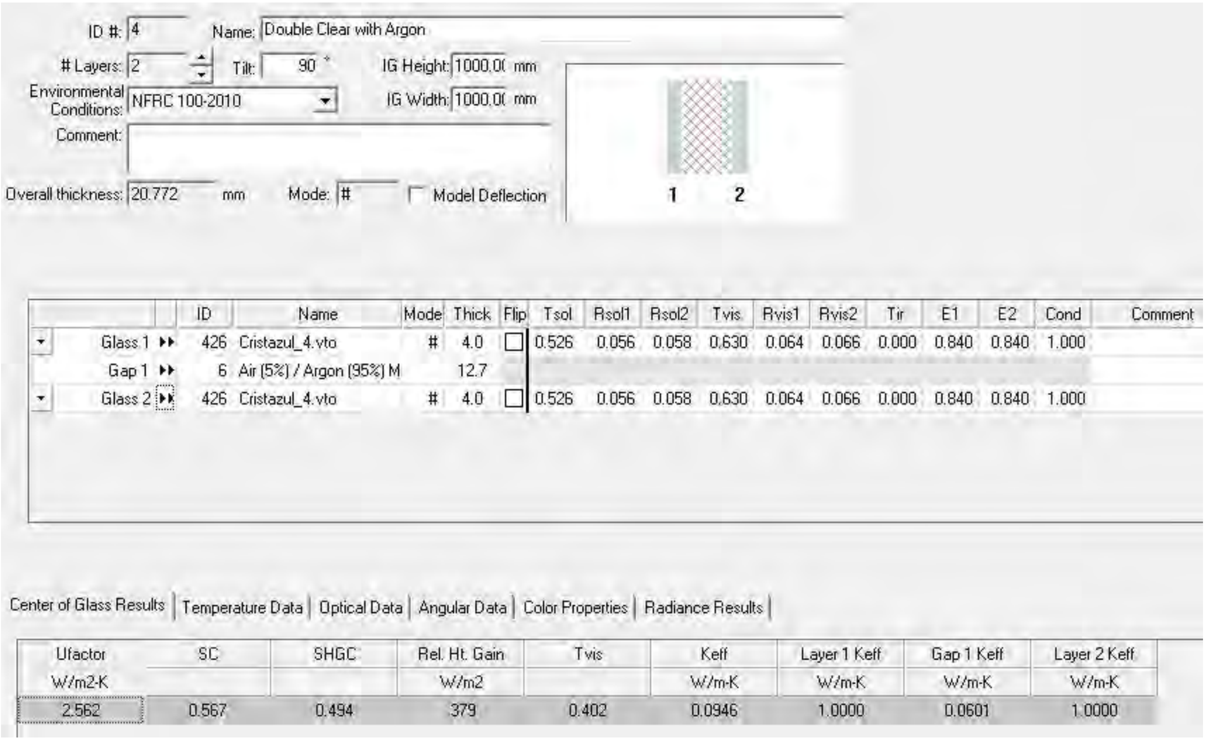

ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 22.250 mm Mode: Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	400	Tintex_5.vto		4.8		0.495	0.056	0.058	0.780	0.073	0.074	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	400	Tintex_5.vto		4.8		0.495	0.056	0.058	0.780	0.073	0.074	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.552	0.550	0.479	368	0.615	0.1007	1.0000	0.0601	1.0000

Figure H134. The characteristic of the glazing system of option number 113 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

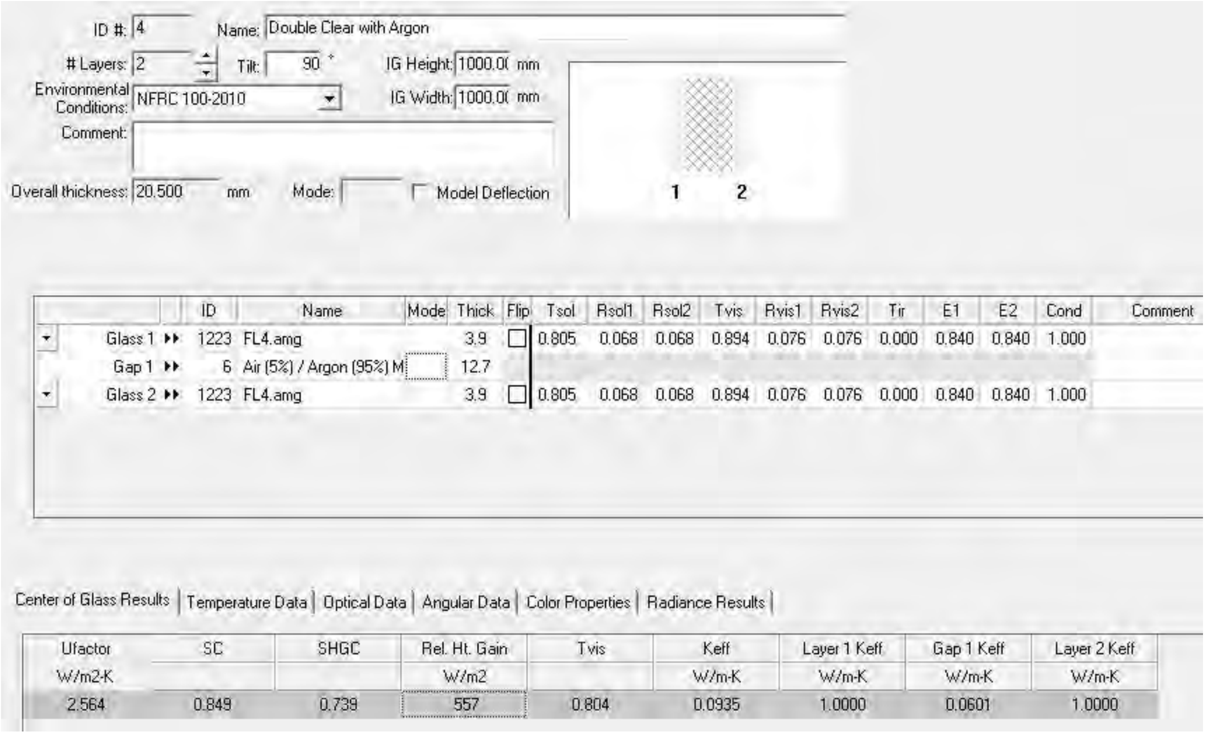

ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 20.772 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	426	Cristazul_4.vto	#	4.0		0.526	0.056	0.058	0.630	0.064	0.066	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	426	Cristazul_4.vto	#	4.0		0.526	0.056	0.058	0.630	0.064	0.066	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.562	0.567	0.494	379	0.402	0.0946	1.0000	0.0601	1.0000

Figure H135. The characteristic of the glazing system of option number 114 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



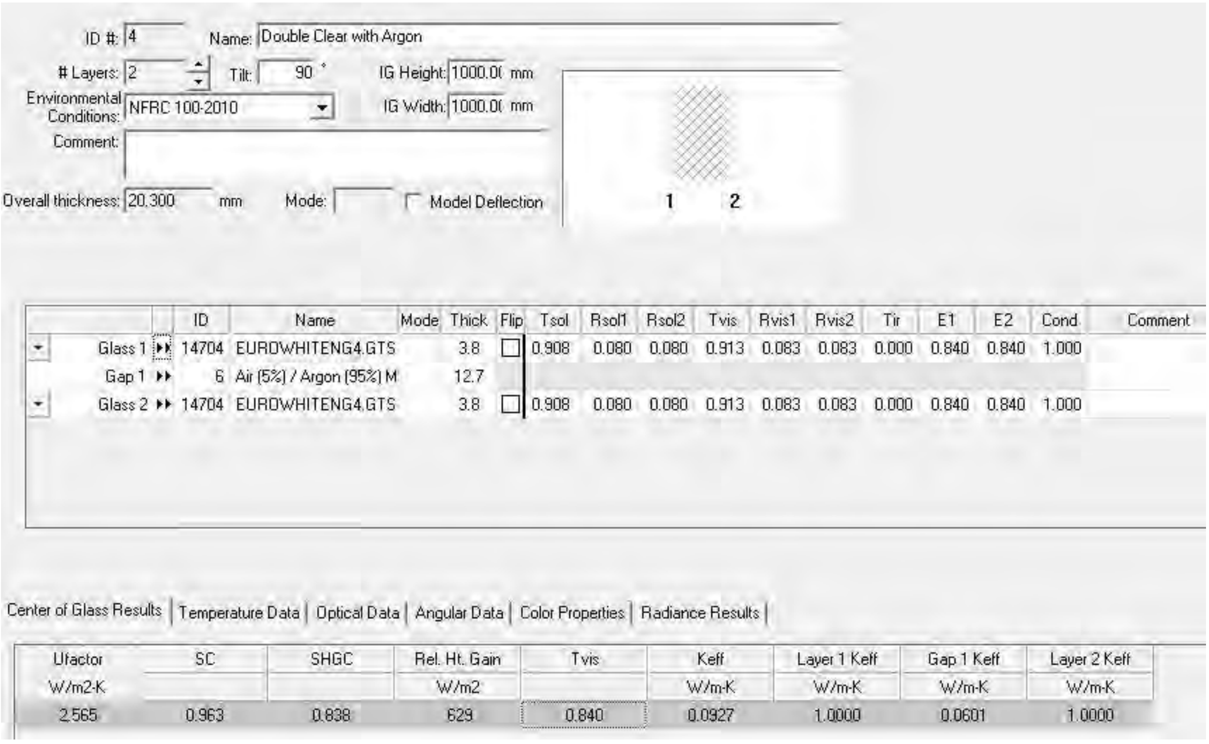
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 20.500 mm Mode: Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1223	FL4.amg		3.9		0.805	0.068	0.068	0.894	0.076	0.076	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	1223	FL4.amg		3.9		0.805	0.068	0.068	0.894	0.076	0.076	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.564	0.849	0.739	557	0.804	0.0935	1.0000	0.0601	1.0000

Figure H136. The characteristic of the glazing system of option number 115 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



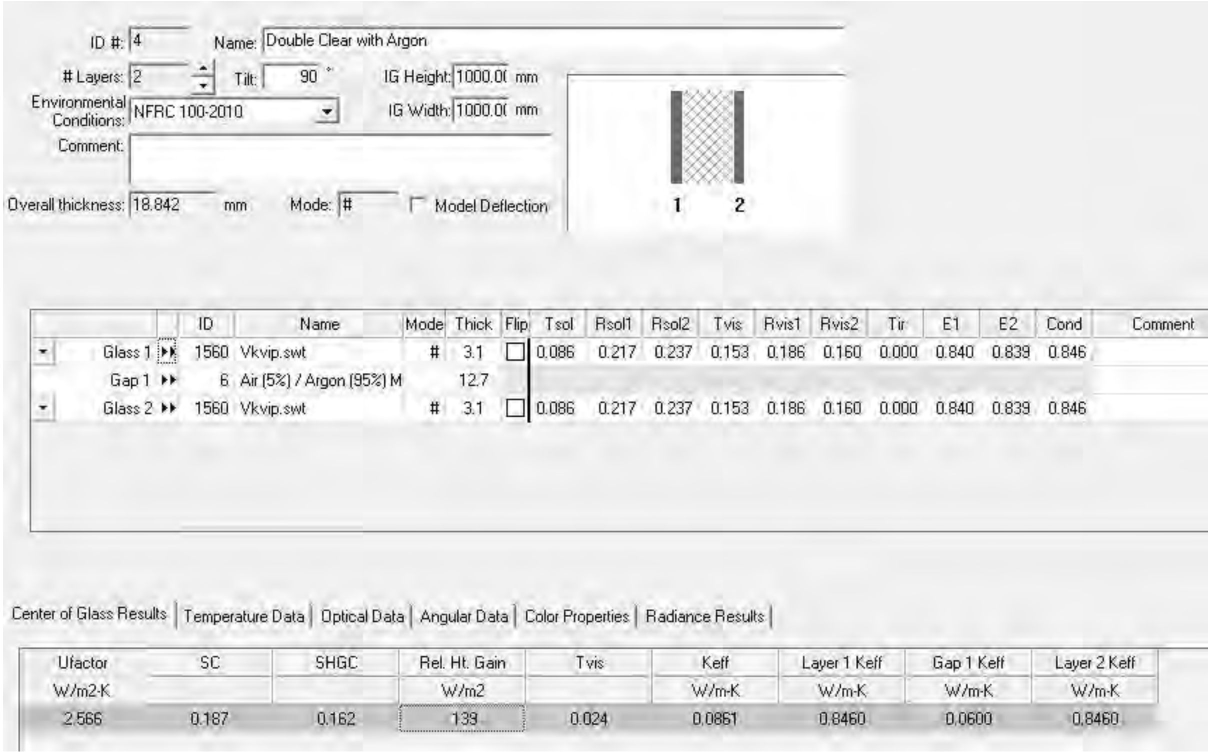
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 20.300 mm Mode: Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	14704	EUROWHITENG4.GTS		3.8		0.908	0.080	0.080	0.913	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	14704	EUROWHITENG4.GTS		3.8		0.908	0.080	0.080	0.913	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.565	0.963	0.838	629	0.840	0.0927	1.0000	0.0601	1.0000

Figure H137. The characteristic of the glazing system of option number 116 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



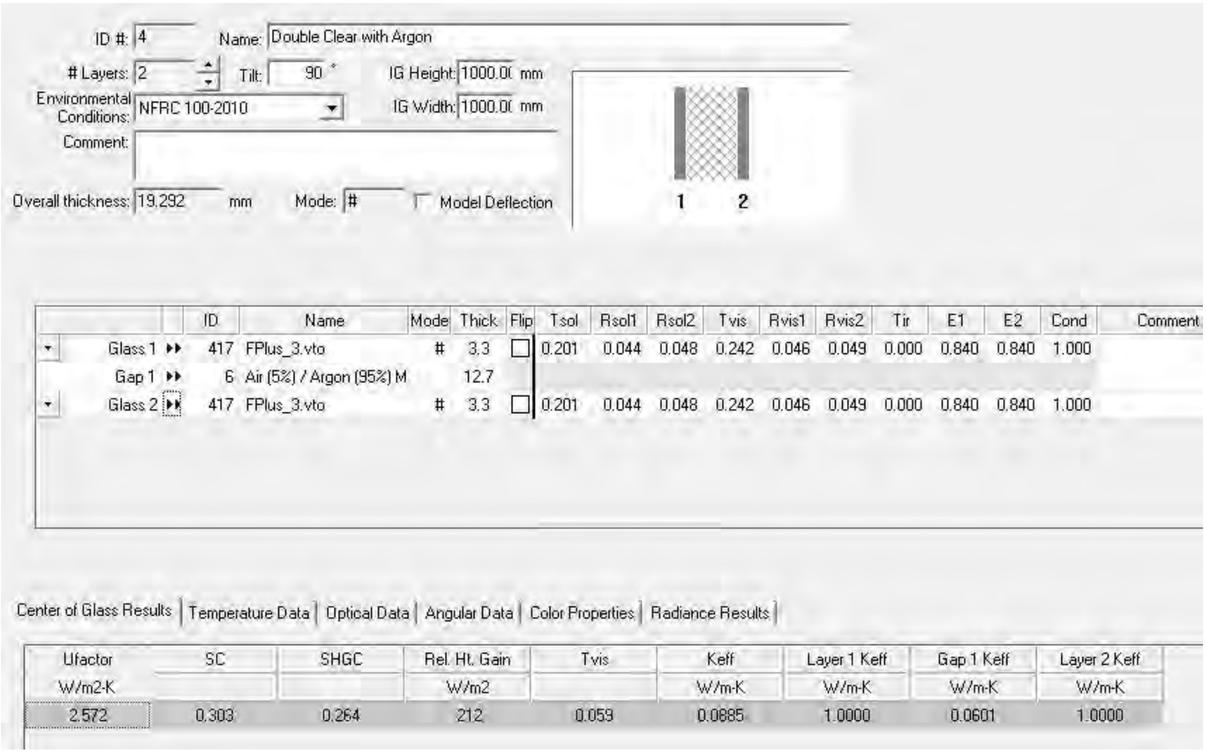
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.842 mm Mode: # Model Deflection
1 2

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
	Glass 1	1560	Vkvip.swt	#	3.1	☐	0.086	0.217	0.237	0.153	0.186	0.160	0.000	0.840	0.839	0.846	
	Gap 1	6	Air (5%) / Argon (95%) M		12.7												
	Glass 2	1560	Vkvip.swt	#	3.1	☐	0.086	0.217	0.237	0.153	0.186	0.160	0.000	0.840	0.839	0.846	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.566	0.187	0.162	139	0.024	0.0861	0.8460	0.0600	0.8460

Figure H138. The characteristic of the glazing system of option number 117 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



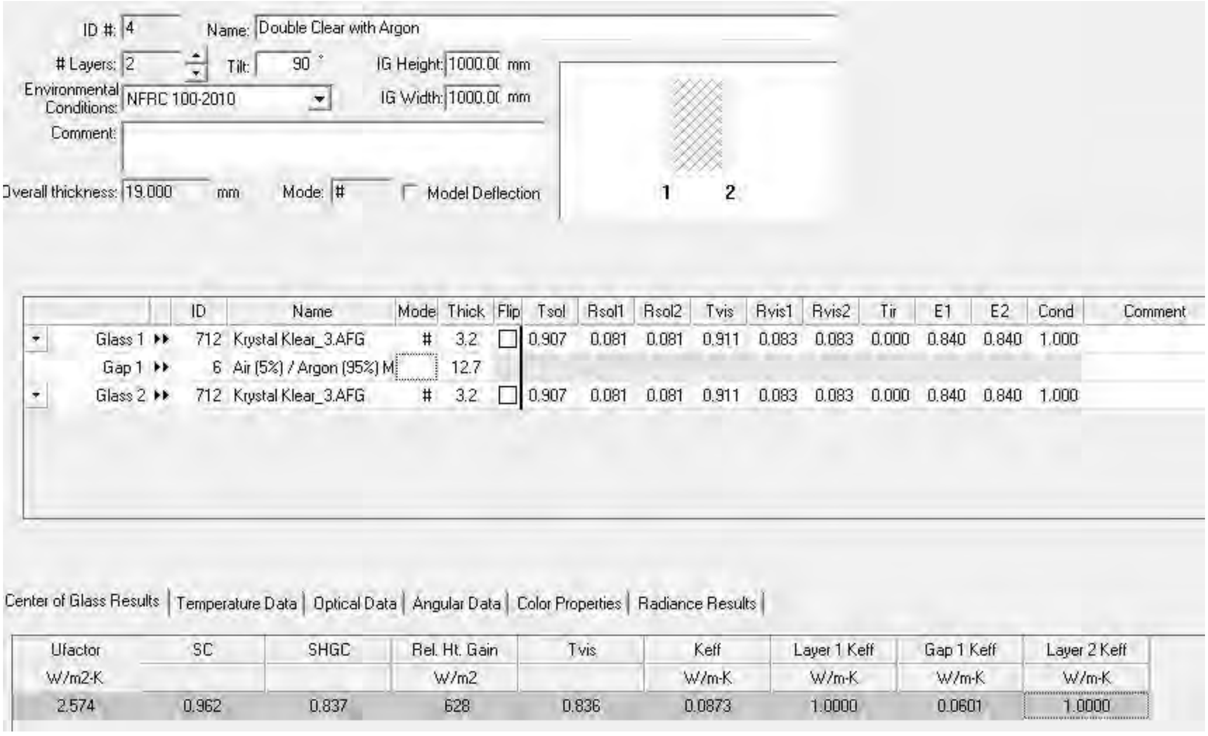
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 19.292 mm Mode: # Model Deflection
1 2

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
	Glass 1	417	FPlus_3.vto	#	3.3	☐	0.201	0.044	0.048	0.242	0.046	0.049	0.000	0.840	0.840	1.000	
	Gap 1	6	Air (5%) / Argon (95%) M		12.7												
	Glass 2	417	FPlus_3.vto	#	3.3	☐	0.201	0.044	0.048	0.242	0.046	0.049	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.572	0.303	0.264	212	0.059	0.0885	1.0000	0.0601	1.0000

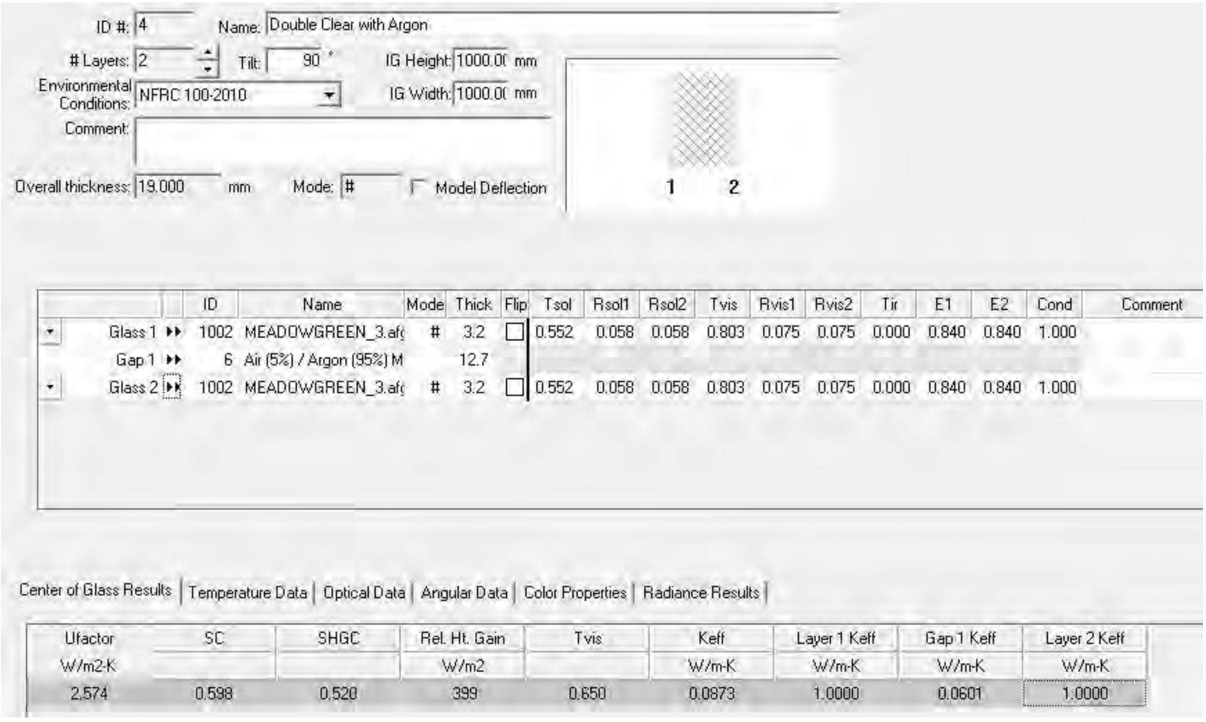
Figure H139. The characteristic of the glazing system of option number 118 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	712	Krystal Klear_3.AFG	#	3.2		0.907	0.081	0.081	0.911	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	712	Krystal Klear_3.AFG	#	3.2		0.907	0.081	0.081	0.911	0.083	0.083	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.574	0.962	0.837	628	0.836	0.0873	1.0000	0.0601	1.0000

Figure H140. The characteristic of the glazing system of option number 119 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1002	MEADOWGREEN_3.af(	#	3.2		0.552	0.058	0.058	0.803	0.075	0.075	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	1002	MEADOWGREEN_3.af(	#	3.2		0.552	0.058	0.058	0.803	0.075	0.075	0.000	0.840	0.840	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.574	0.598	0.520	399	0.650	0.0873	1.0000	0.0601	1.0000

Figure H141. The characteristic of the glazing system of option number 120 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

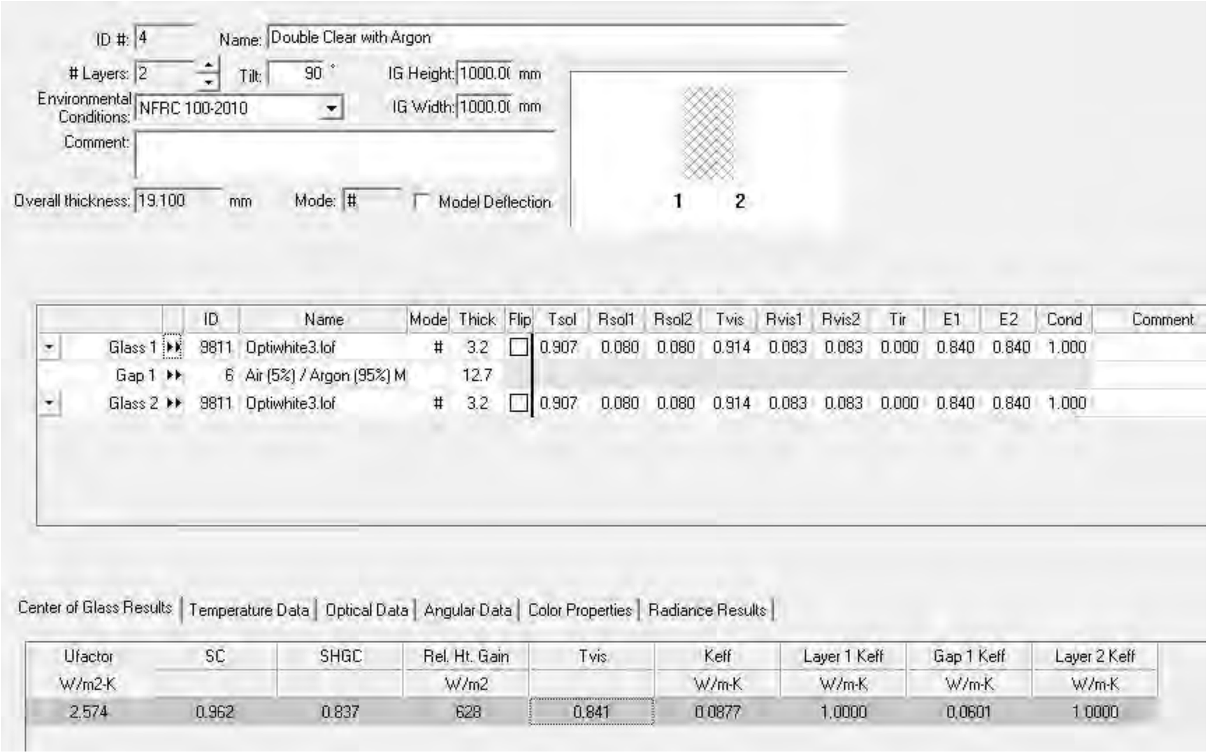


Figure H142. The characteristic of the glazing system of option number 121 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

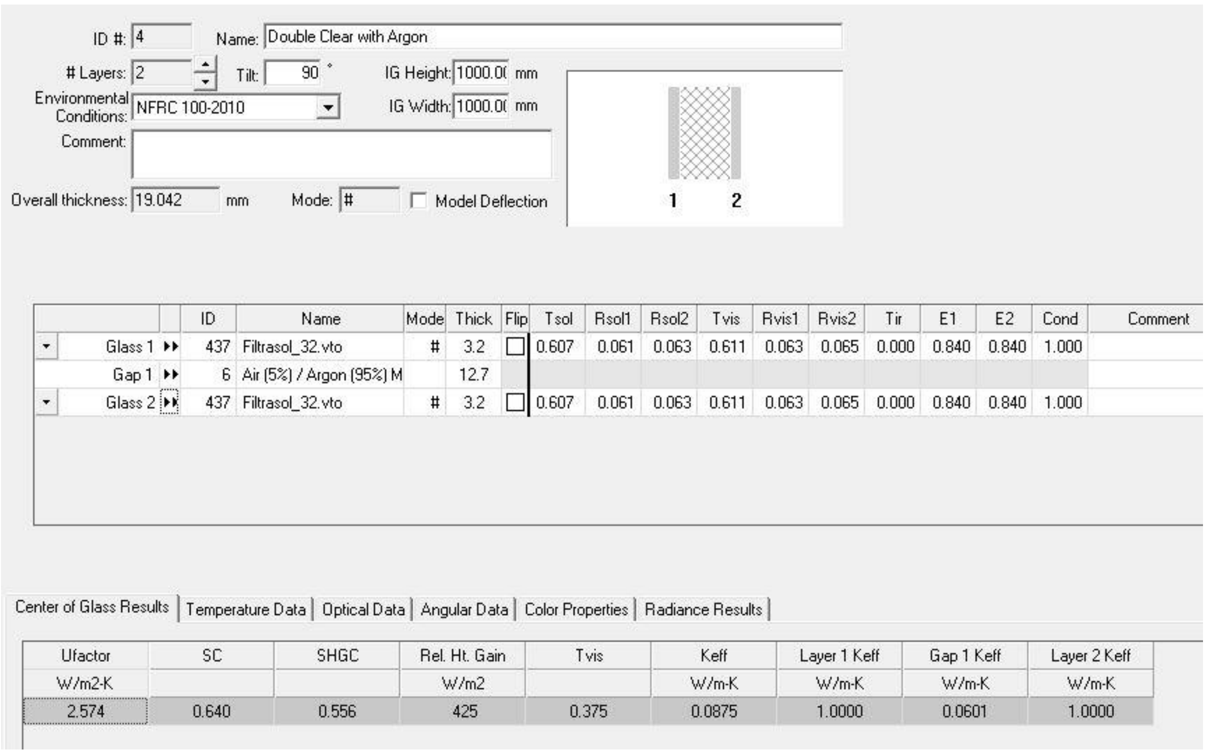
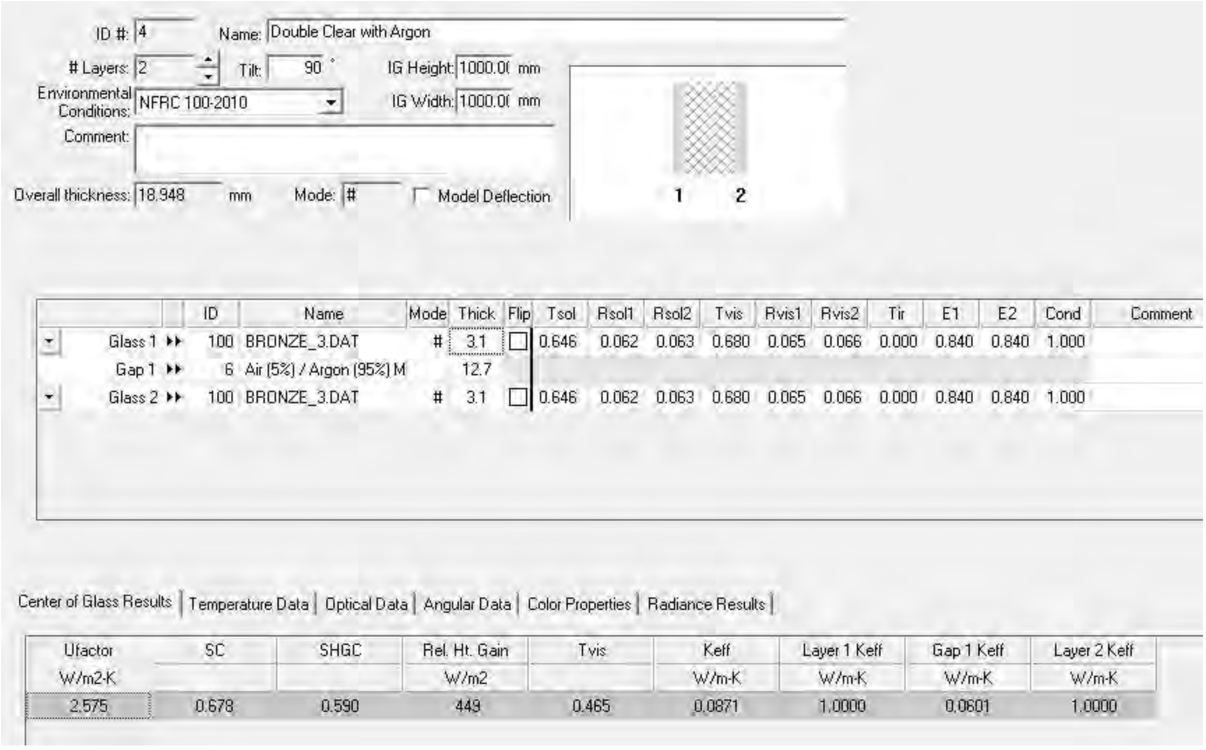


Figure H143. The characteristic of the glazing system of option number 122 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

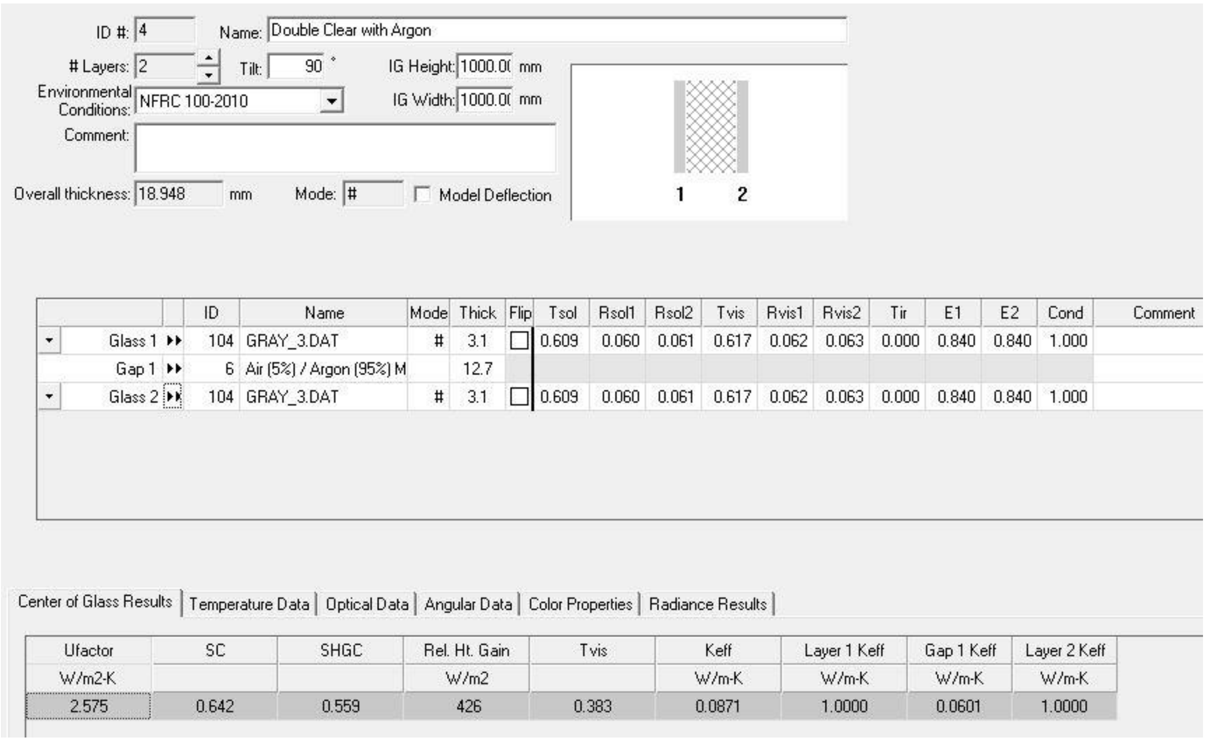


	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1 ▸▸	100	BRONZE_3.DAT	#	3.1	☐	0.646	0.062	0.063	0.680	0.065	0.066	0.000	0.840	0.840	1.000	
Gap 1 ▸▸	6	Air (5%) / Argon (95%) M		12.7												
Glass 2 ▸▸	100	BRONZE_3.DAT	#	3.1	☐	0.646	0.062	0.063	0.680	0.065	0.066	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.575	0.678	0.590	449	0.465	0.0871	1.0000	0.0601	1.0000

Figure H144. The characteristic of the glazing system of option number 123 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1 ▸▸	104	GRAY_3.DAT	#	3.1	☐	0.609	0.060	0.061	0.617	0.062	0.063	0.000	0.840	0.840	1.000	
Gap 1 ▸▸	6	Air (5%) / Argon (95%) M		12.7												
Glass 2 ▸▸	104	GRAY_3.DAT	#	3.1	☐	0.609	0.060	0.061	0.617	0.062	0.063	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.575	0.642	0.559	426	0.383	0.0871	1.0000	0.0601	1.0000

Figure H145. The characteristic of the glazing system of option number 124 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

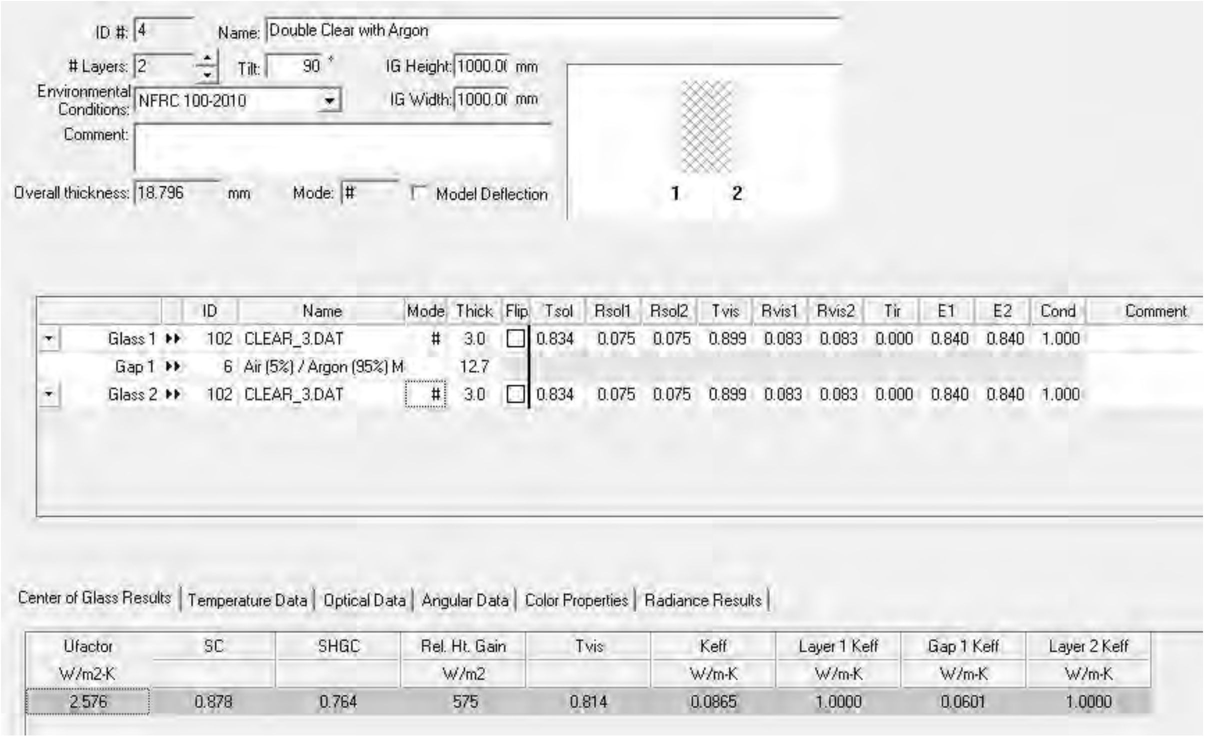


Figure H146. The characteristic of the glazing system of option number 125 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

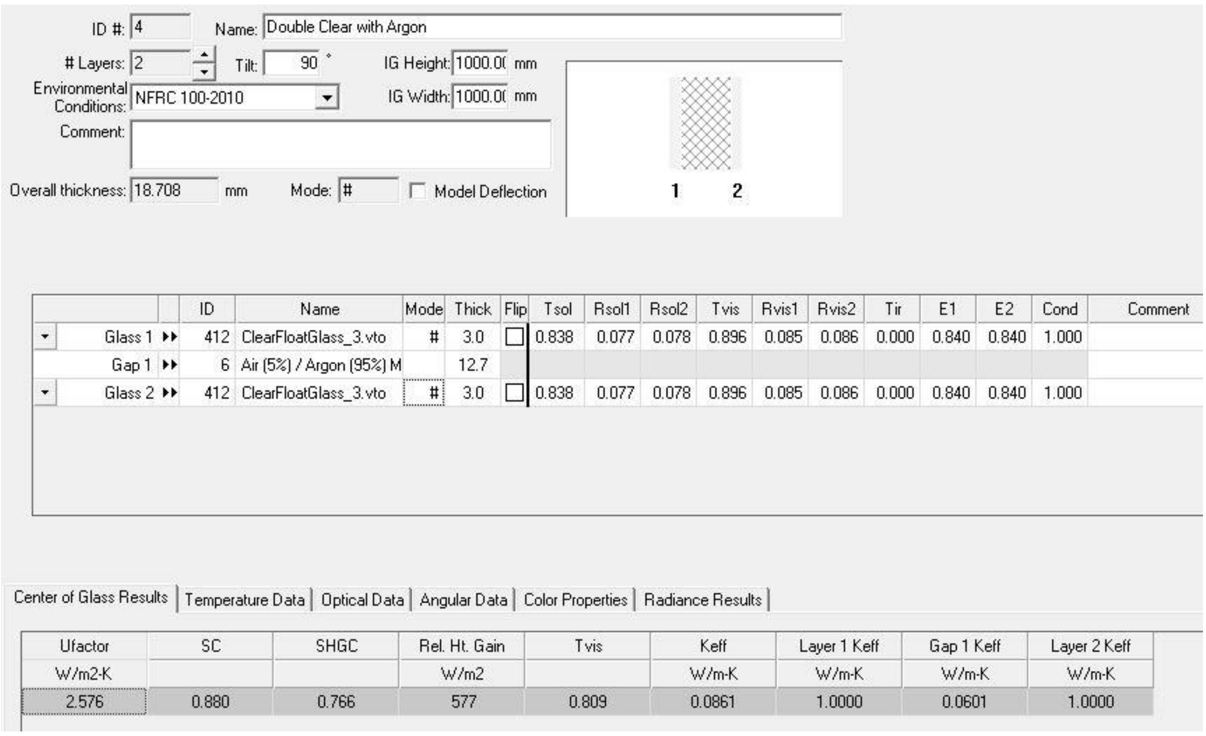
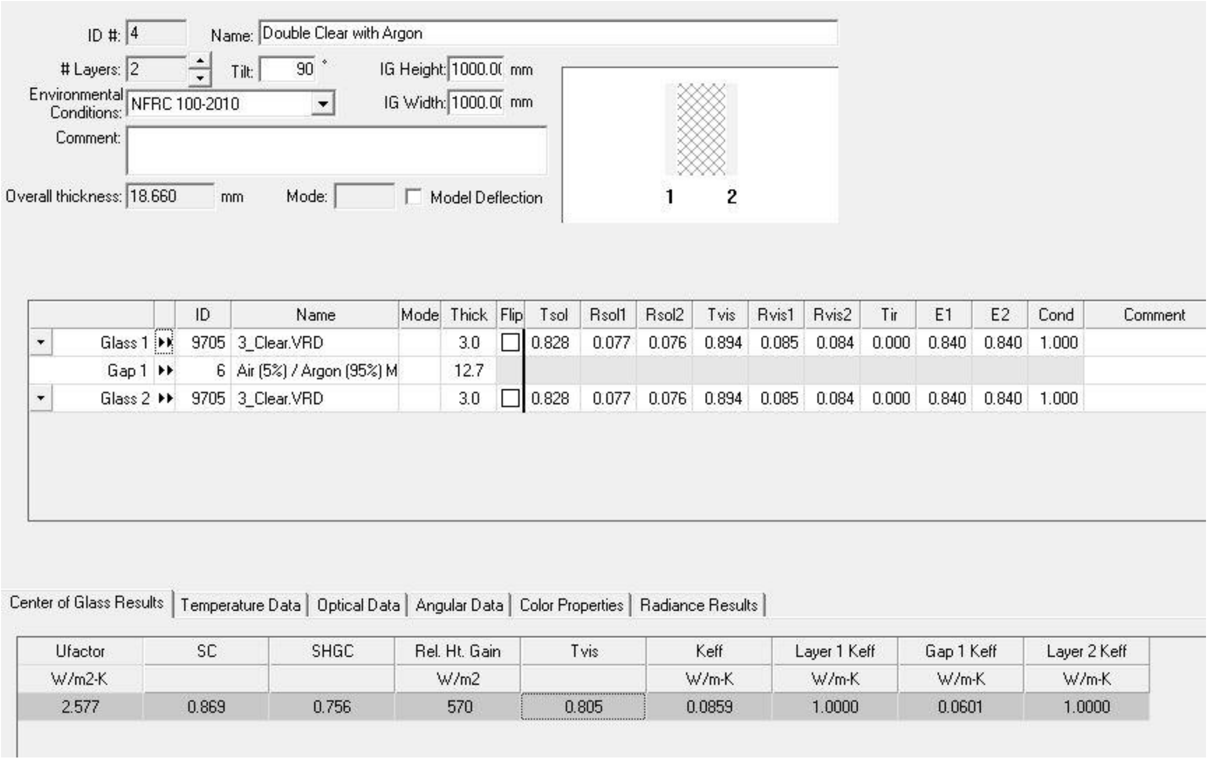


Figure H147. The characteristic of the glazing system of option number 126 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



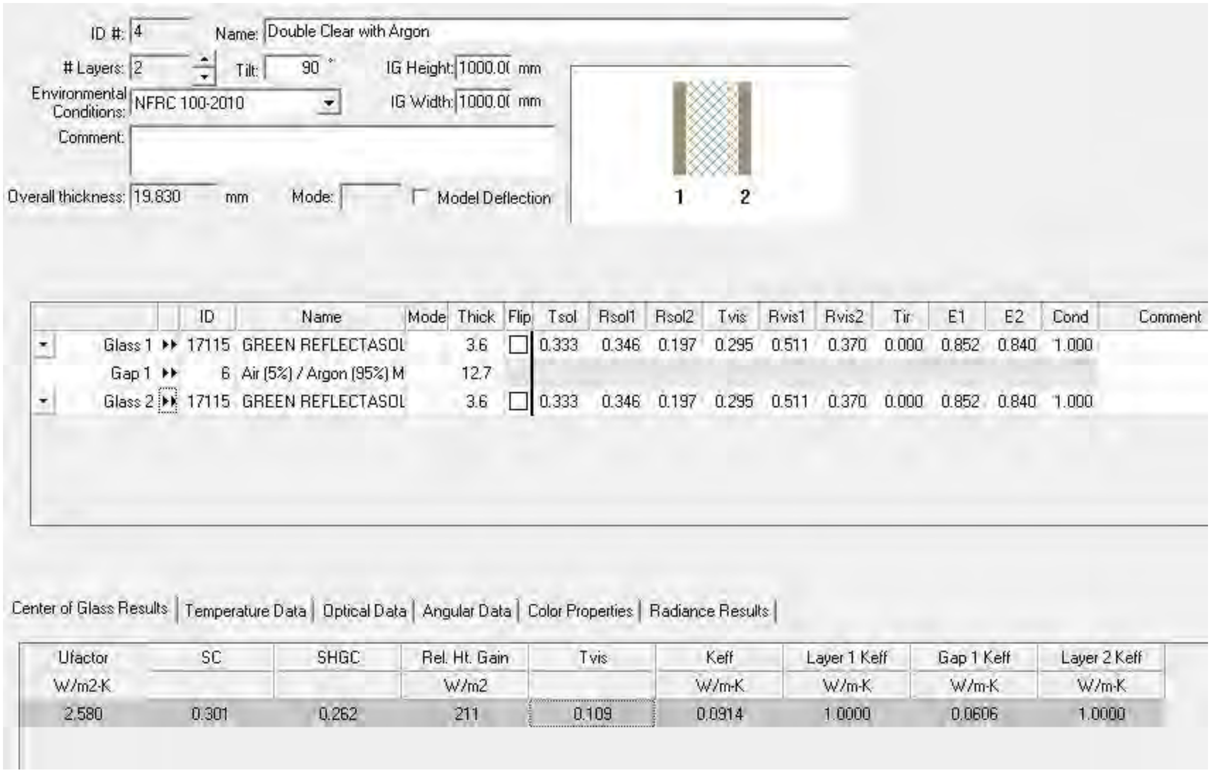
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.660 mm Mode: Model Deflection

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	▸▸	9705	3_Clear.VRD		3.0	☐	0.828	0.077	0.076	0.894	0.085	0.084	0.000	0.840	0.840	1.000	
Gap 1	▸▸	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	▸▸	9705	3_Clear.VRD		3.0	☐	0.828	0.077	0.076	0.894	0.085	0.084	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.577	0.869	0.756	570	0.805	0.0859	1.0000	0.0601	1.0000

Figure H148. The characteristic of the glazing system of option number 127 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



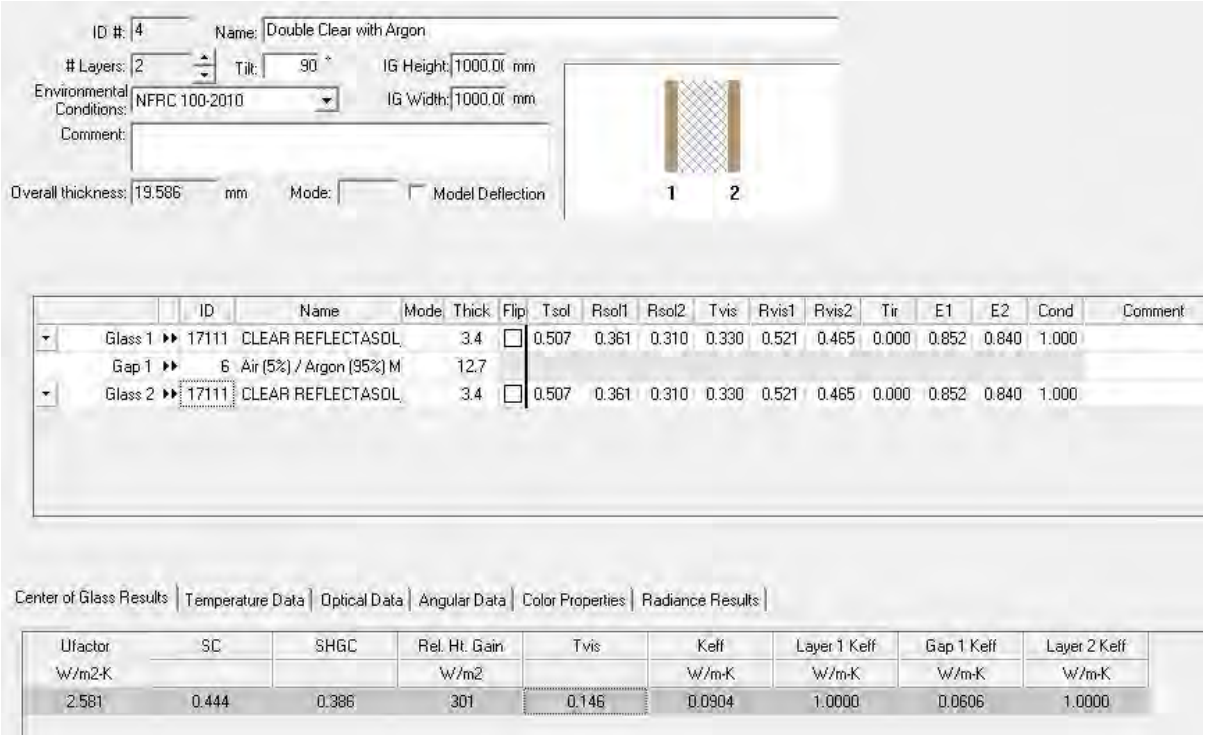
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 19.830 mm Mode: Model Deflection

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	▸▸	17115	GREEN REFLECTASOL		3.6	☐	0.333	0.346	0.197	0.295	0.511	0.370	0.000	0.852	0.840	1.000	
Gap 1	▸▸	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	▸▸	17115	GREEN REFLECTASOL		3.6	☐	0.333	0.346	0.197	0.295	0.511	0.370	0.000	0.852	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.580	0.301	0.262	211	0.109	0.0914	1.0000	0.0606	1.0000

Figure H149. The characteristic of the glazing system of option number 128 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

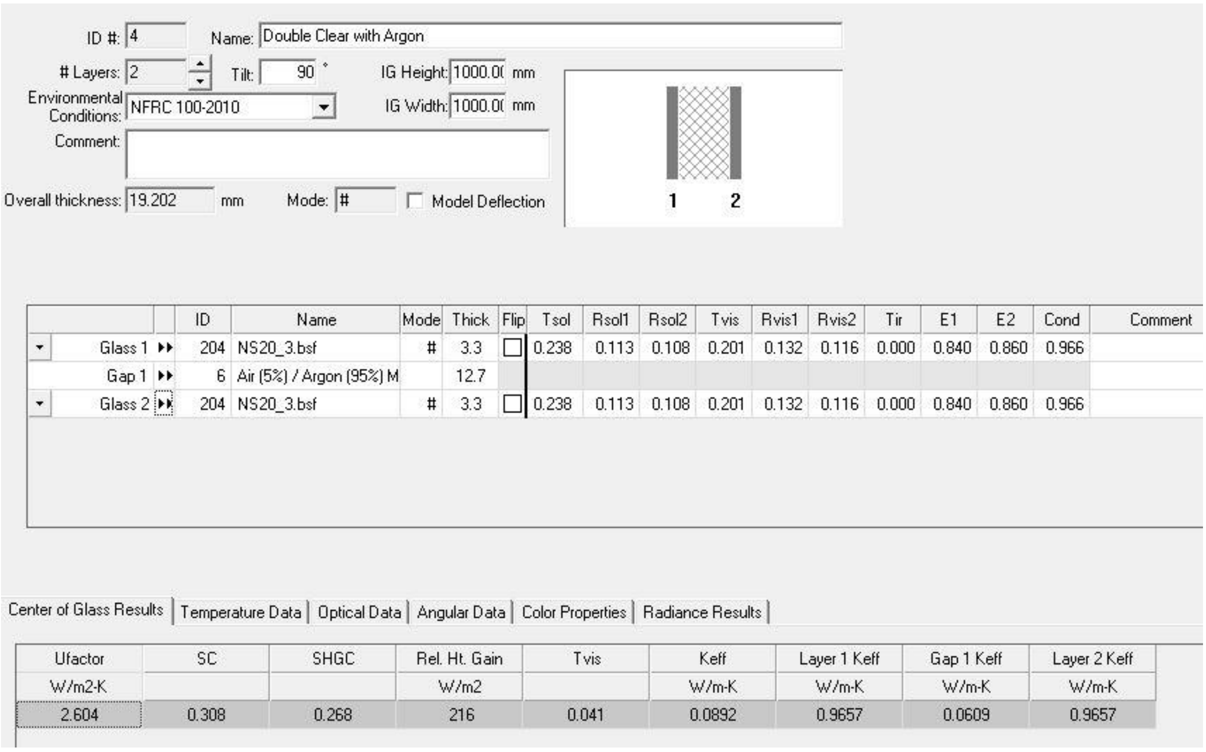


	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	17111	CLEAR REFLECTASOL		3.4	☐	0.507	0.361	0.310	0.330	0.521	0.465	0.000	0.852	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	17111	CLEAR REFLECTASOL		3.4	☐	0.507	0.361	0.310	0.330	0.521	0.465	0.000	0.852	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.581	0.444	0.386	301	0.146	0.0904	1.0000	0.0606	1.0000

Figure H150. The characteristic of the glazing system of option number 129 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	204	NS20_3.bsf	#	3.3	☐	0.238	0.113	0.108	0.201	0.132	0.116	0.000	0.840	0.860	0.966	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	204	NS20_3.bsf	#	3.3	☐	0.238	0.113	0.108	0.201	0.132	0.116	0.000	0.840	0.860	0.966	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.604	0.308	0.268	216	0.041	0.0892	0.9657	0.0609	0.9657

Figure H151. The characteristic of the glazing system of option number 130 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

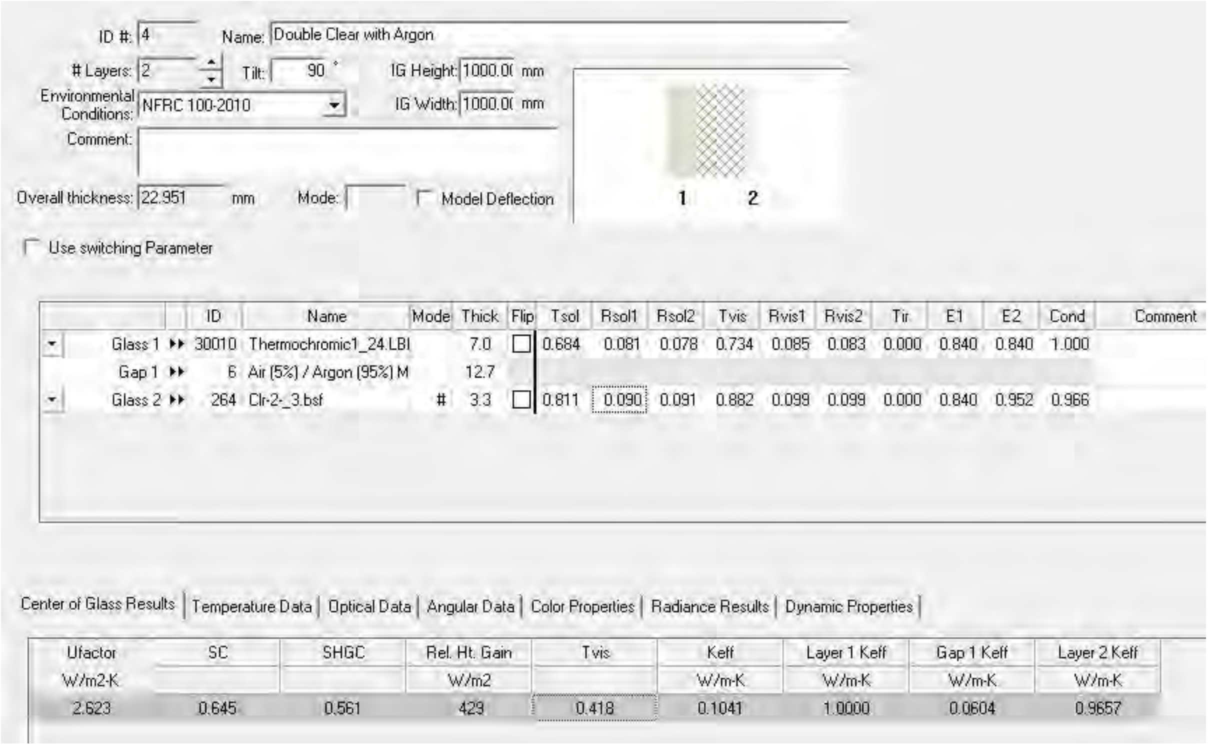


Figure H152. The characteristic of the glazing system of option number 131 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

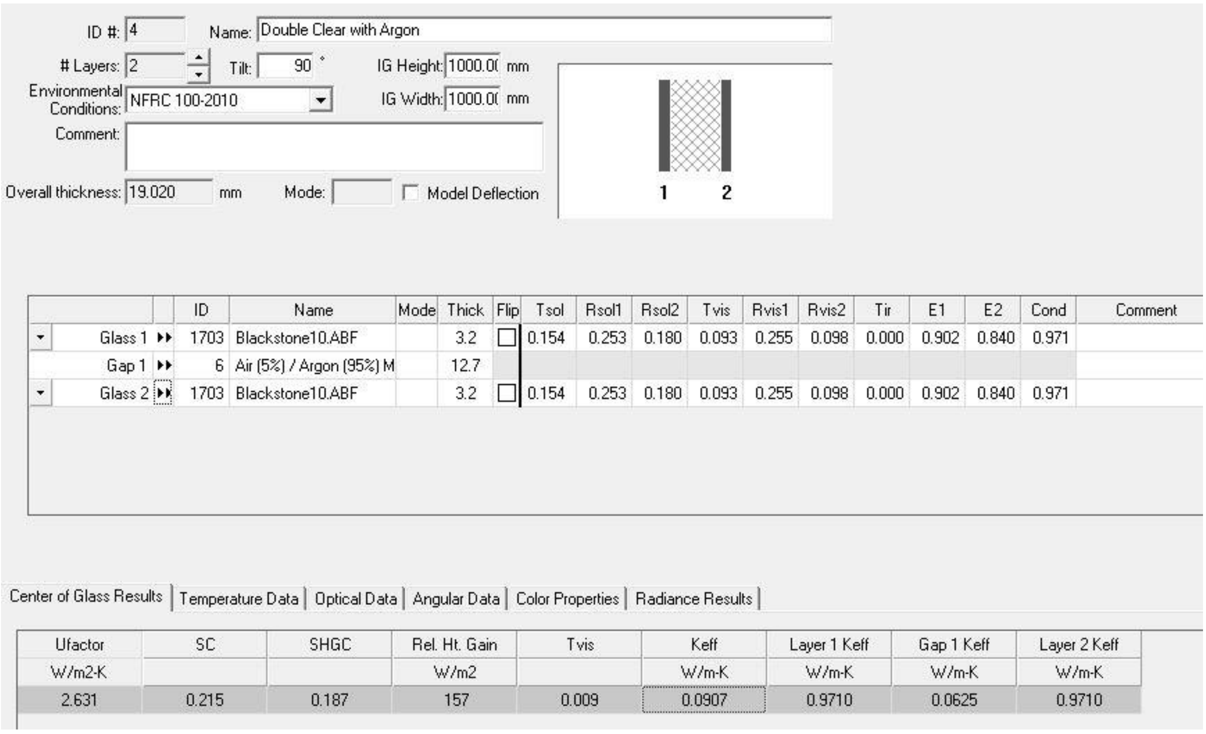


Figure H153. The characteristic of the glazing system of option number 132 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

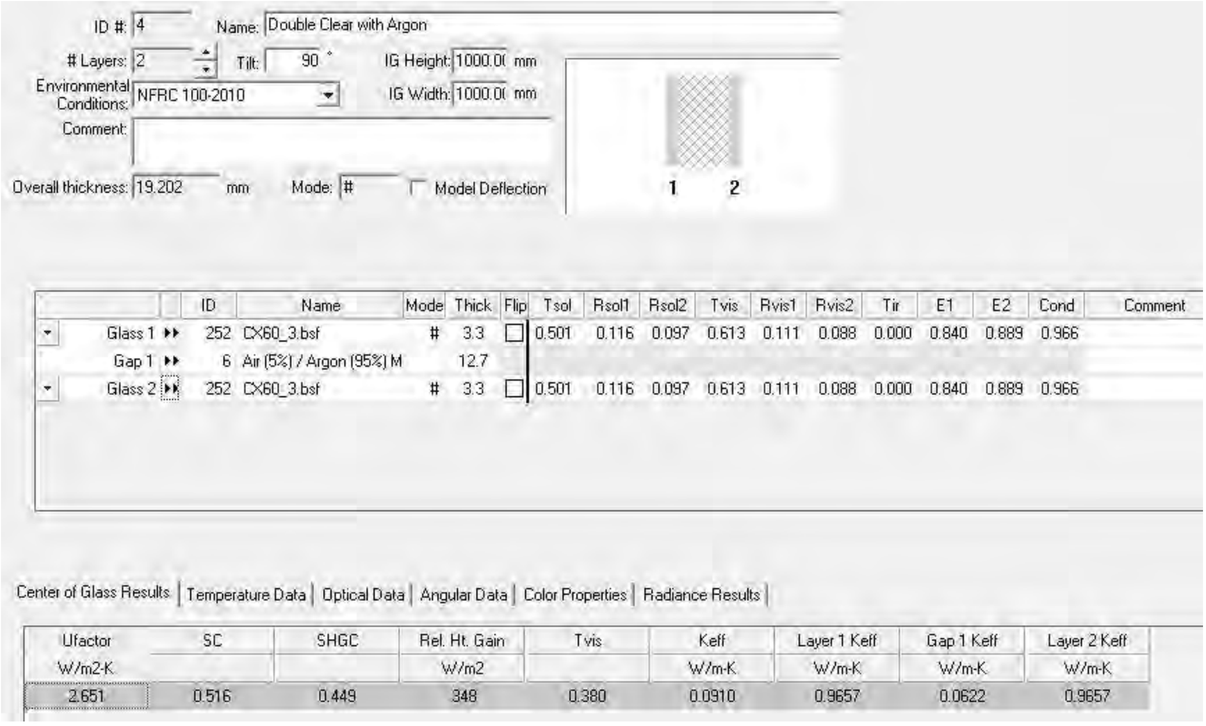


Figure H154. The characteristic of the glazing system of option number 133 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

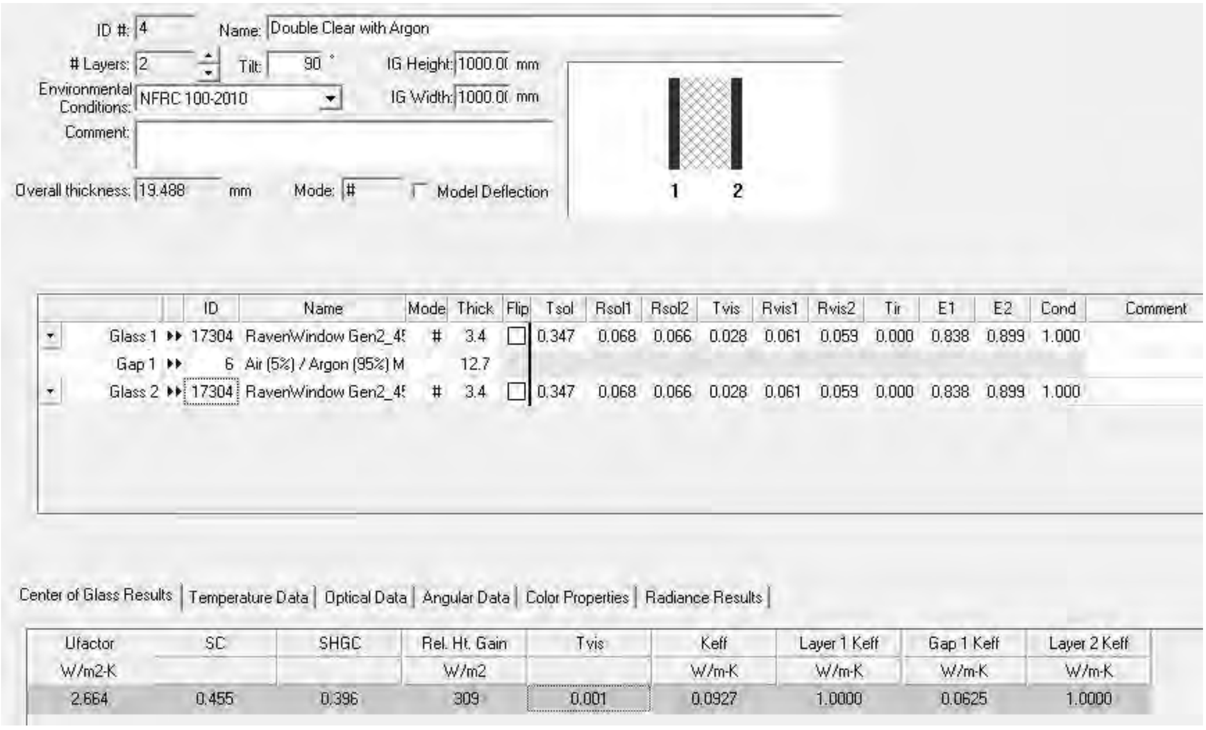
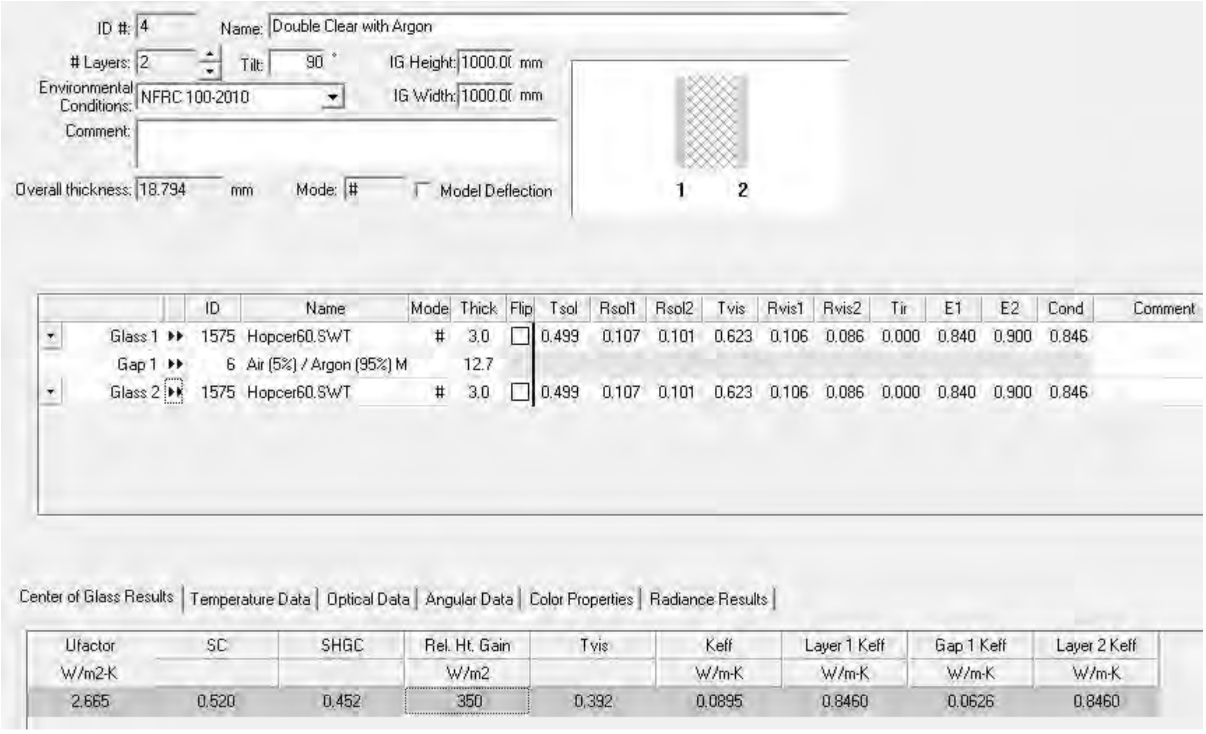


Figure H155. The characteristic of the glazing system of option number 134 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



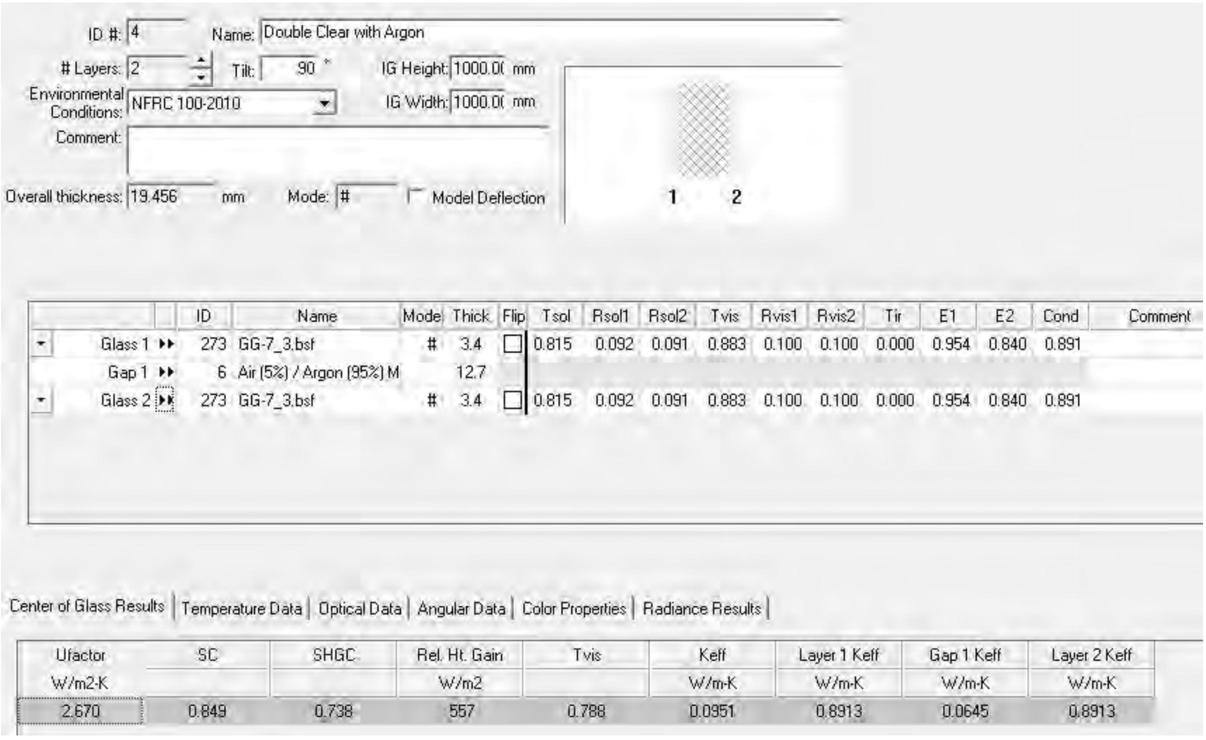
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 18.794 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1575	Hopcer60.SWT	#	3.0		0.499	0.107	0.101	0.623	0.106	0.086	0.000	0.840	0.900	0.846	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	1575	Hopcer60.SWT	#	3.0		0.499	0.107	0.101	0.623	0.106	0.086	0.000	0.840	0.900	0.846	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.665	0.520	0.452	350	0.392	0.0895	0.8460	0.0626	0.8460

Figure H156. The characteristic of the glazing system of option number 135 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



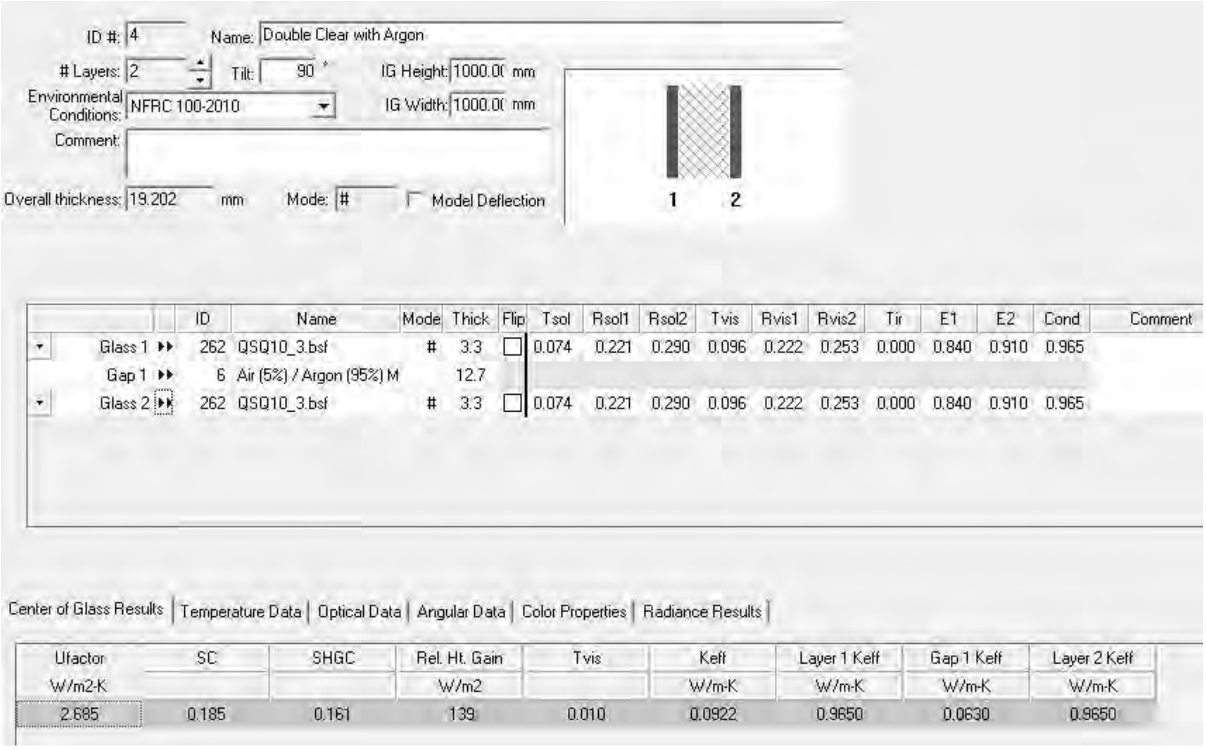
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 19.456 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	273	GG-7_3.bsf	#	3.4		0.815	0.092	0.091	0.883	0.100	0.100	0.000	0.954	0.840	0.891	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	273	GG-7_3.bsf	#	3.4		0.815	0.092	0.091	0.883	0.100	0.100	0.000	0.954	0.840	0.891	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.670	0.849	0.738	557	0.788	0.0951	0.8913	0.0645	0.8913

Figure H157. The characteristic of the glazing system of option number 136 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



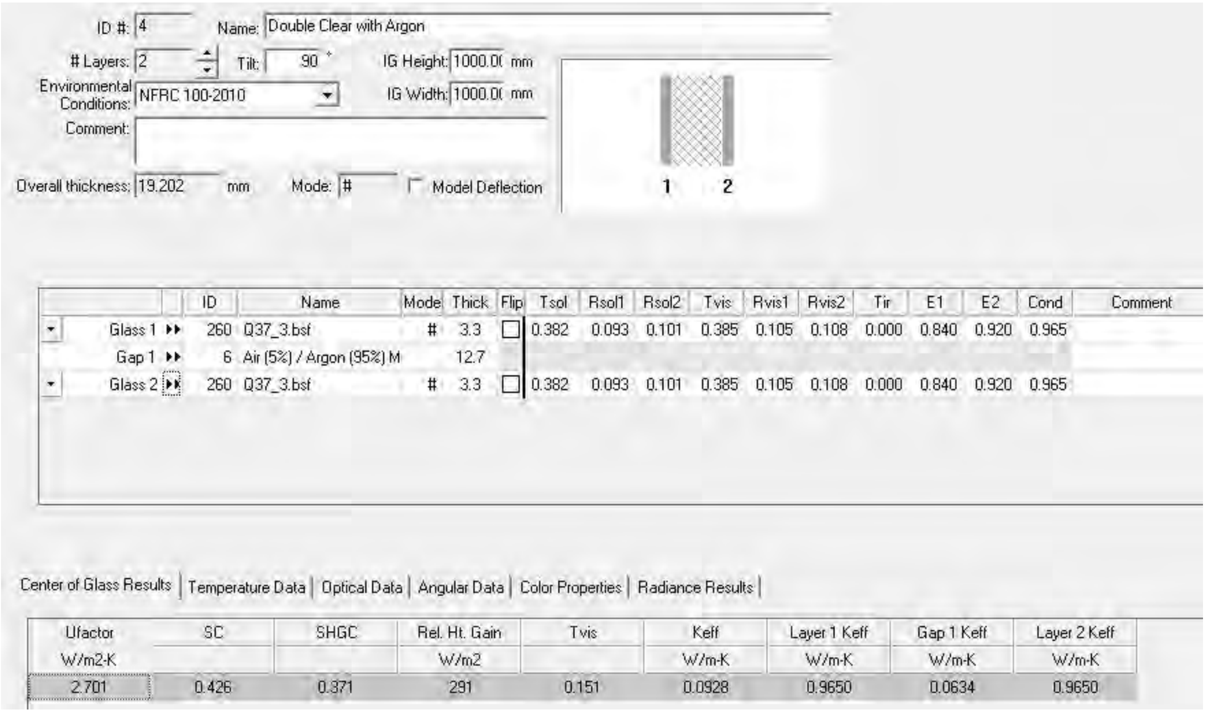
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 19.202 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	262	QSQ10_3.bsf	#	3.3		0.074	0.221	0.290	0.096	0.222	0.253	0.000	0.840	0.910	0.965	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	262	QSQ10_3.bsf	#	3.3		0.074	0.221	0.290	0.096	0.222	0.253	0.000	0.840	0.910	0.965	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.685	0.185	0.161	139	0.010	0.0922	0.9650	0.0630	0.9650

Figure H158. The characteristic of the glazing system of option number 137 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



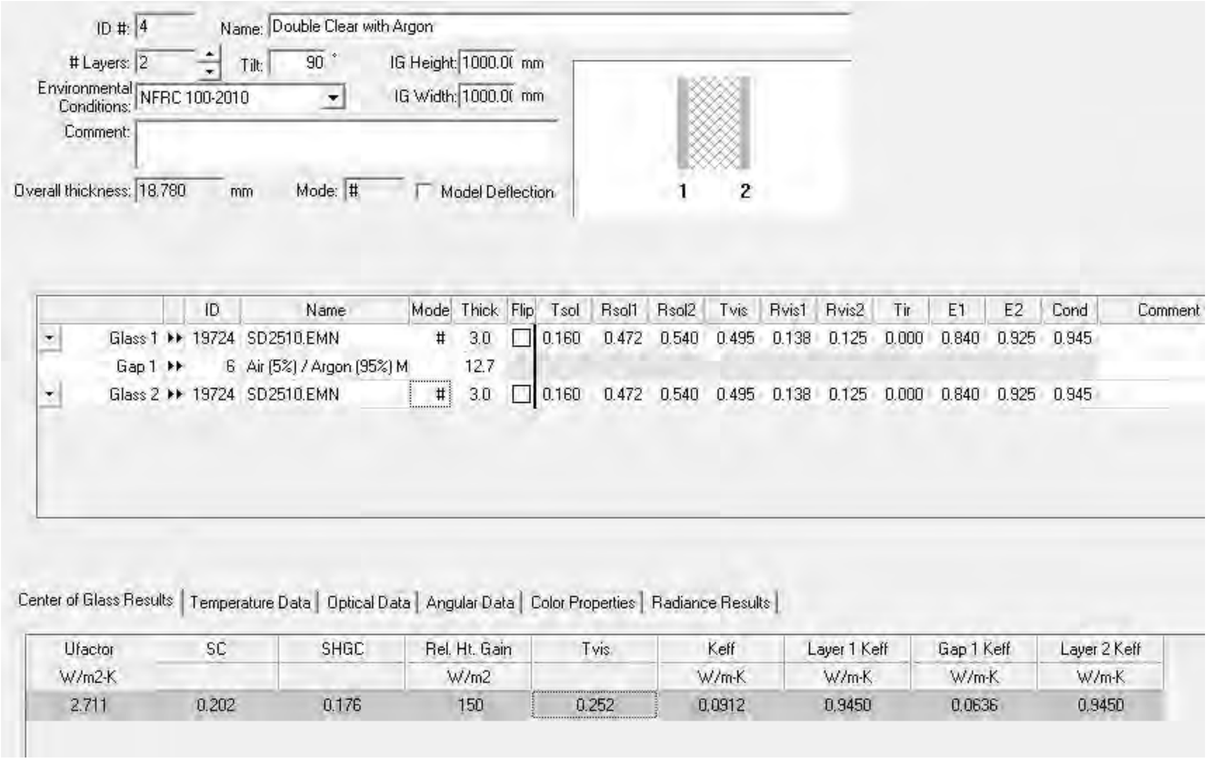
ID #: 4 Name: Double Clear with Argon
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 19.202 mm Mode: # Model Deflection

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	260	Q37_3.bsf	#	3.3		0.382	0.093	0.101	0.385	0.105	0.108	0.000	0.840	0.920	0.965	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	260	Q37_3.bsf	#	3.3		0.382	0.093	0.101	0.385	0.105	0.108	0.000	0.840	0.920	0.965	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.701	0.426	0.371	291	0.151	0.0928	0.9650	0.0634	0.9650

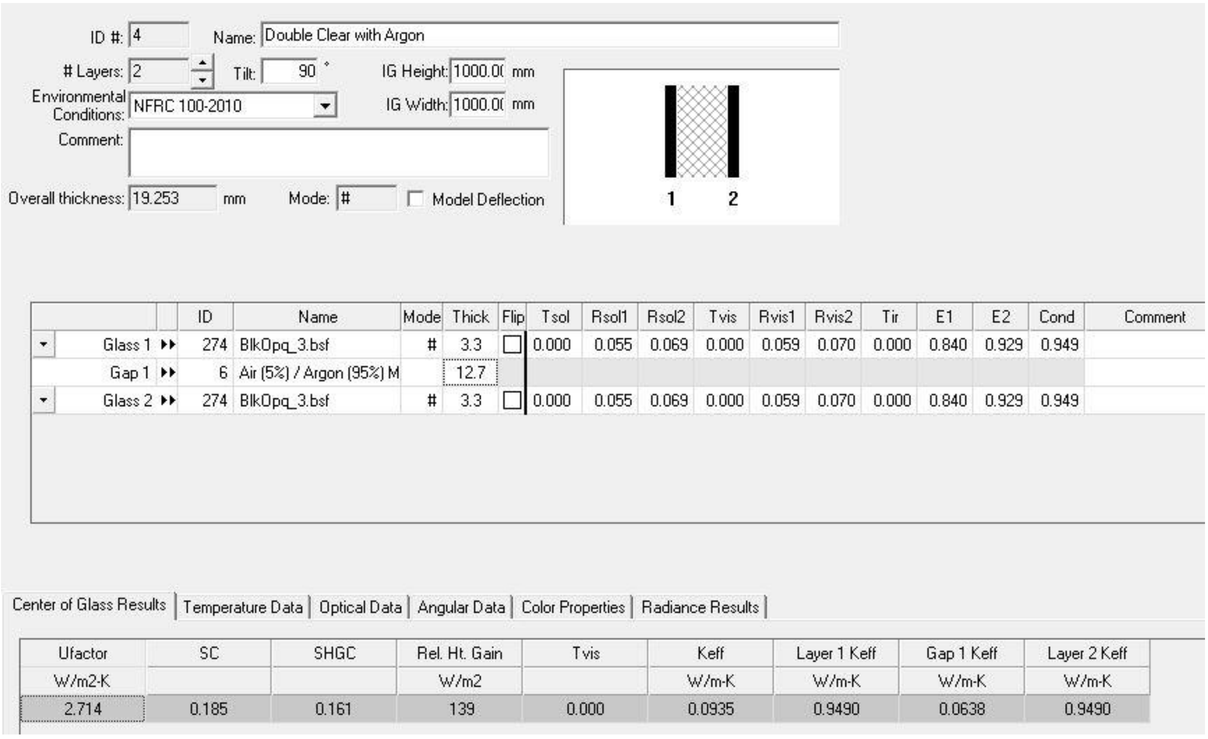
Figure H159. The characteristic of the glazing system of option number 138 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1 ▸▸	19724	SD2510.EMN	#	3.0	☐	0.160	0.472	0.540	0.495	0.138	0.125	0.000	0.840	0.925	0.945	
Gap 1 ▸▸	6	Air (5%) / Argon (95%) M		12.7												
Glass 2 ▸▸	19724	SD2510.EMN	#	3.0	☐	0.160	0.472	0.540	0.495	0.138	0.125	0.000	0.840	0.925	0.945	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.711	0.202	0.176	150	0.252	0.0912	0.9450	0.0636	0.9450

Figure H160. The characteristic of the glazing system of option number 139 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1 ▸▸	274	BlkOpq_3.bsf	#	3.3	☐	0.000	0.055	0.069	0.000	0.059	0.070	0.000	0.840	0.929	0.949	
Gap 1 ▸▸	6	Air (5%) / Argon (95%) M		12.7												
Glass 2 ▸▸	274	BlkOpq_3.bsf	#	3.3	☐	0.000	0.055	0.069	0.000	0.059	0.070	0.000	0.840	0.929	0.949	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.714	0.185	0.161	139	0.000	0.0935	0.9490	0.0638	0.9490

Figure H161. The characteristic of the glazing system of option number 140 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

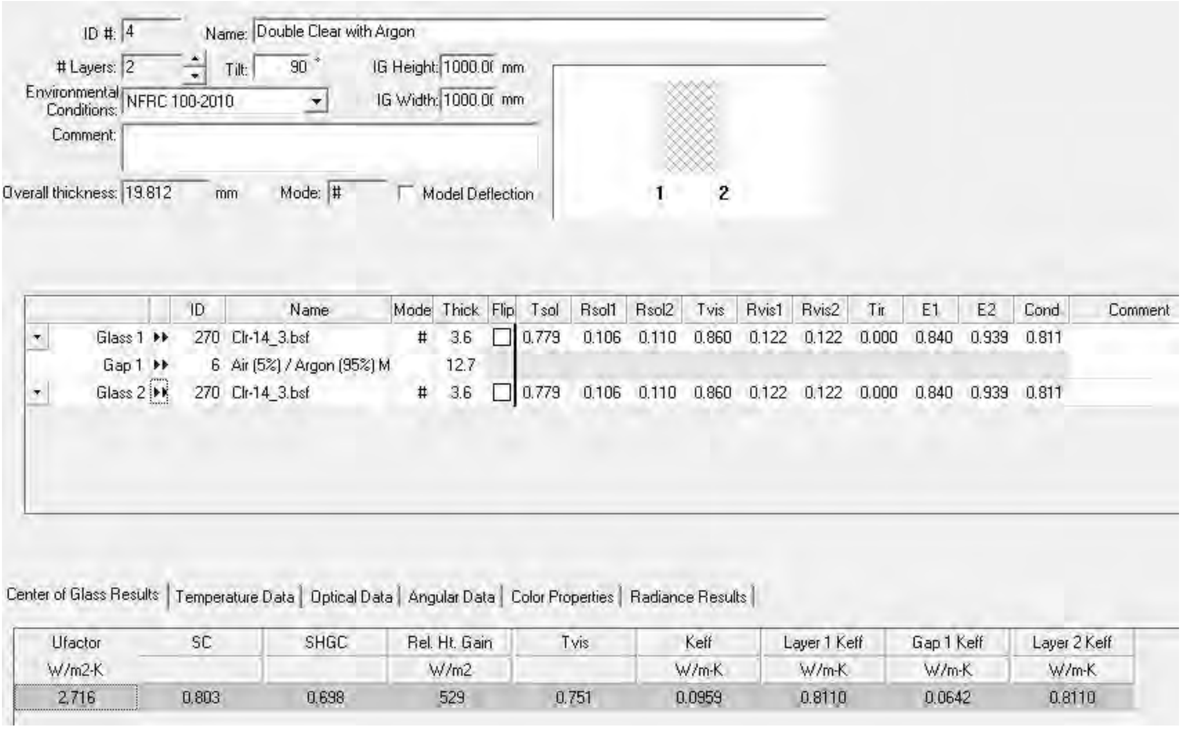


Figure H162. The characteristic of the glazing system of option number 141 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

H.2.2.2 Thickness of glass

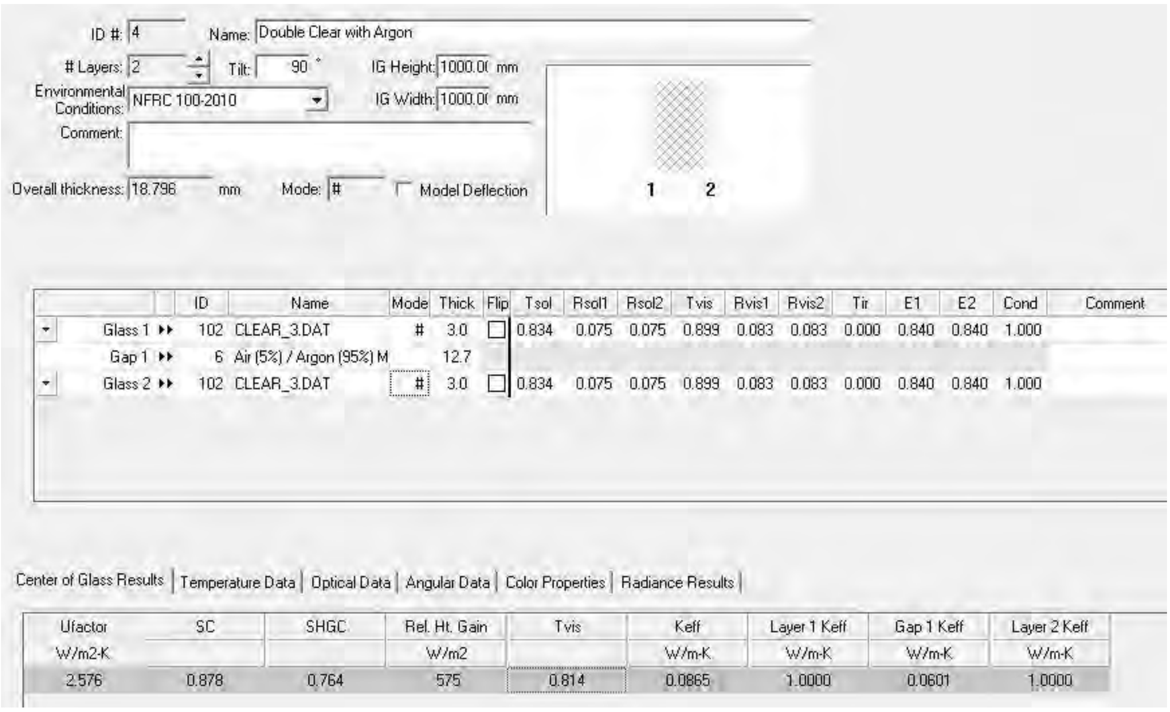


Figure H163. The characteristic of the glazing system of option number 142 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

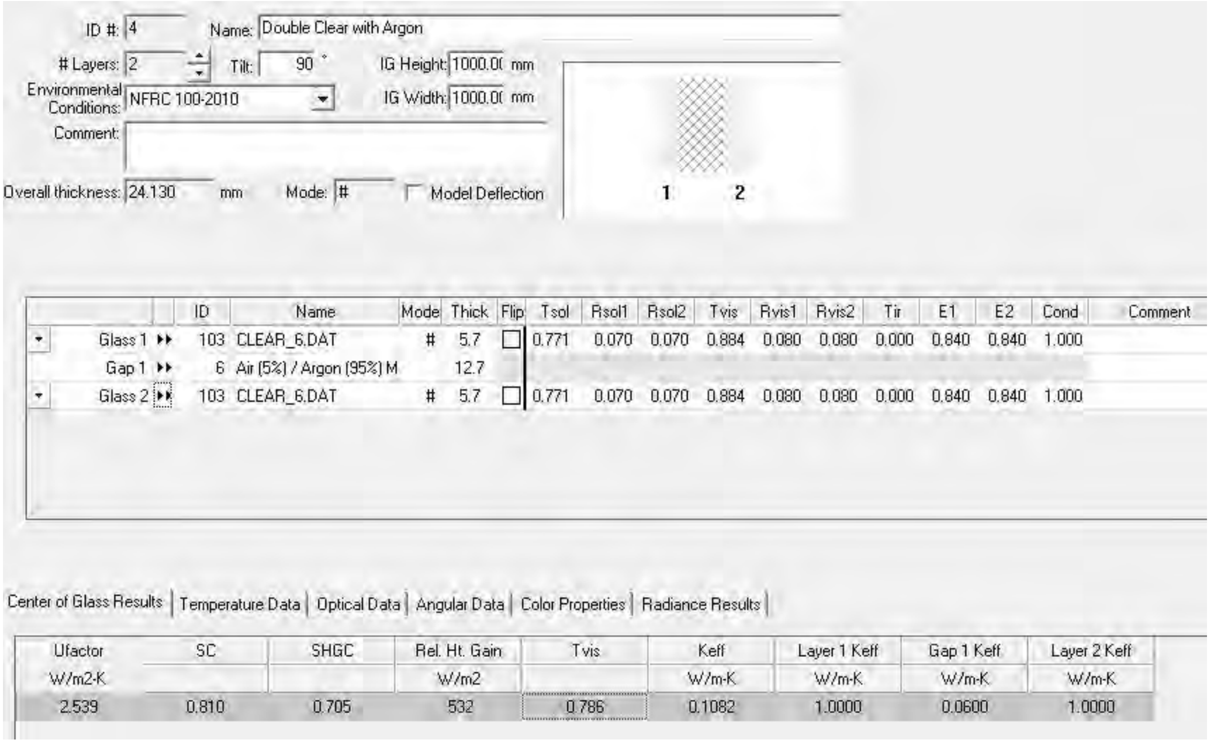


Figure H164. The characteristic of the glazing system of option number 143 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

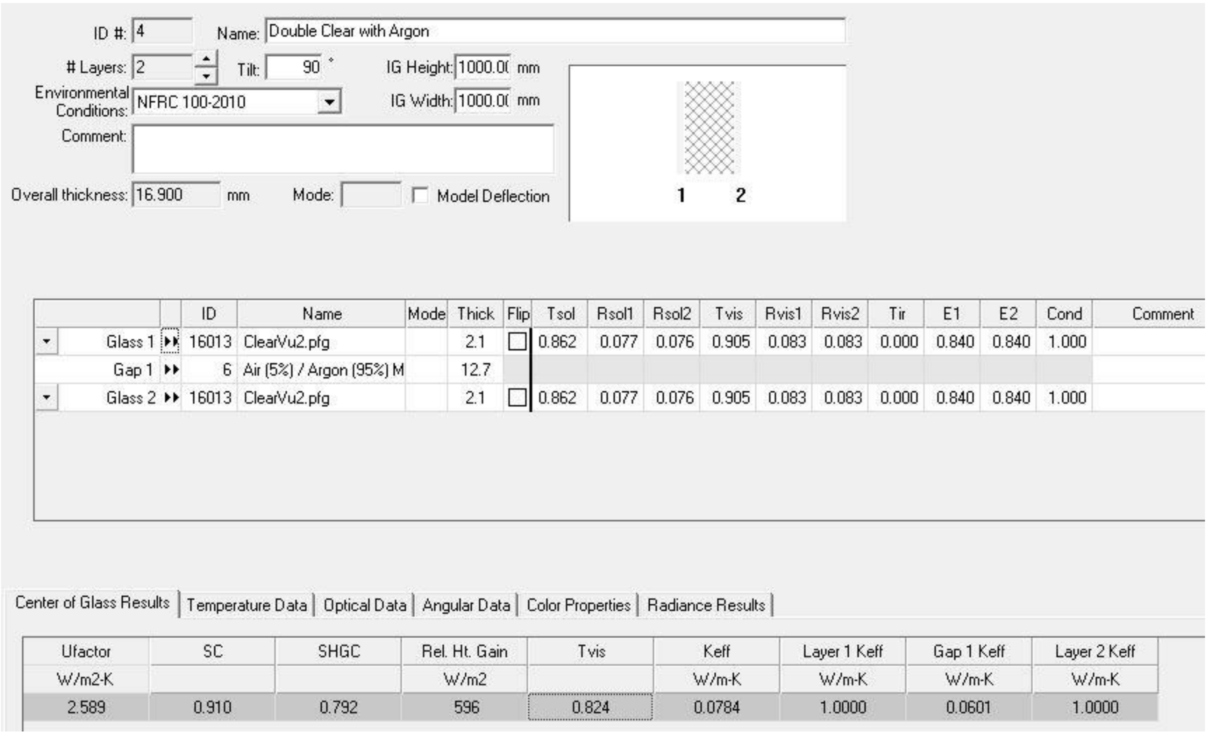


Figure H165. The characteristic of the glazing system of option number 144 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

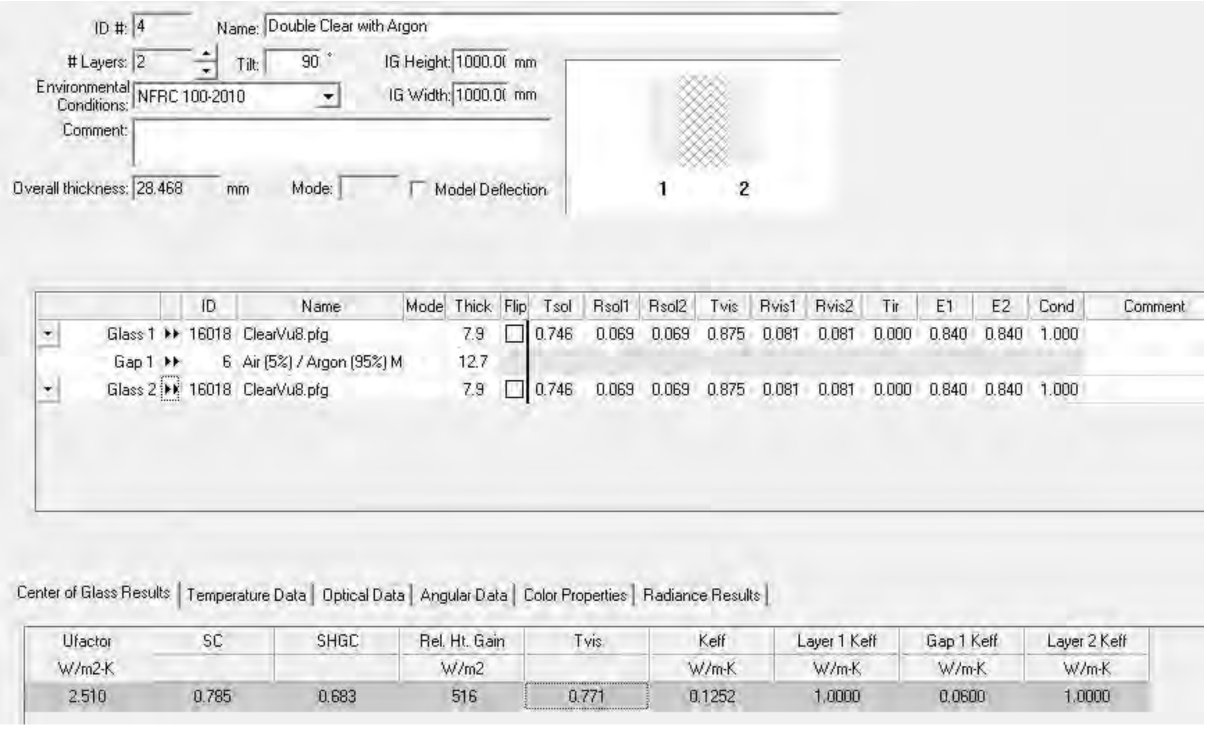


Figure H166. The characteristic of the glazing system of option number 145 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

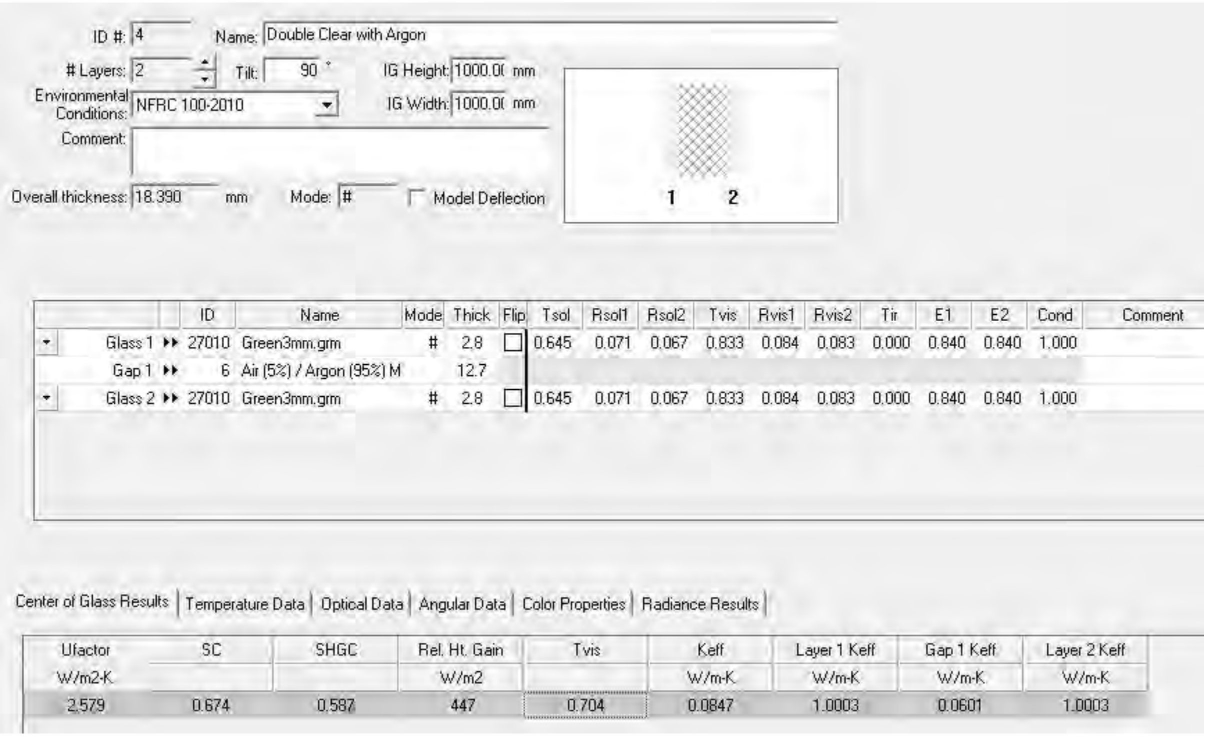


Figure H167. The characteristic of the glazing system of option number 146 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

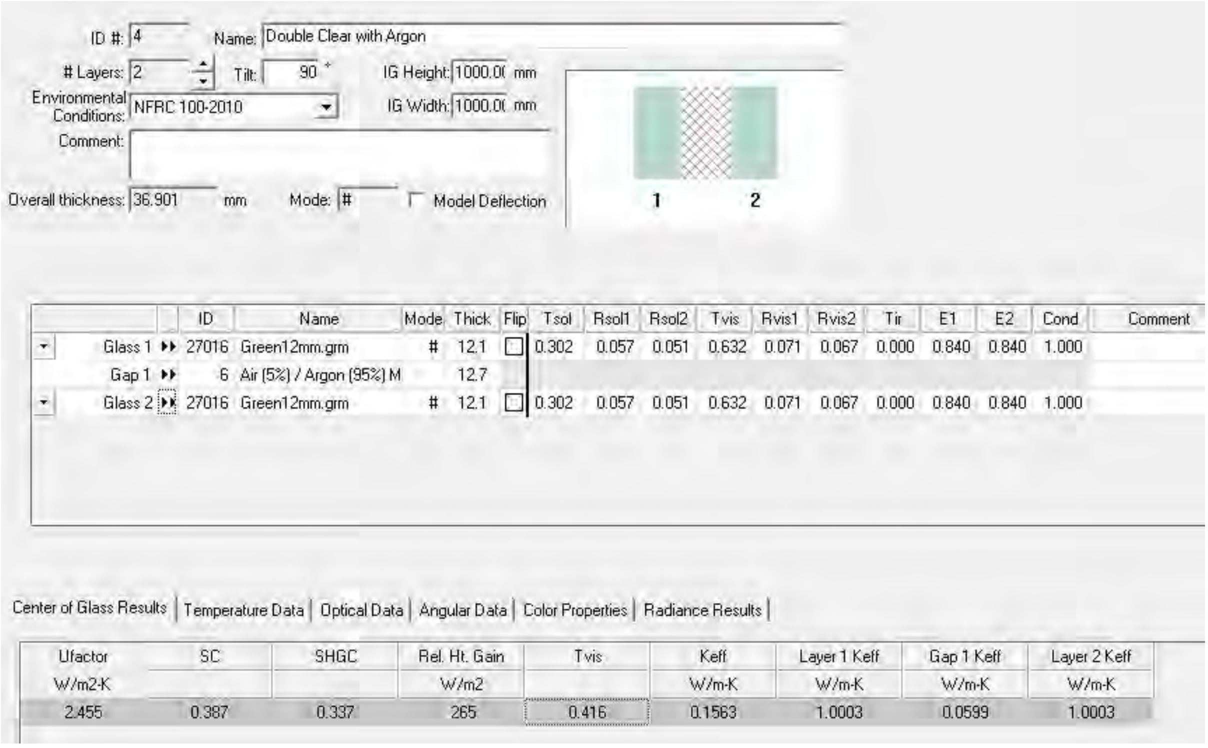


Figure H168. The characteristic of the glazing system of option number 147 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

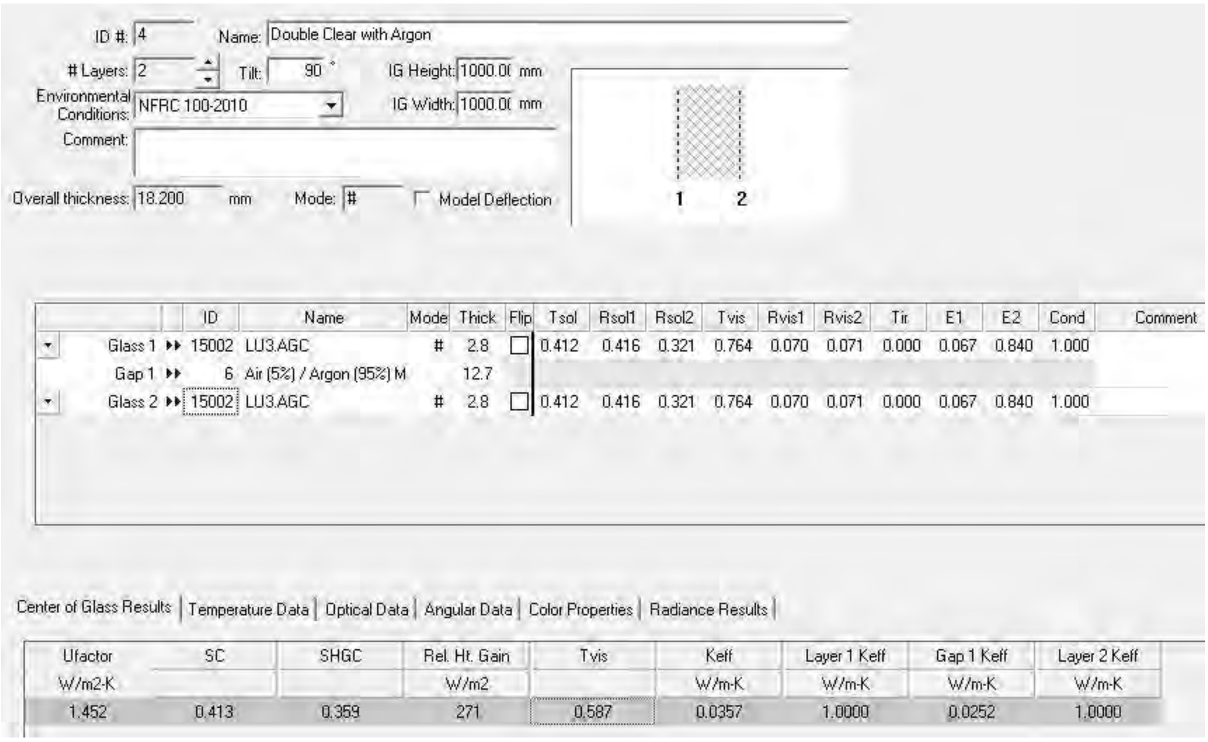
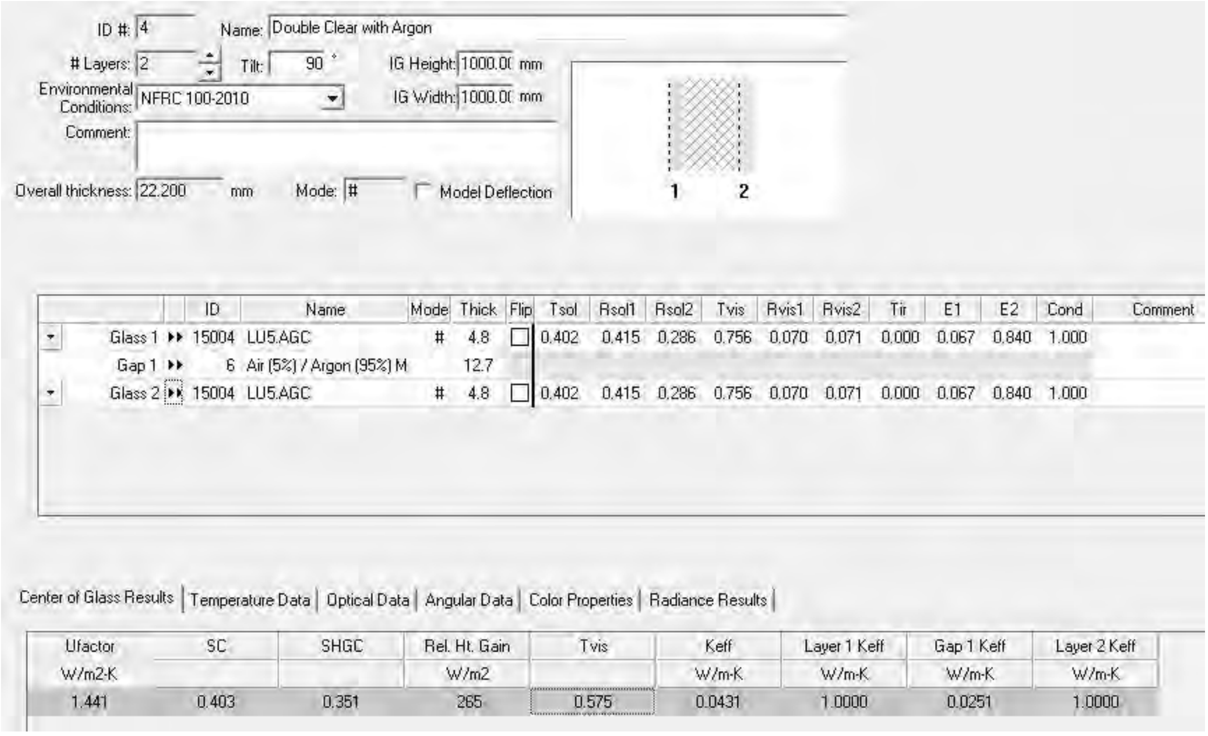


Figure H169. The characteristic of the glazing system of option number 148 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

Overall thickness: 22.200 mm Mode: # Model Deflection

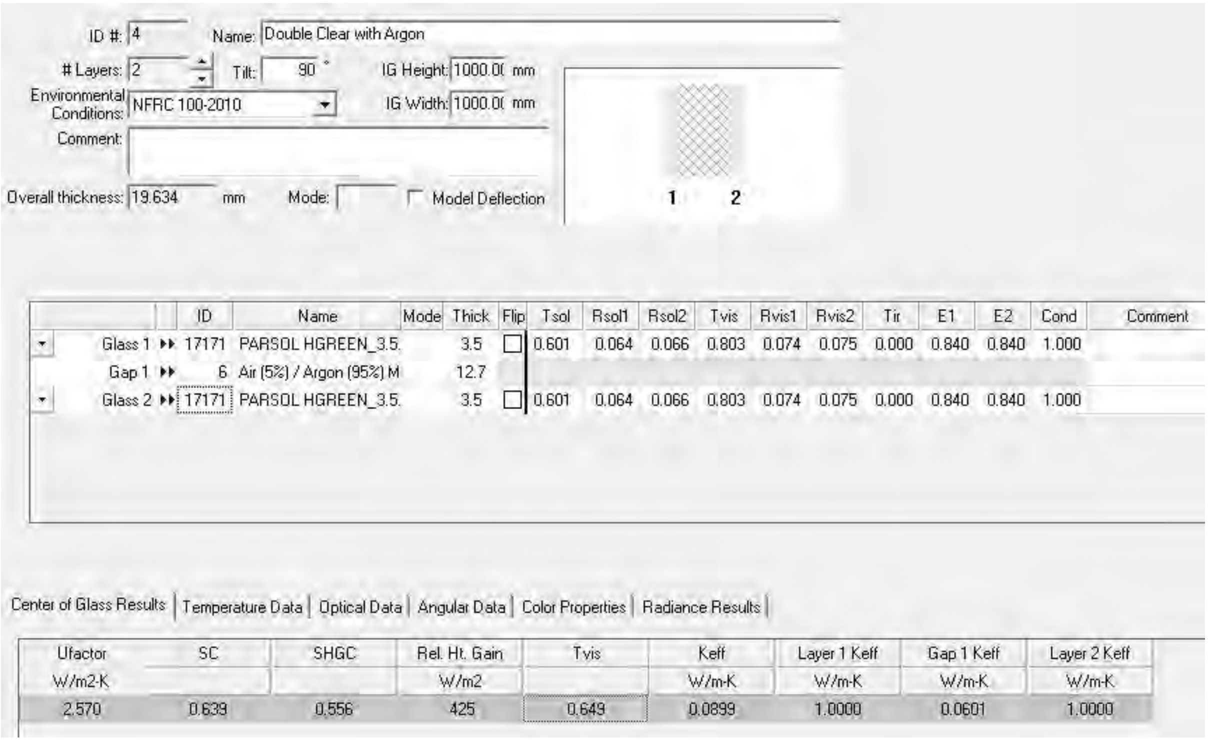
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	15004	LU5.AGC	#	4.8		0.402	0.415	0.286	0.756	0.070	0.071	0.000	0.067	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	15004	LU5.AGC	#	4.8		0.402	0.415	0.286	0.756	0.070	0.071	0.000	0.067	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.441	0.403	0.351	265	0.575	0.0431	1.0000	0.0251	1.0000

Figure H170. The characteristic of the glazing system of option number 149 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 4 Name: Double Clear with Argon

Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm

Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm

Comment:

Overall thickness: 19.634 mm Mode: Model Deflection

1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	17171	PARSOL HGREEN_3.5.		3.5		0.601	0.064	0.066	0.803	0.074	0.075	0.000	0.840	0.840	1.000	
Gap 1	6	Air (5%) / Argon (95%) M		12.7												
Glass 2	17171	PARSOL HGREEN_3.5.		3.5		0.601	0.064	0.066	0.803	0.074	0.075	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
2.570	0.639	0.556	425	0.649	0.0899	1.0000	0.0601	1.0000

Figure H171. The characteristic of the glazing system of option number 150 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

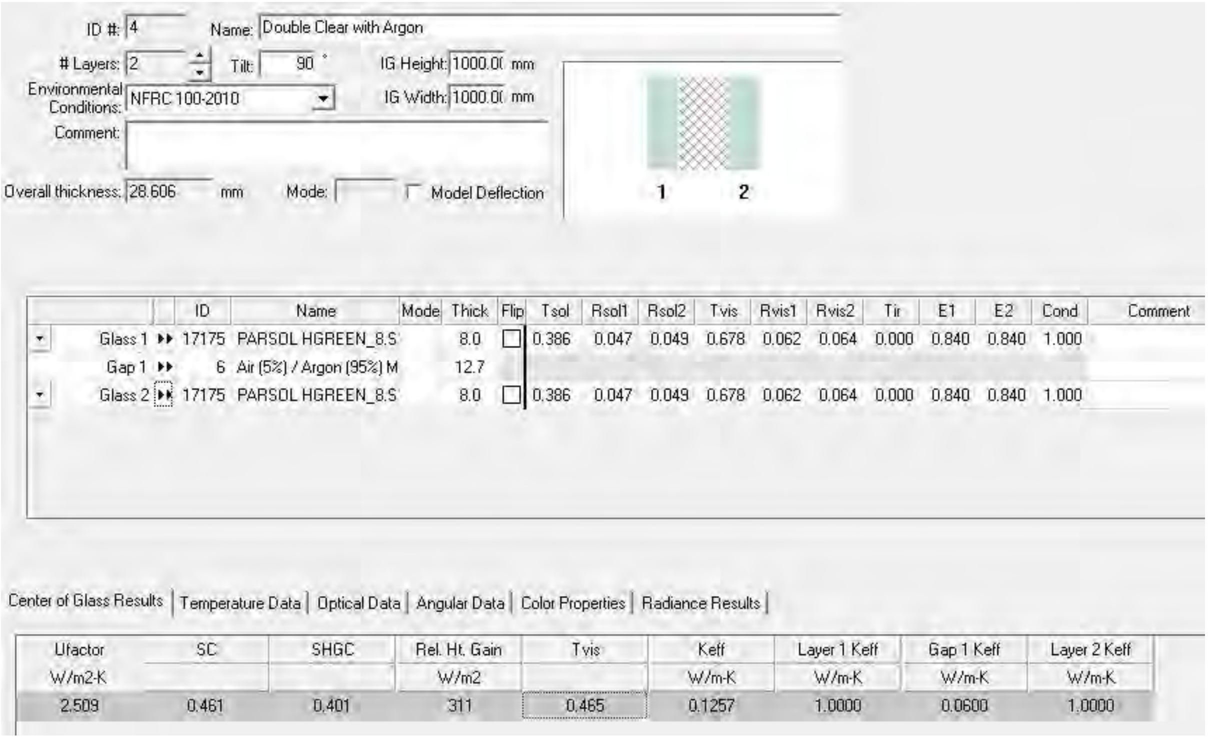


Figure H172. The characteristic of the glazing system of option number 151 windows. , analysed by Lawrence Berkeley National Laboratory (LBNL) software.

Appendix I. Results of LNBL software for case studies

I.1. Case 1. The window of a traditional house (age = 102)

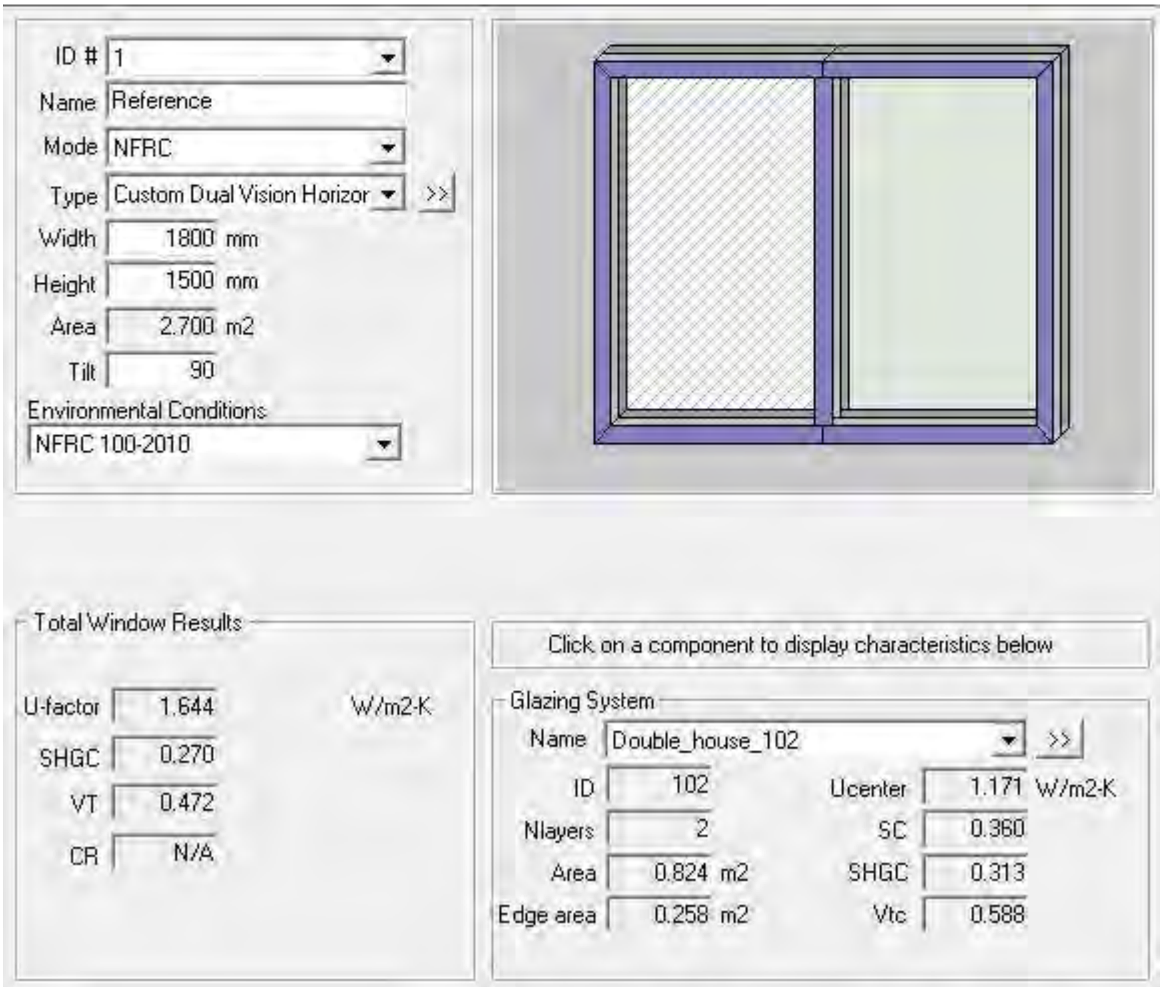


Figure I1. Characteristic of the whole double window, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

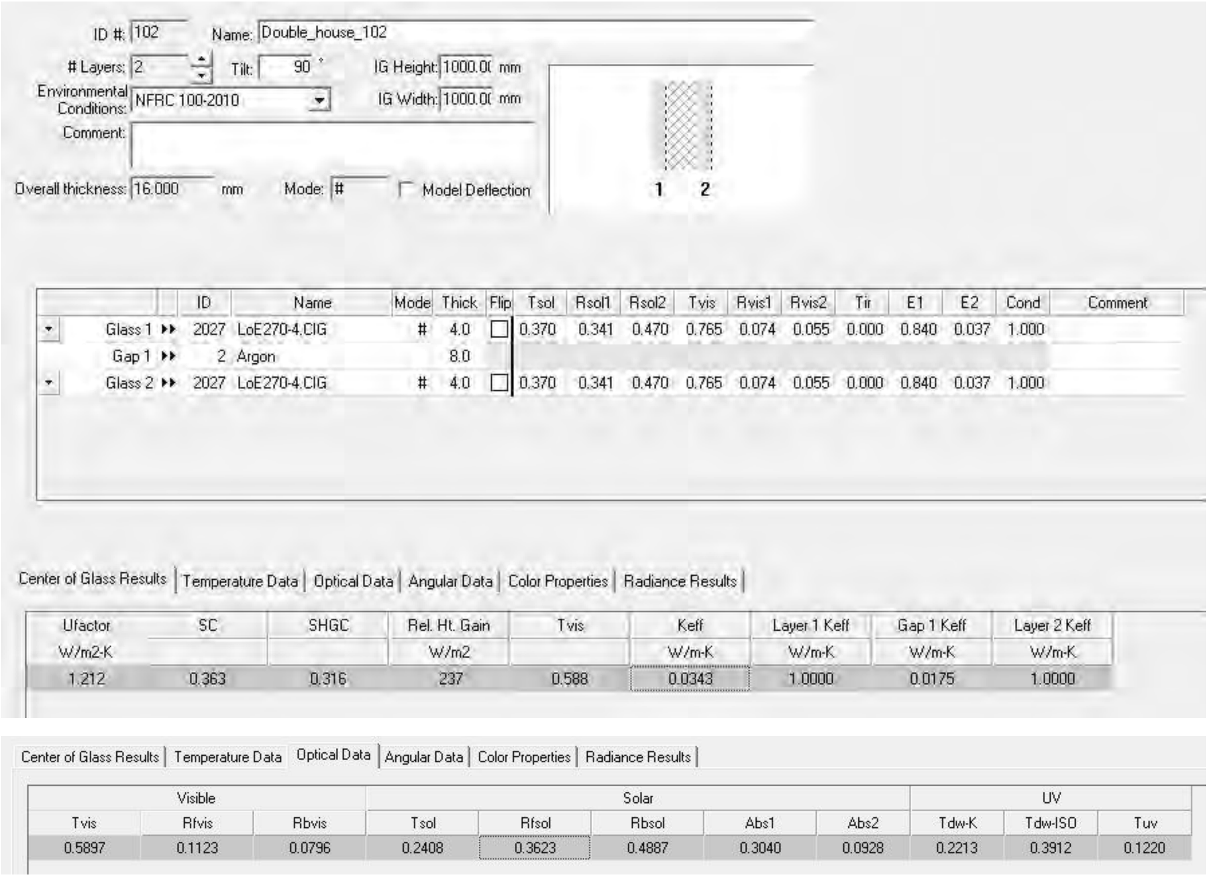


Figure I2. Characteristic of the glazing system, analysed by Lawrence Berkeley National Laboratory (LBNL) software.

Table I1. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.239	0.242	0.236	0.229	0.221	0.206	0.175	0.121	0.053	0.000	0.192
Abs1	0.302	0.304	0.310	0.314	0.314	0.315	0.322	0.321	0.255	0.001	0.309
Abs2	0.090	0.092	0.094	0.095	0.095	0.094	0.092	0.083	0.052	0.000	0.089
Rfsol	0.369	0.362	0.360	0.362	0.371	0.385	0.411	0.476	0.640	0.999	0.400
Rbsol	0.495	0.489	0.487	0.489	0.497	0.509	0.530	0.583	0.715	0.999	0.519
Tvis	0.588	0.596	0.580	0.563	0.542	0.506	0.429	0.294	0.128	0.000	0.471
Rfvis	0.117	0.105	0.102	0.106	0.120	0.144	0.185	0.284	0.516	0.999	0.170
Rbvis	0.087	0.075	0.071	0.076	0.091	0.116	0.160	0.263	0.504	0.999	0.143
SHGC	0.316	0.319	0.315	0.309	0.300	0.285	0.254	0.194	0.101	0.000	0.268

Table I2. Annual optical graphs.

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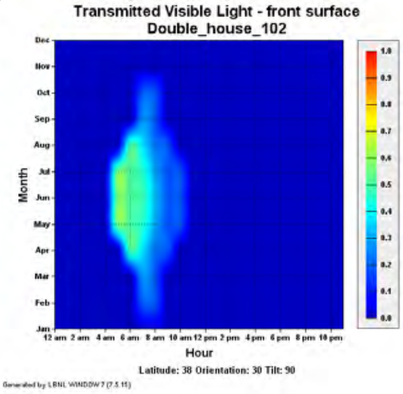
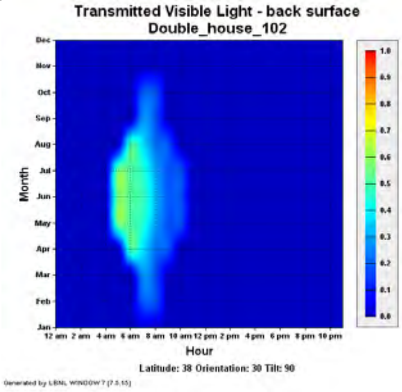
<tr><th></th><th>Front surface</th><th>Back surface</th></tr>
<tr><td>Transmitted visible light</td><td>
</td><td>
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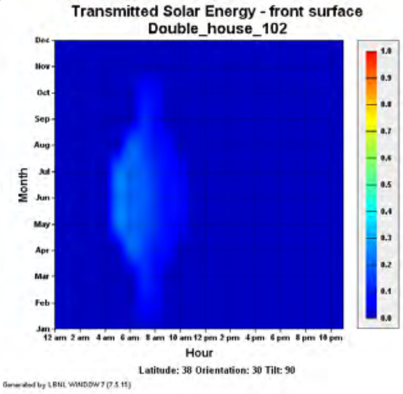
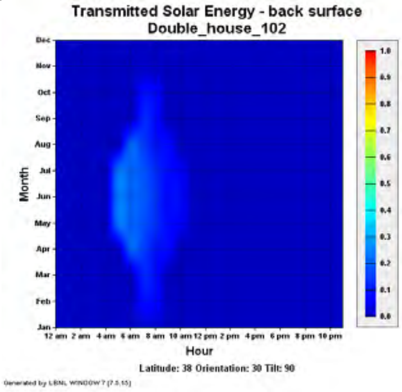
<tr><td>Transmitted solar energy</td><td>
</td><td>
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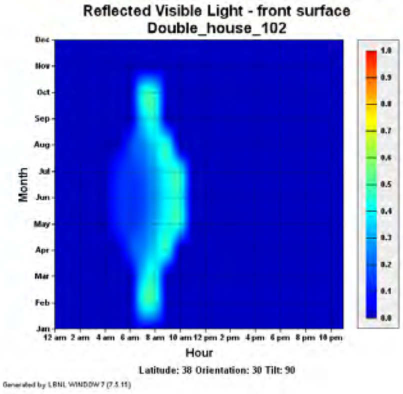
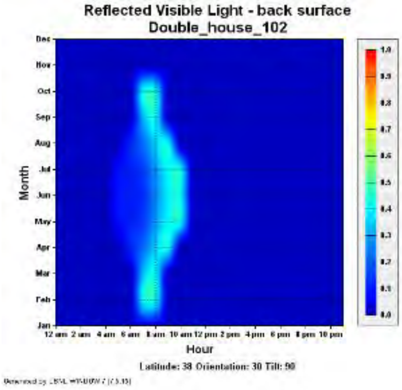
<tr><td>Reflected visible light</td><td>
</td><td>
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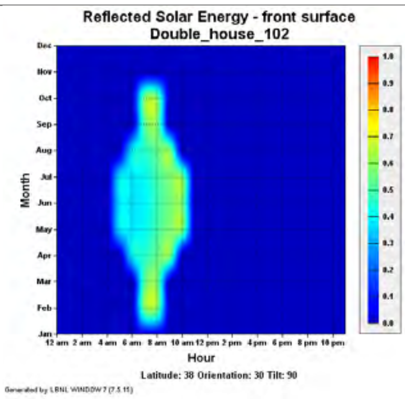
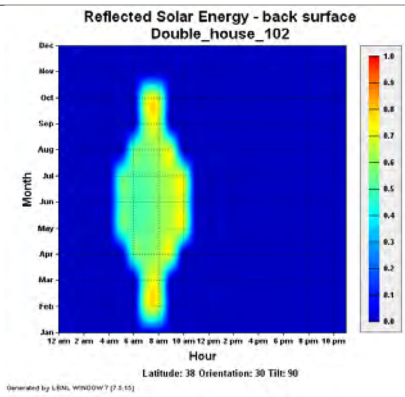
<tr><td>Reflected solar energy</td><td>
</td><td>
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I.2. Case 2. The window of a traditional house (age = 107)

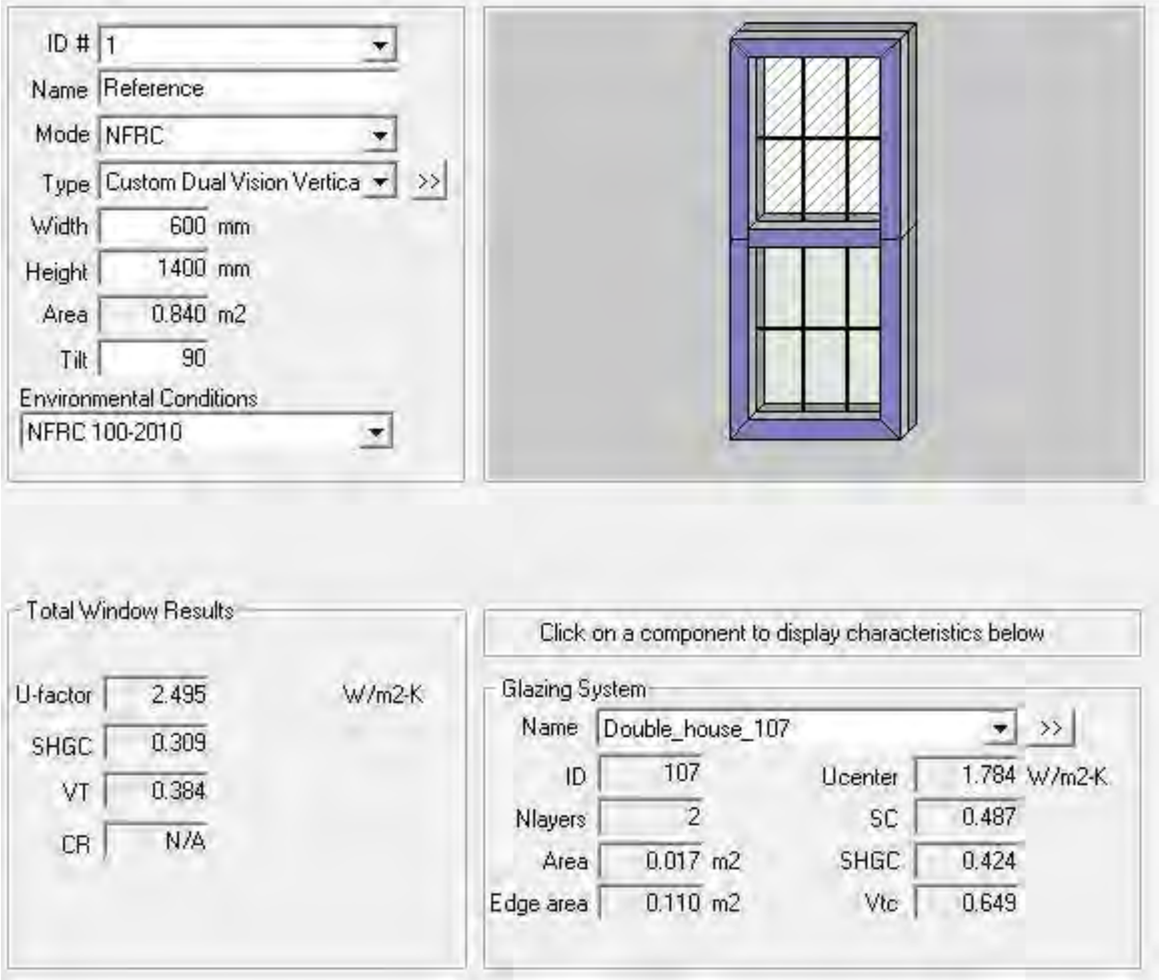


Figure I3. The characteristic of the whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

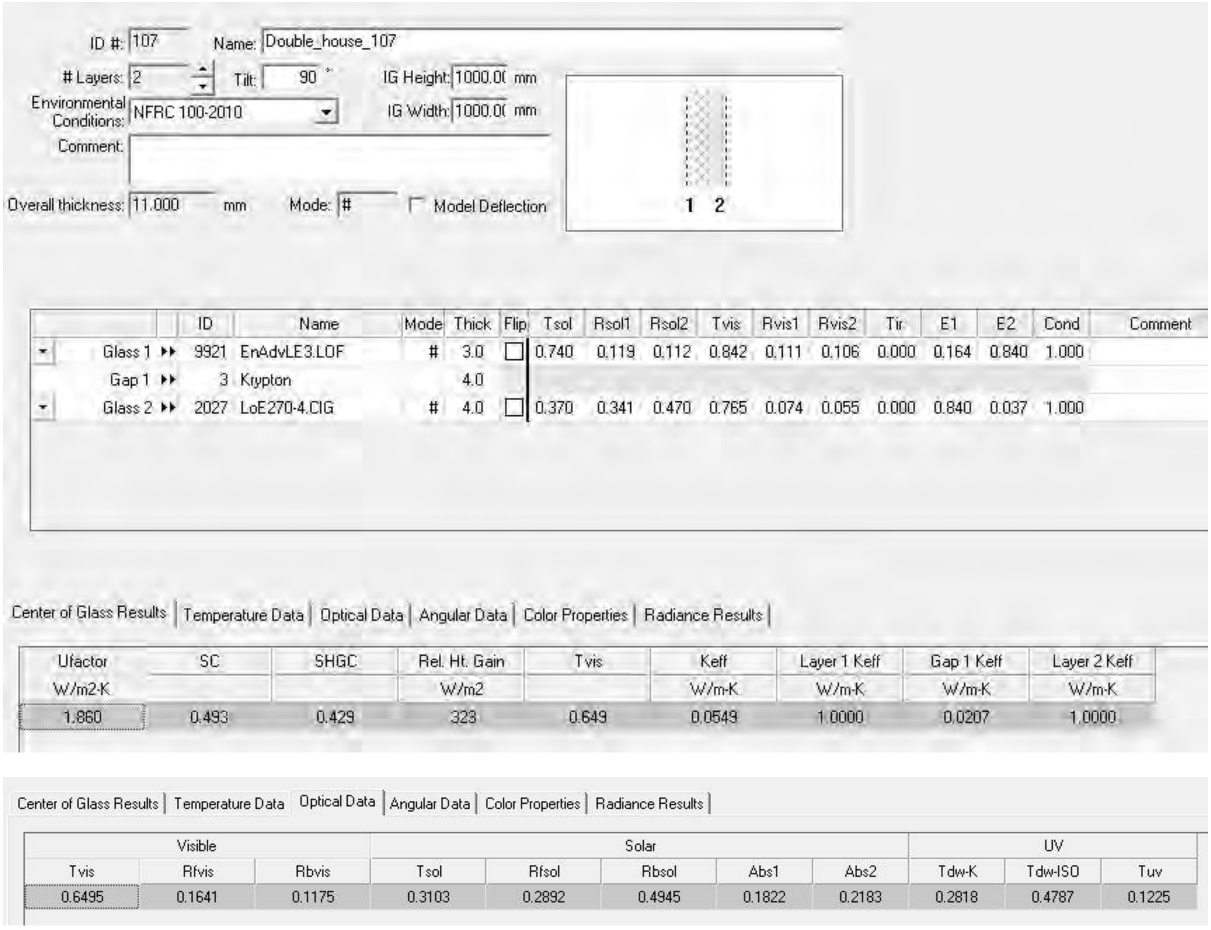
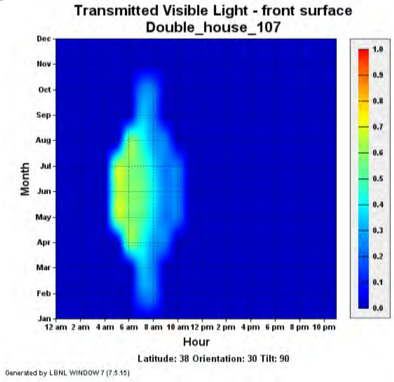
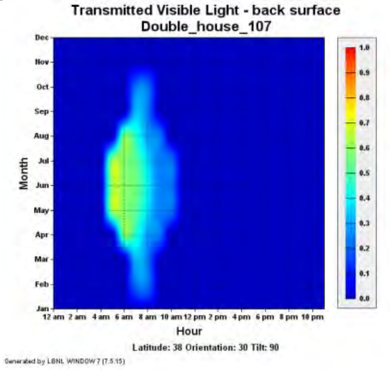
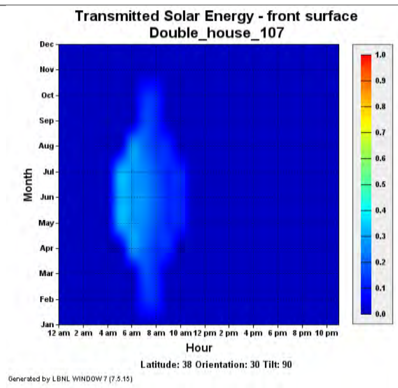
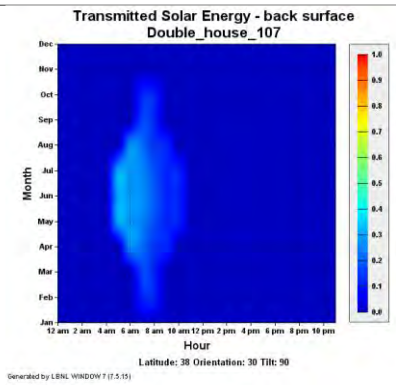
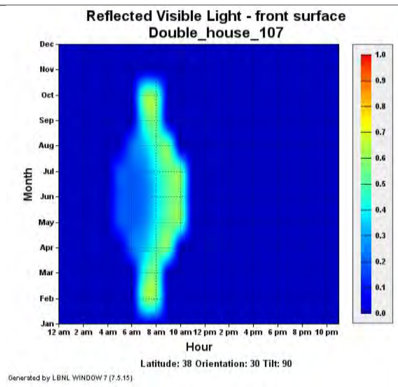
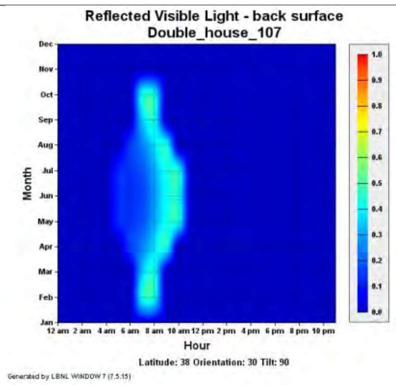
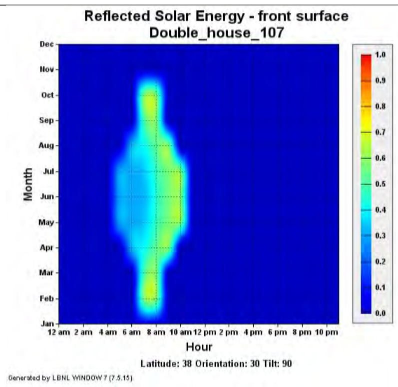
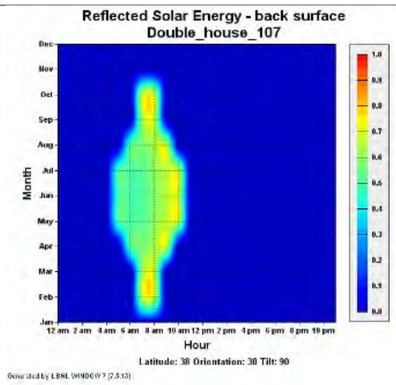


Figure I4. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

Table I3. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.310	0.312	0.306	0.300	0.293	0.278	0.242	0.174	0.082	0.000	0.257
Abs1	0.182	0.183	0.186	0.188	0.188	0.188	0.189	0.185	0.145	0.000	0.183
Abs2	0.218	0.220	0.224	0.226	0.225	0.222	0.217	0.192	0.121	0.000	0.211
Rfsol	0.289	0.285	0.283	0.286	0.294	0.312	0.352	0.448	0.651	1.000	0.339
Rbsol	0.495	0.490	0.489	0.491	0.497	0.509	0.532	0.588	0.719	0.999	0.520
Tvis	0.649	0.653	0.641	0.628	0.612	0.581	0.504	0.360	0.168	0.000	0.537
Rfvis	0.164	0.158	0.157	0.162	0.174	0.199	0.256	0.387	0.632	1.000	0.236
Rbvis	0.118	0.110	0.108	0.110	0.122	0.144	0.188	0.290	0.518	0.999	0.173
SHGC	0.429	0.432	0.428	0.423	0.415	0.399	0.361	0.281	0.152	0.000	0.373

Figure I4. Annual optical graphs.

	Front surface	Back surface
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.3. Case 3. The window of a traditional house (age = 115)

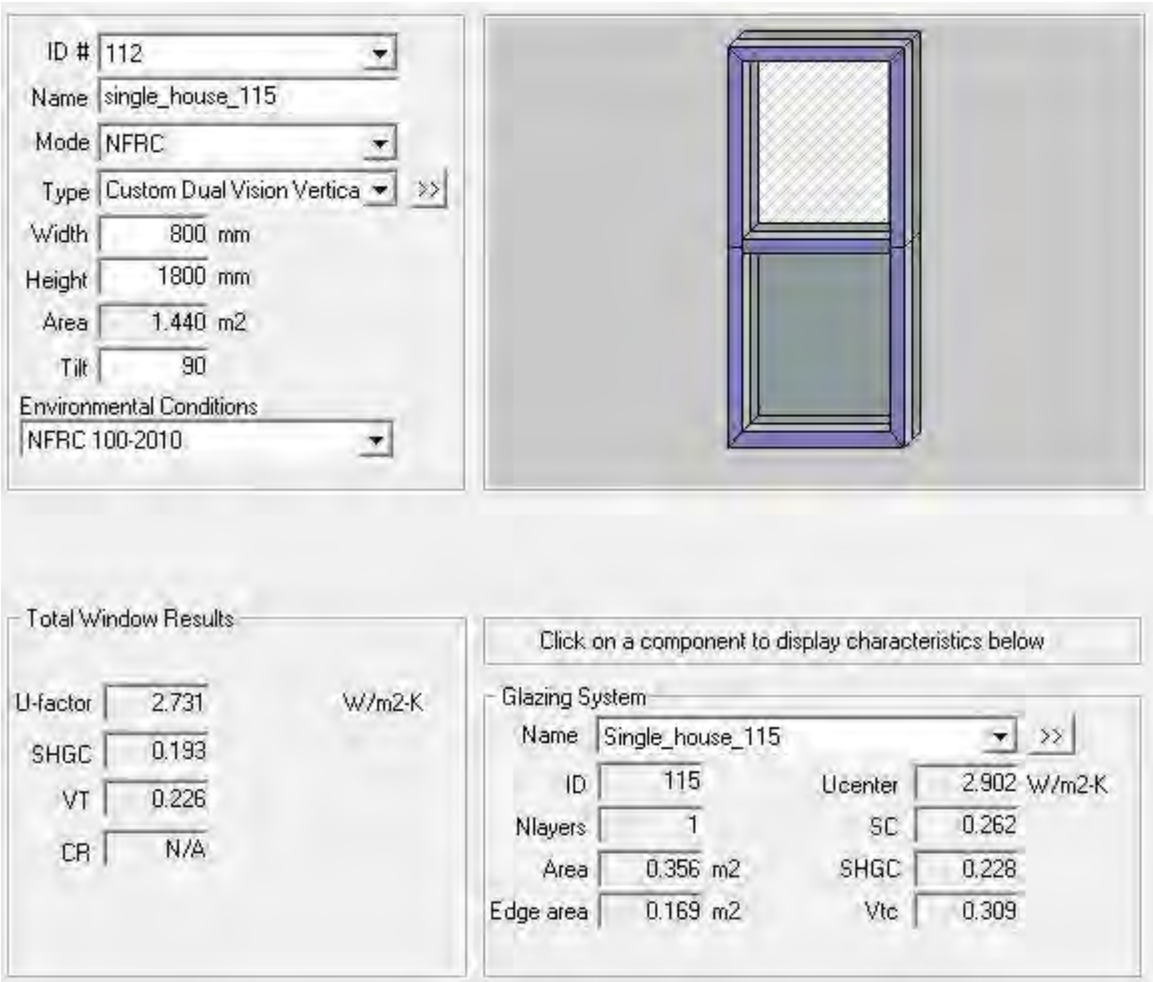
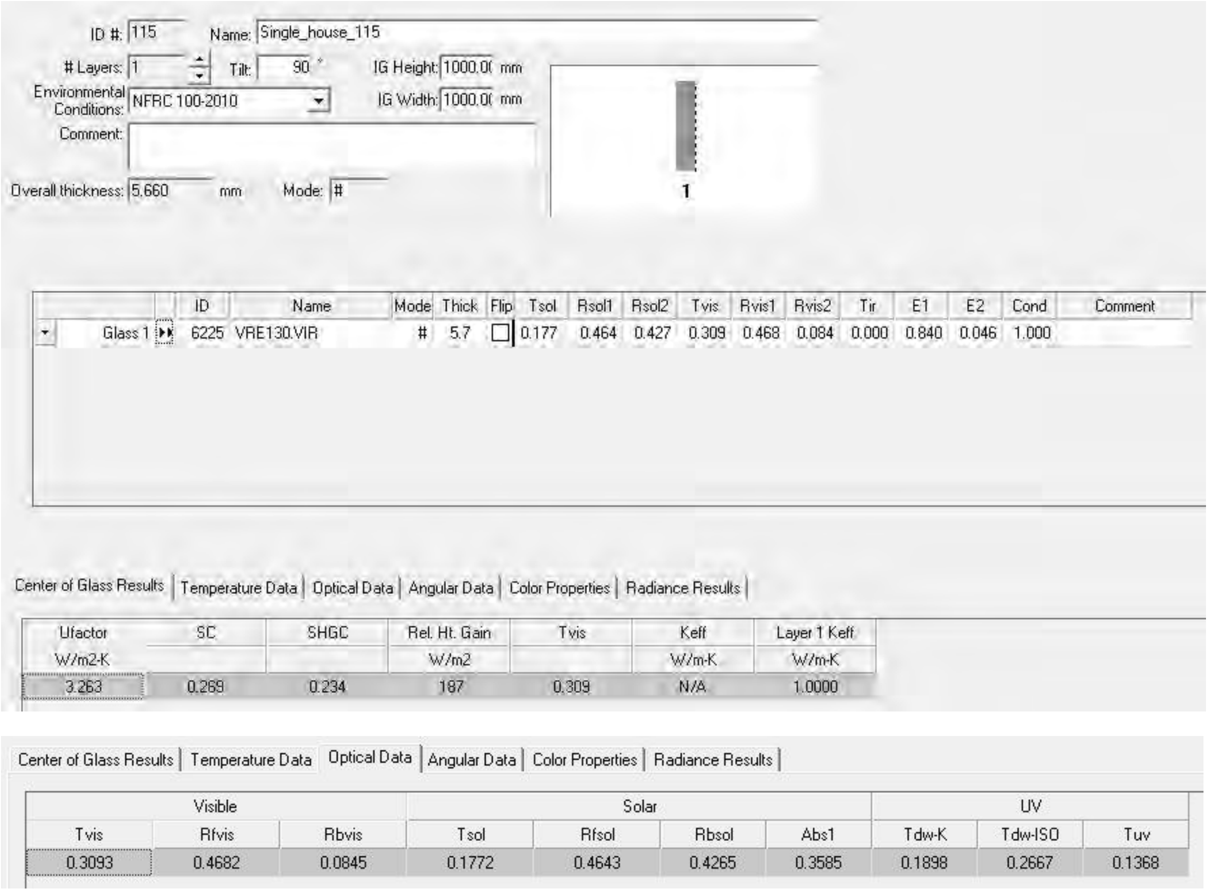


Figure I5. The characteristic of the whole single window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 115 Name: Single_house_115
Layers: 1 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 5.660 mm Mode: #

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	6225	VRE130.VIR	#	5.7	☐	0.177	0.464	0.427	0.309	0.468	0.084	0.000	0.840	0.046	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor W/m2-K	SC	SHGC	Rel. Ht. Gain W/m2	Tvis	Keff W/m-K	Layer 1 Keff W/m-K
3.263	0.269	0.234	187	0.309	N/A	1.0000

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

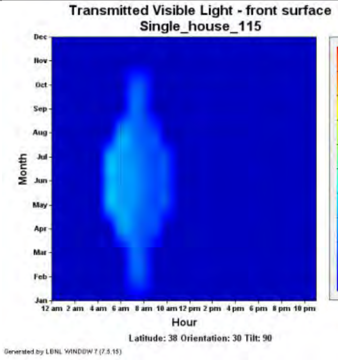
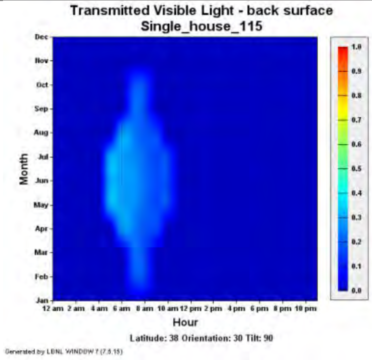
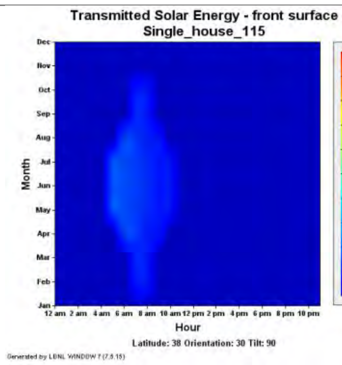
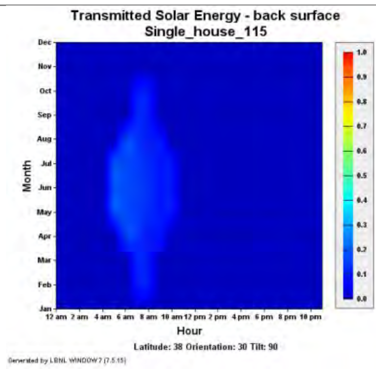
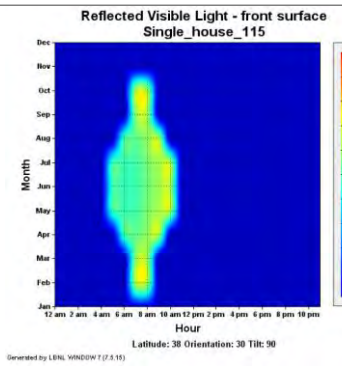
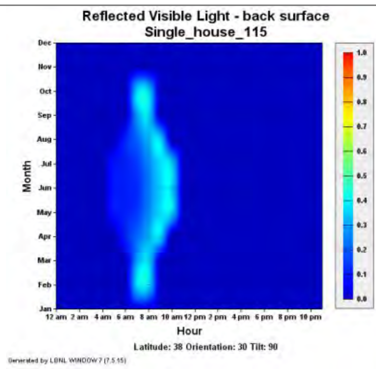
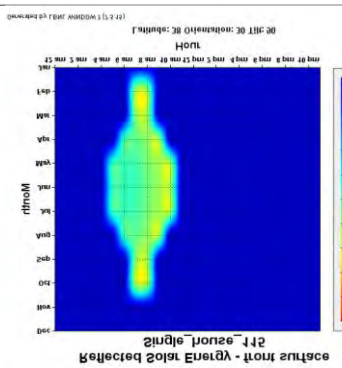
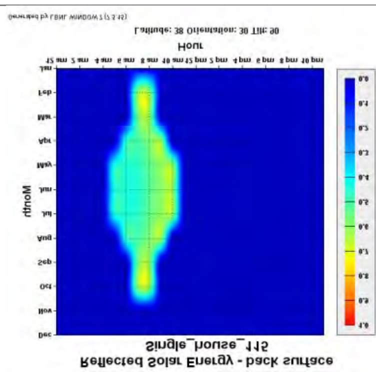
Visible			Solar				UV		
Tvis	Rfvis	Rbvis	Tsol	Rfsol	Rbsol	Abs1	Tdw-K	Tdw-ISO	Tuv
0.3093	0.4682	0.0845	0.1772	0.4643	0.4265	0.3585	0.1898	0.2667	0.1368

Figure I6. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table 15. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.177	0.178	0.176	0.173	0.170	0.164	0.151	0.123	0.074	0.000	0.155
Abs1	0.358	0.362	0.365	0.366	0.363	0.359	0.353	0.329	0.240	0.001	0.346
Rfsol	0.464	0.460	0.459	0.461	0.467	0.477	0.497	0.549	0.686	0.999	0.488
Rbsol	0.427	0.422	0.421	0.423	0.429	0.440	0.461	0.517	0.664	0.999	0.453
Tvis	0.309	0.311	0.307	0.303	0.297	0.286	0.263	0.214	0.129	0.000	0.270
Rfvis	0.468	0.464	0.463	0.465	0.471	0.481	0.500	0.552	0.689	0.999	0.492
Rbvis	0.084	0.077	0.075	0.078	0.089	0.106	0.140	0.229	0.464	0.999	0.133
SHGC	0.234	0.236	0.234	0.231	0.227	0.221	0.206	0.174	0.111	0.000	0.210

Table I6. Annual optical graphs.

	Front surface	**Back surface**
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.4. Case 4. The window of a traditional house (age = 126)

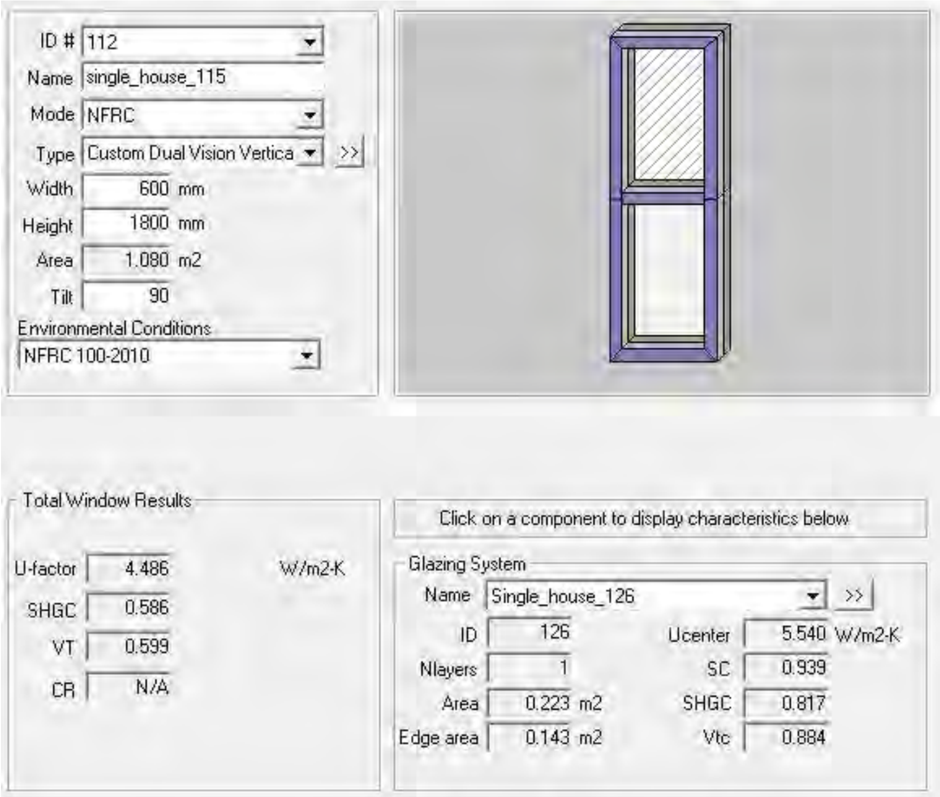


Figure 17. The characteristic of the whole single divided windows that analysed by Lawrence Berkeley National Laboratory (LBNL) software

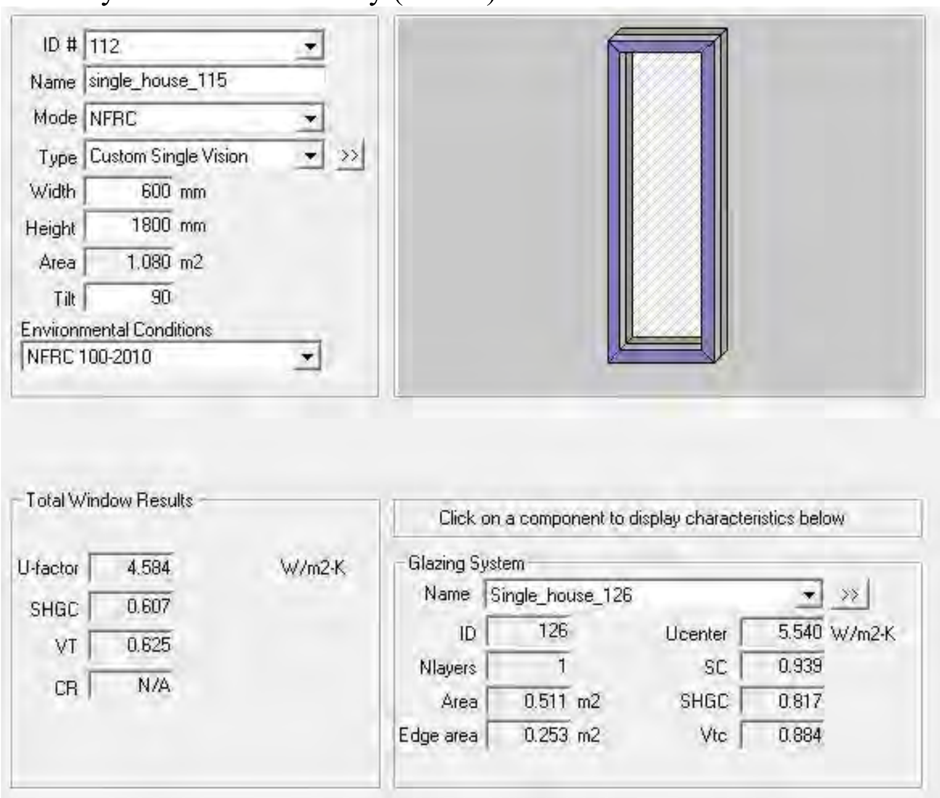


Figure 18. The characteristic of the whole single windows that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

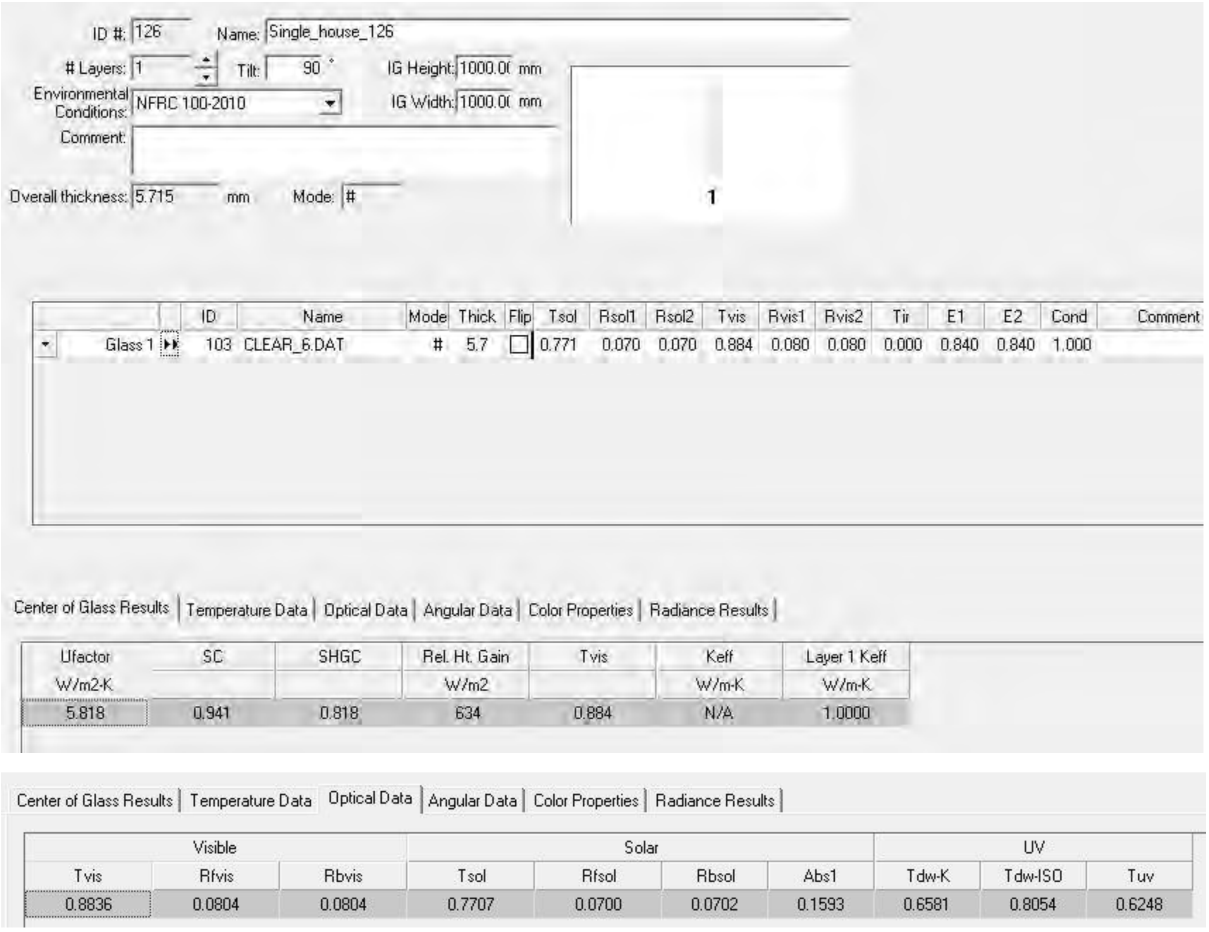
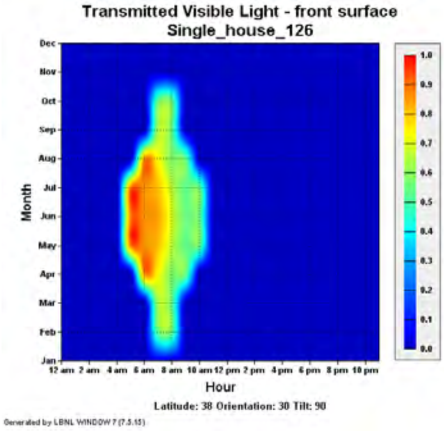
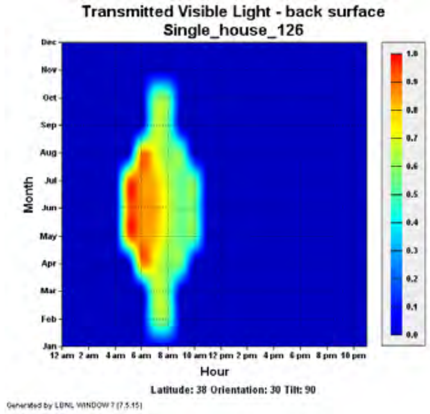


Figure I9. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

Table I7. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.771	0.770	0.767	0.761	0.750	0.727	0.680	0.575	0.346	0.000	0.689
Abs1	0.159	0.160	0.163	0.167	0.173	0.180	0.185	0.186	0.170	0.000	0.173
Rfsol	0.070	0.070	0.070	0.072	0.077	0.093	0.134	0.239	0.484	1.000	0.128
Rbsol	0.070	0.070	0.070	0.072	0.077	0.093	0.134	0.239	0.484	1.000	0.128
Tvis	0.884	0.883	0.882	0.879	0.872	0.852	0.804	0.688	0.427	0.000	0.805
Rfvis	0.080	0.080	0.081	0.083	0.089	0.106	0.152	0.267	0.528	1.000	0.144
Rbvis	0.080	0.080	0.081	0.083	0.089	0.106	0.152	0.267	0.528	1.000	0.144
SHGC	0.818	0.818	0.816	0.811	0.802	0.781	0.736	0.631	0.397	0.000	0.741

Table I8. Annual optical graphs.

<table>
<tr><th></th><th>Front surface</th><th>Back surface</th></tr>
<tr><td>Transmitted visible light</td><td>
</td><td>
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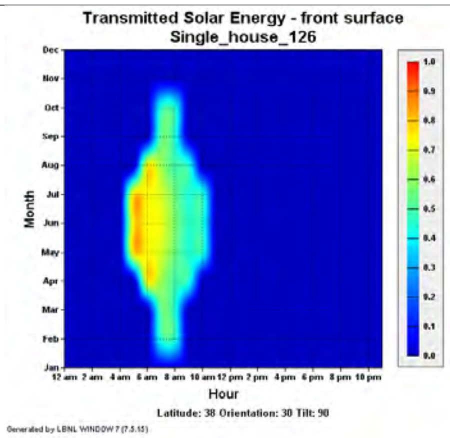
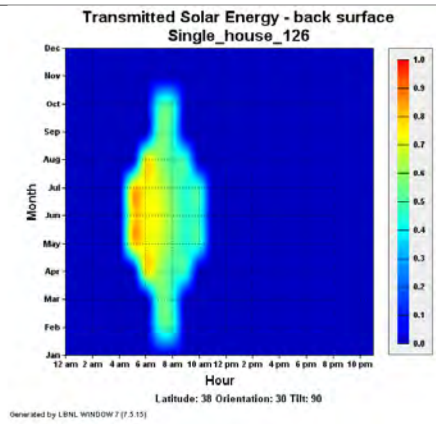
<tr><td>Transmitted solar energy</td><td>
</td><td>
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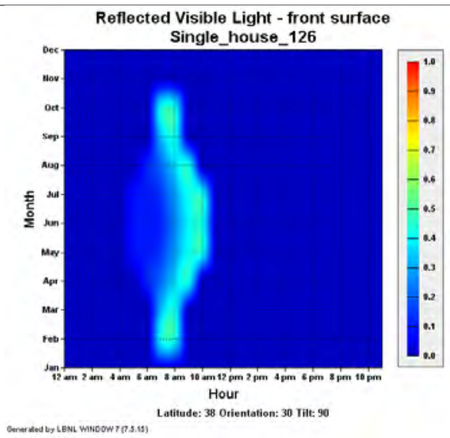
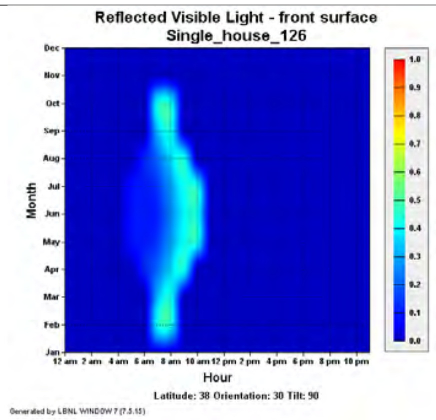
<tr><td>Reflected visible light</td><td>
</td><td>
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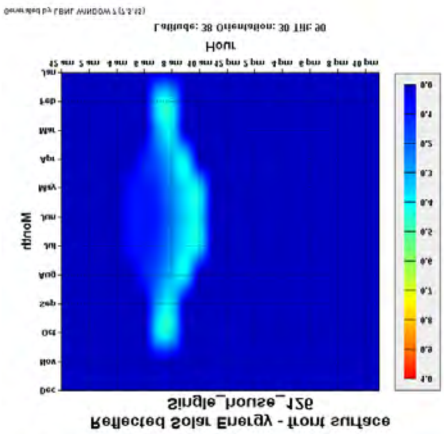
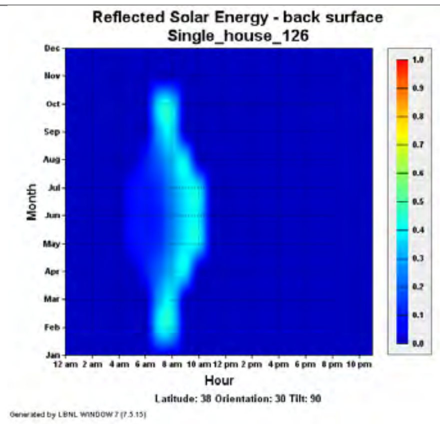
Reflected solar energy





I.4.1. Recommended solution

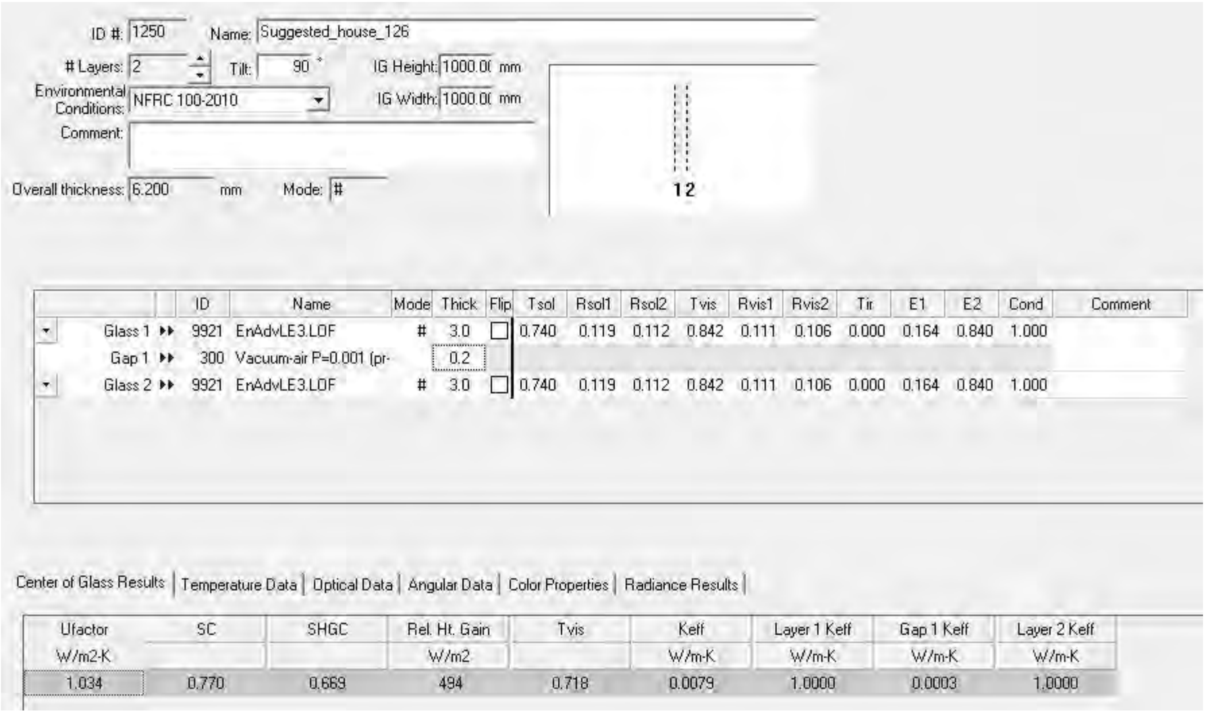


Figure I10. The characteristic of the suggested glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

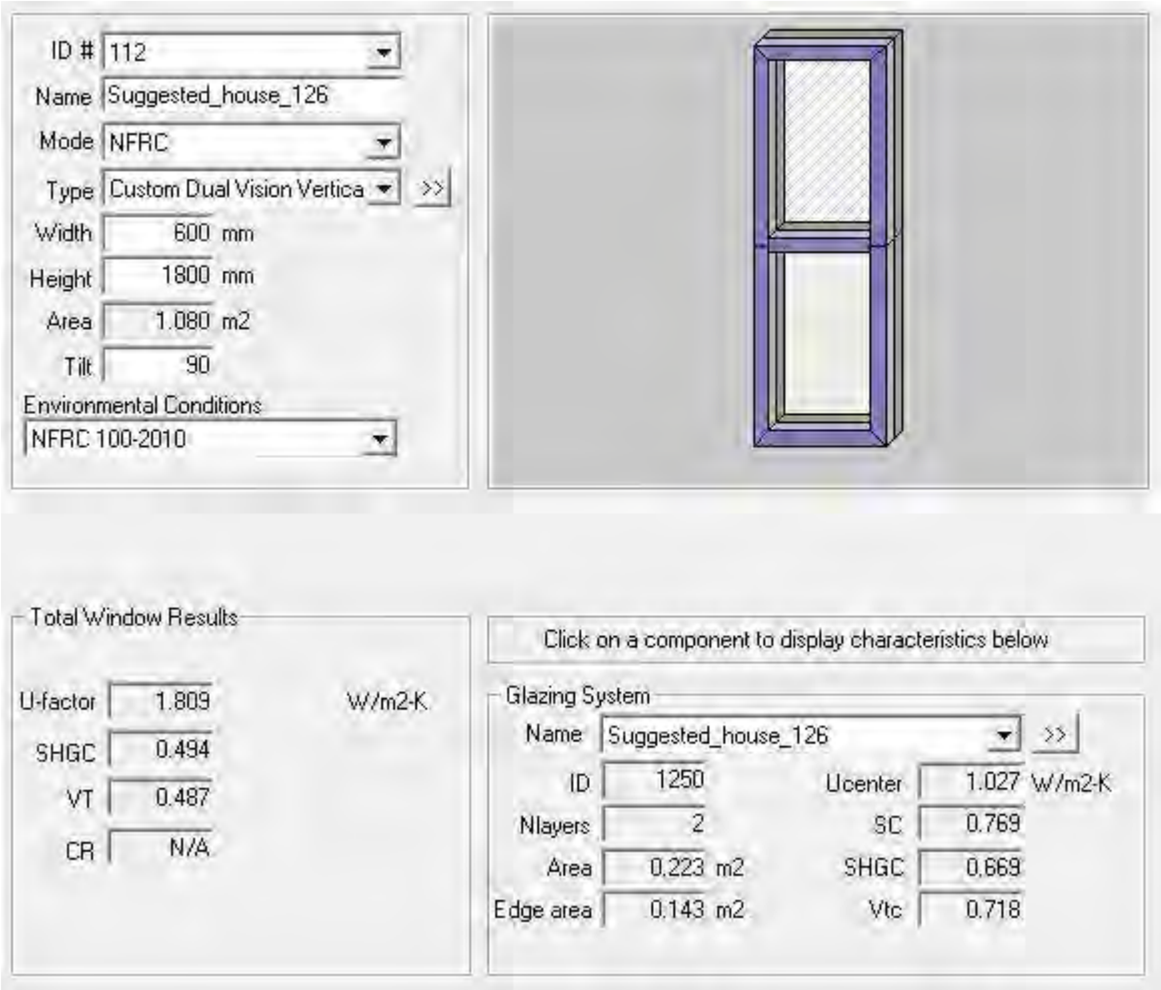


Figure I11. The characteristic of the suggested whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

I.5. Case 5. The window of a traditional house (age = 132)

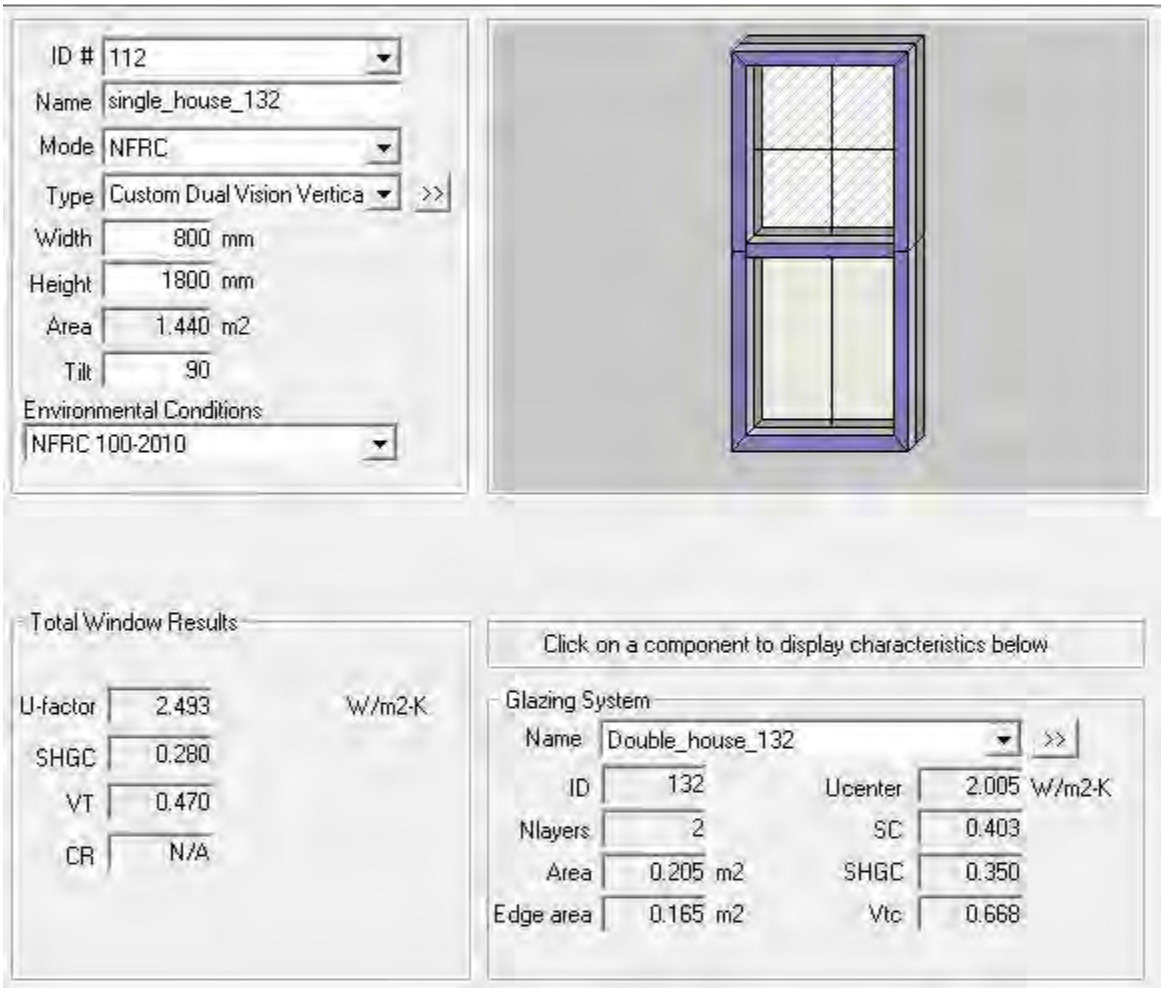


Figure I12. The characteristic of the whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

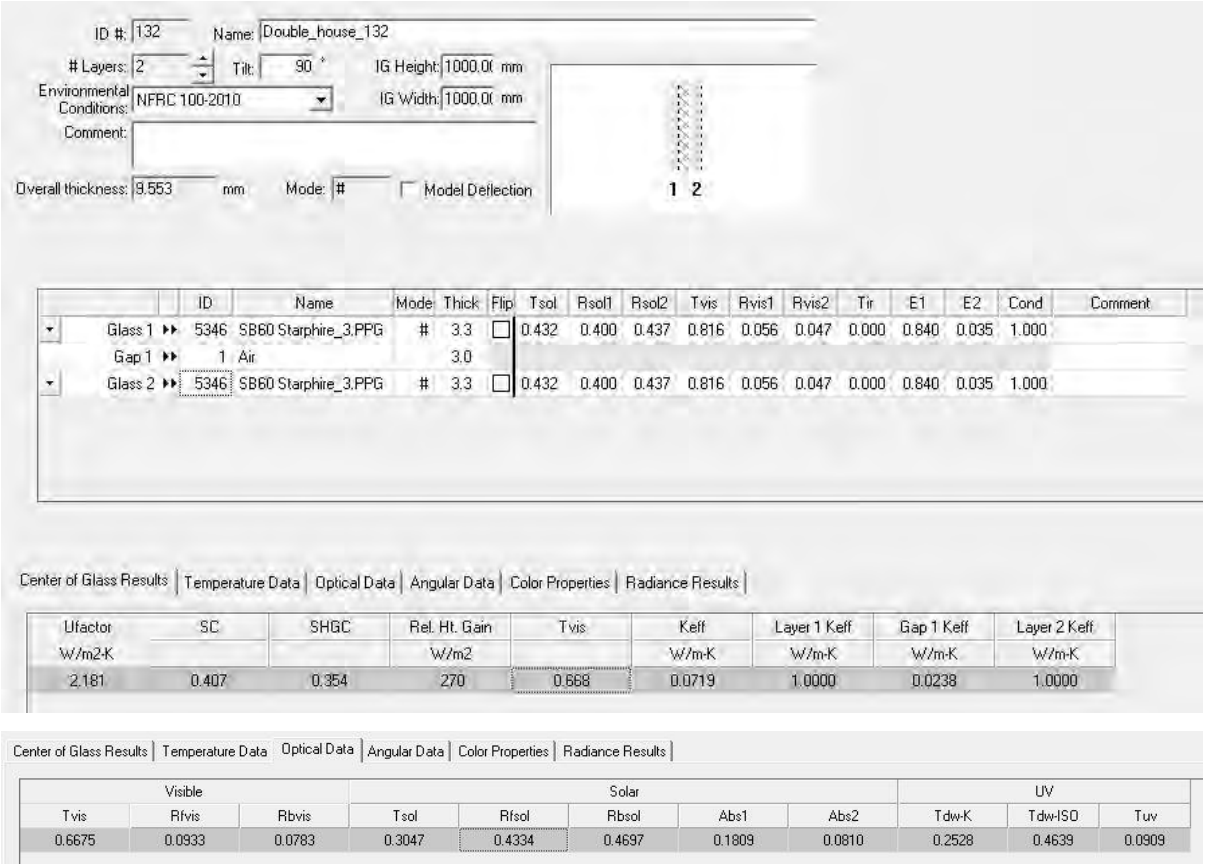
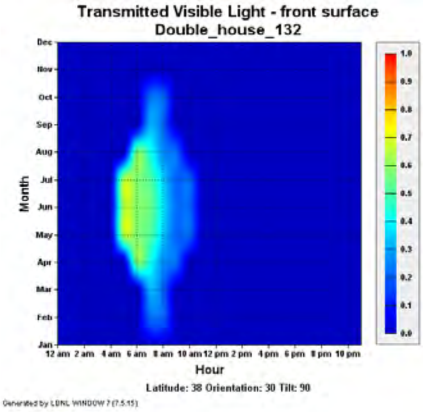
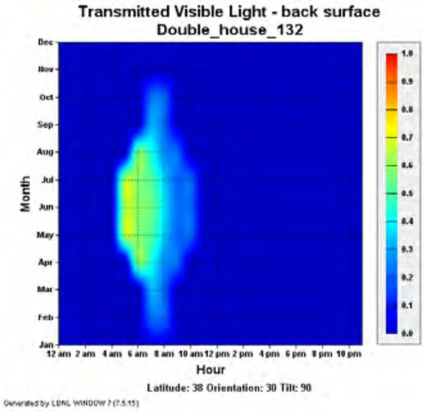


Figure I13. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I9. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.305	0.308	0.300	0.291	0.281	0.262	0.223	0.153	0.067	0.000	0.244
Abs1	0.181	0.183	0.189	0.195	0.196	0.201	0.214	0.229	0.197	0.001	0.200
Abs2	0.081	0.083	0.086	0.088	0.088	0.088	0.090	0.084	0.054	0.000	0.084
Rfsol	0.433	0.426	0.424	0.426	0.435	0.449	0.473	0.533	0.681	0.999	0.461
Rbsol	0.470	0.463	0.461	0.463	0.471	0.484	0.507	0.564	0.703	0.999	0.495
Tvis	0.668	0.676	0.659	0.638	0.615	0.574	0.486	0.332	0.144	0.000	0.534
Rfvis	0.093	0.081	0.077	0.081	0.097	0.123	0.168	0.273	0.512	0.999	0.150
Rbvis	0.078	0.066	0.062	0.067	0.083	0.110	0.156	0.262	0.506	0.999	0.137
SHGC	0.354	0.359	0.353	0.345	0.335	0.317	0.280	0.210	0.109	0.000	0.297

Table I10. Annual optical graphs.

<table>
<tr><th></th><th>Front surface</th><th>Back surface</th></tr>
<tr><td>Transmitted visible light</td><td>
</td><td>
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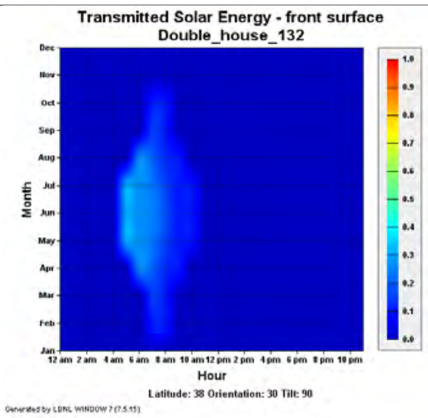
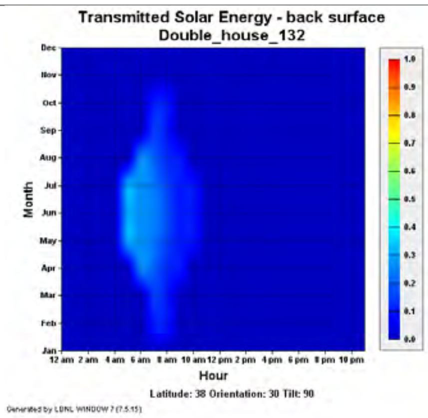
<tr><td>Transmitted solar energy</td><td>
</td><td>
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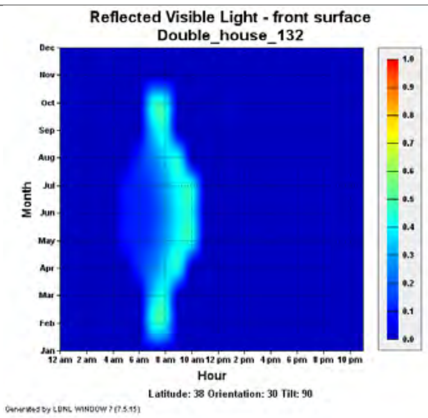
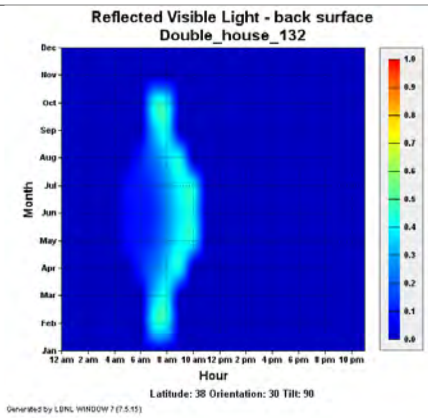
<tr><td>Reflected visible light</td><td>
</td><td>
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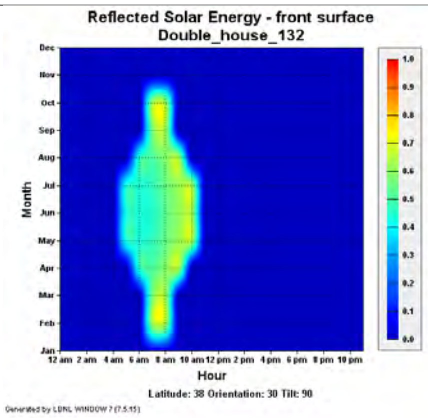
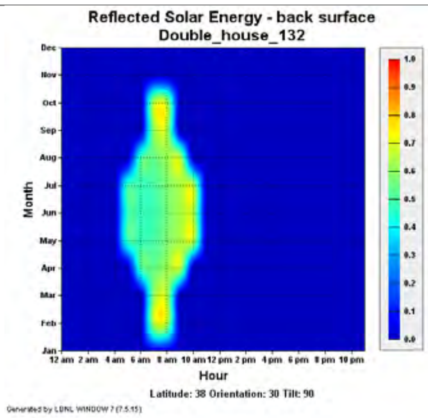
<tr><td>Reflected solar energy</td><td>
</td><td>
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I.6. Case 6. The window of a traditional house (age = 140)

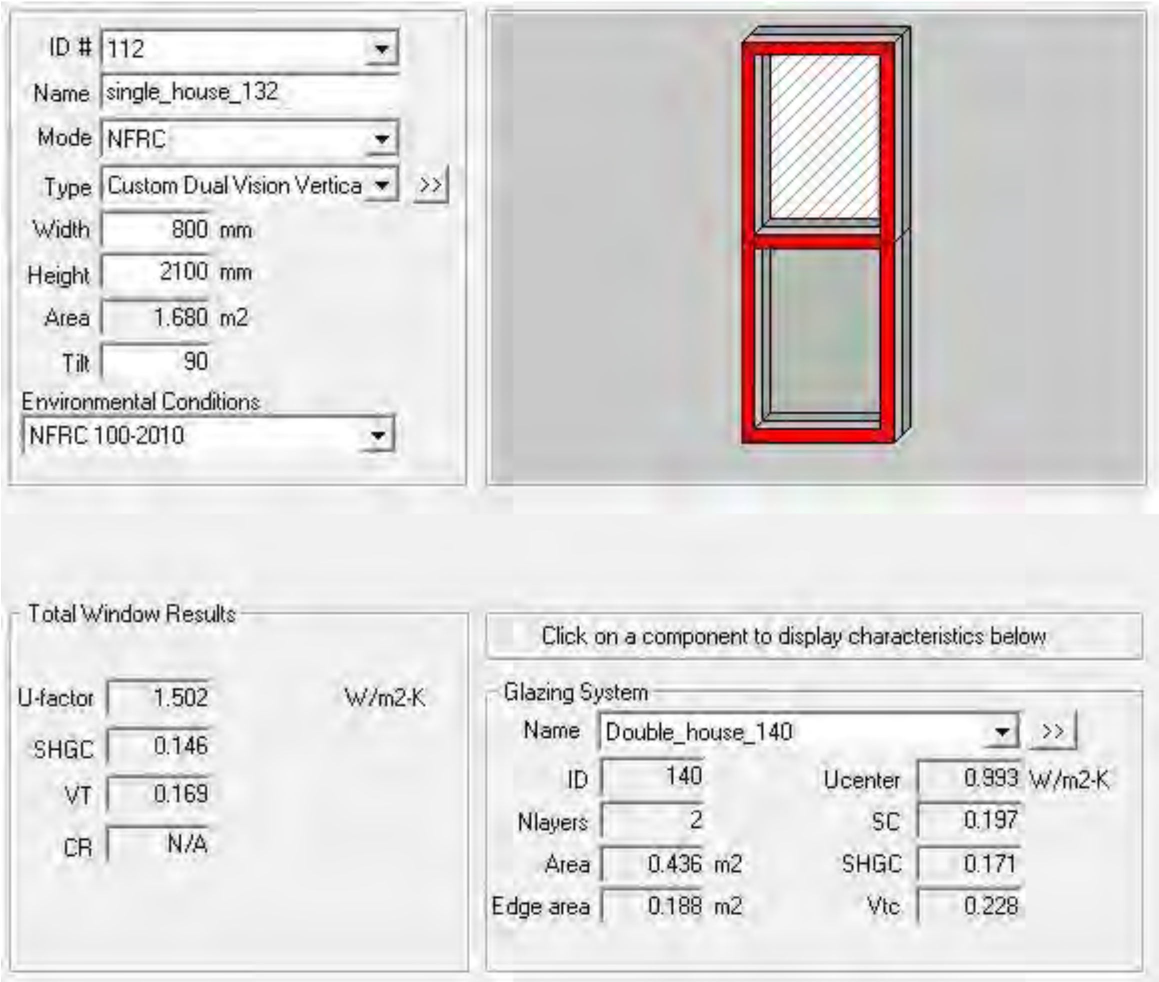


Figure I14. The characteristic of the whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

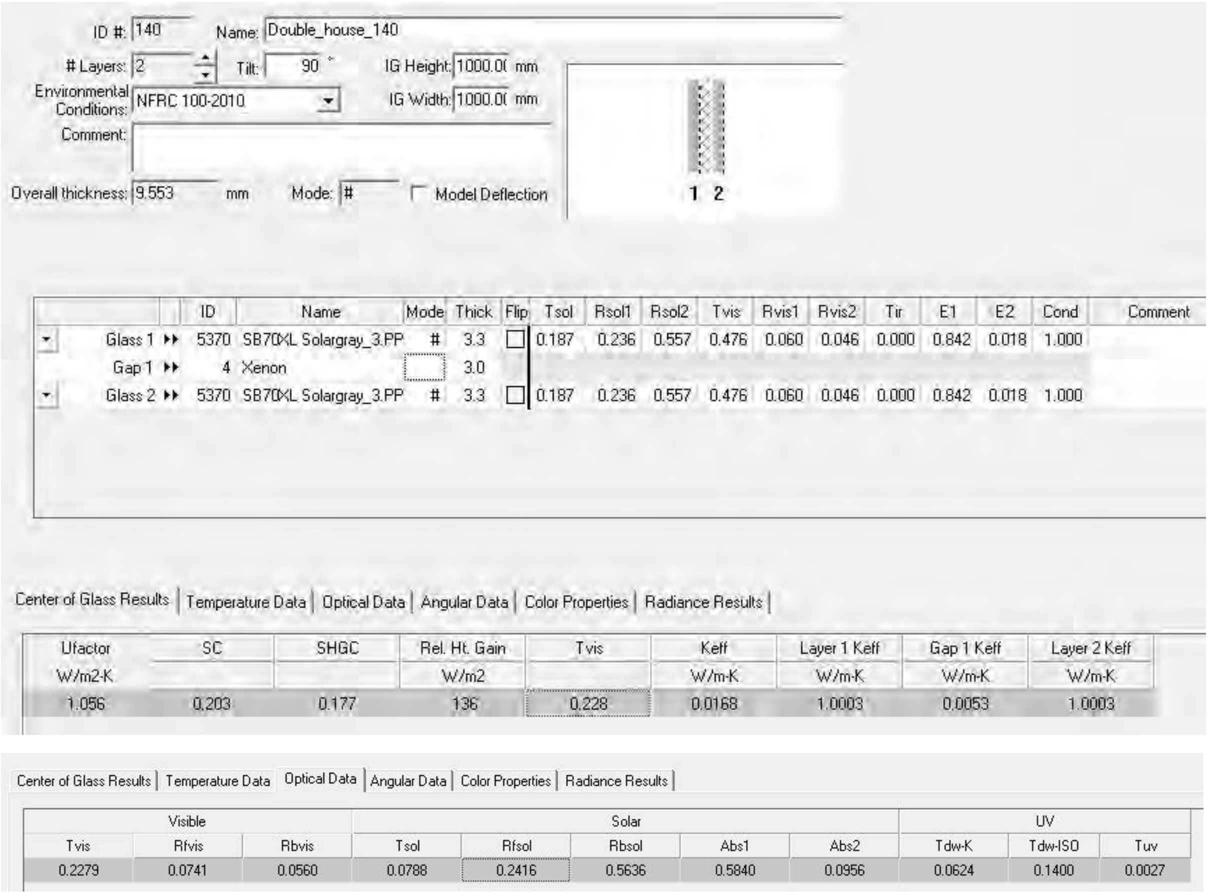
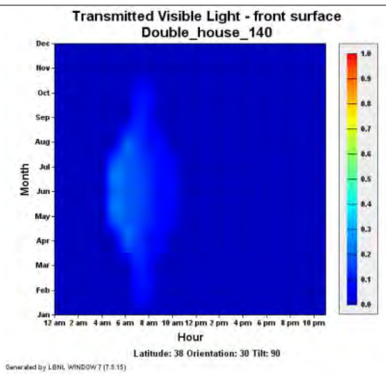
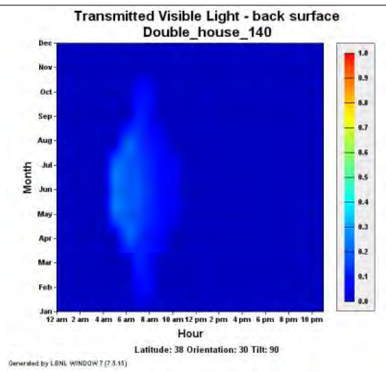
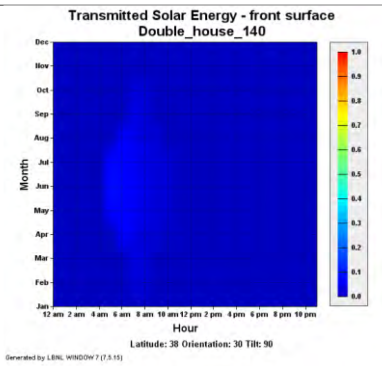
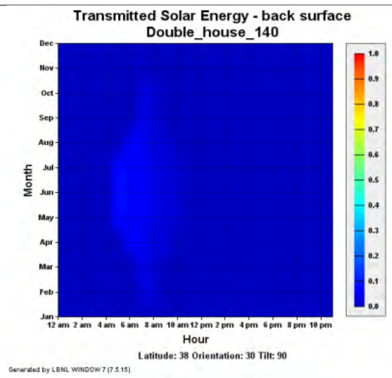
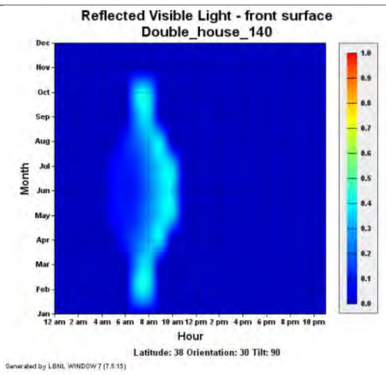
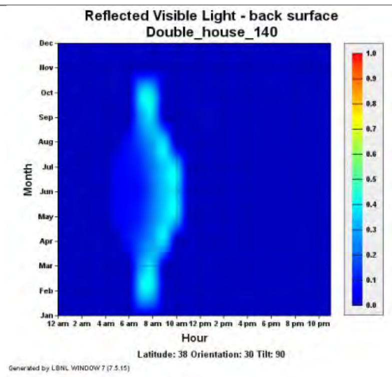
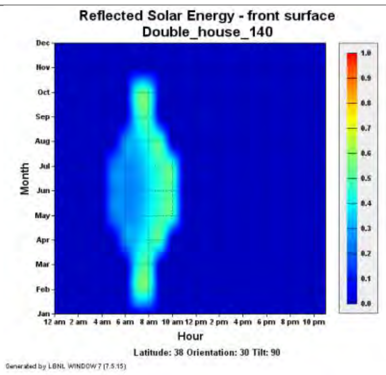
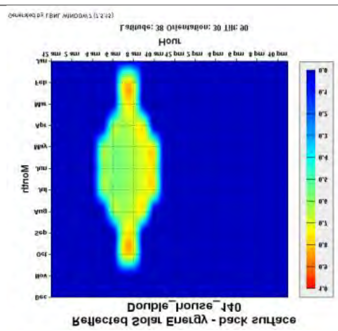


Figure I15. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I11. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.079	0.080	0.078	0.075	0.073	0.068	0.058	0.039	0.017	0.000	0.063
Abs1	0.584	0.589	0.592	0.593	0.588	0.581	0.569	0.528	0.385	0.001	0.560
Abs2	0.096	0.097	0.097	0.096	0.094	0.091	0.084	0.067	0.037	0.000	0.085
Rfsol	0.242	0.235	0.233	0.236	0.245	0.261	0.290	0.365	0.561	0.999	0.281
Rbsol	0.564	0.559	0.558	0.560	0.565	0.575	0.592	0.636	0.749	1.000	0.582
Tvis	0.228	0.231	0.225	0.218	0.210	0.196	0.166	0.113	0.049	0.000	0.182
Rfvis	0.074	0.065	0.062	0.066	0.078	0.099	0.137	0.232	0.472	0.999	0.126
Rbvis	0.056	0.046	0.044	0.048	0.061	0.082	0.121	0.218	0.463	0.999	0.110
SHGC	0.177	0.179	0.177	0.174	0.170	0.162	0.147	0.115	0.063	0.000	0.153

Table I12. Annual optical graphs.

	Front surface	Back surface
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.7. Case 7. The windows of a traditional house (age = 151)

I.7.1. Double glazing window

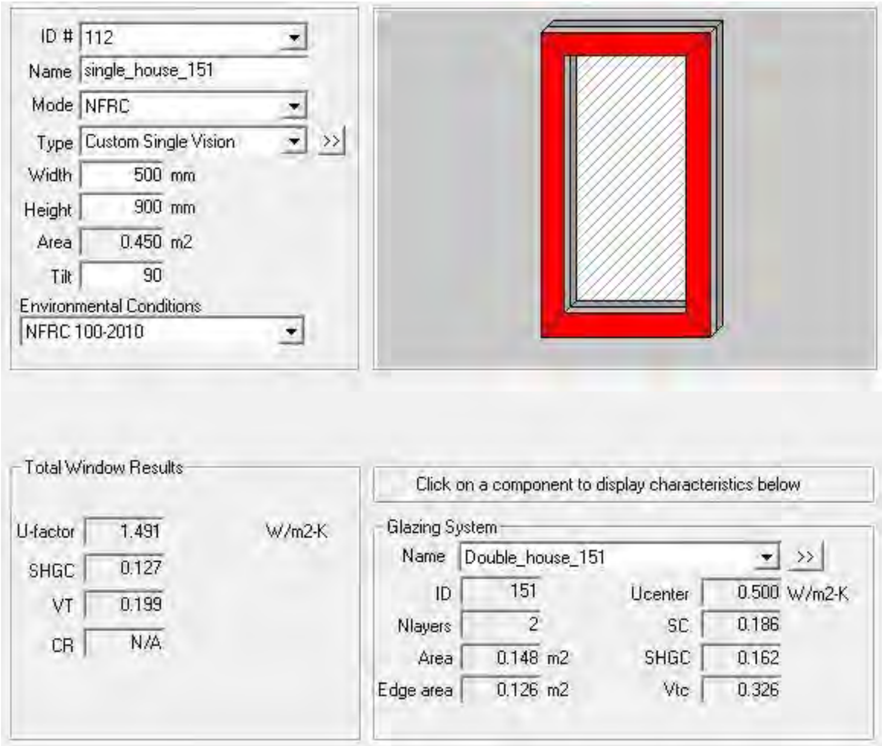


Figure I16. The characteristic of the whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

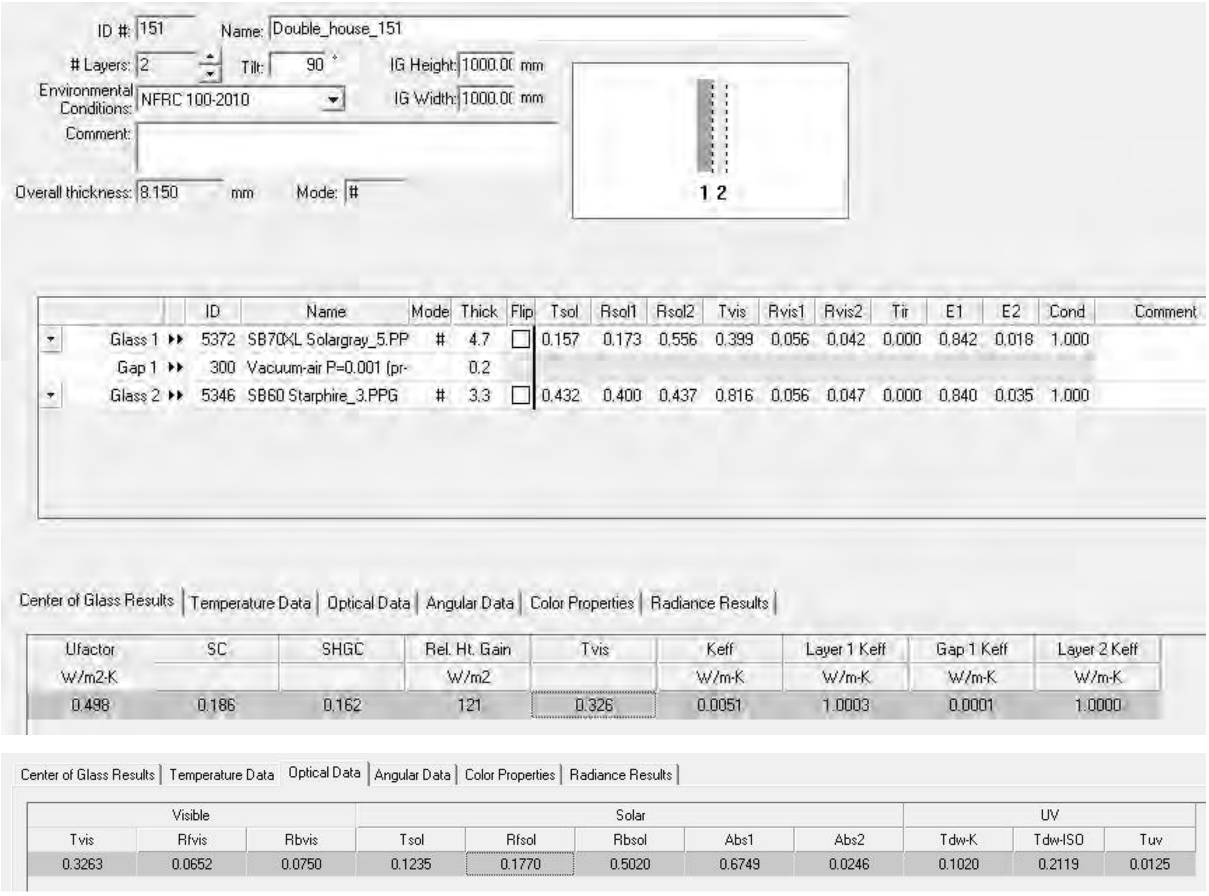
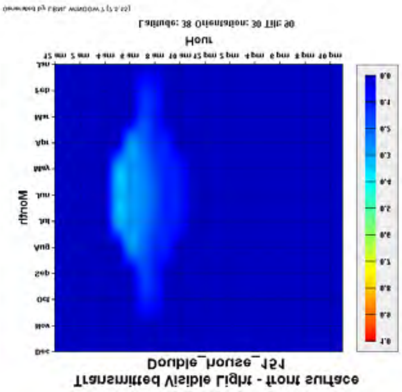
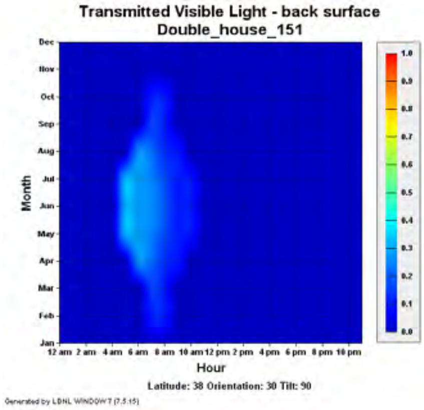
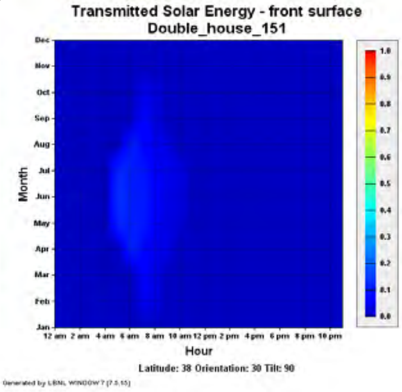
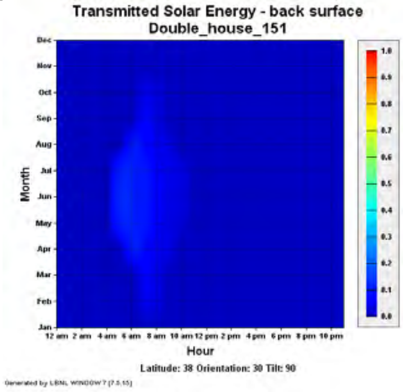
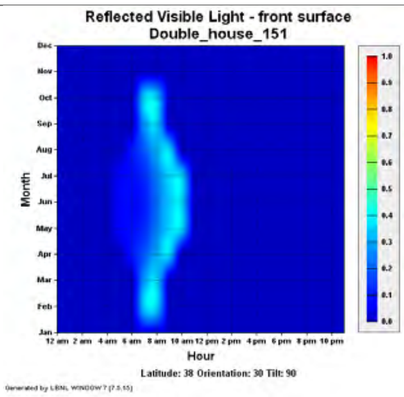
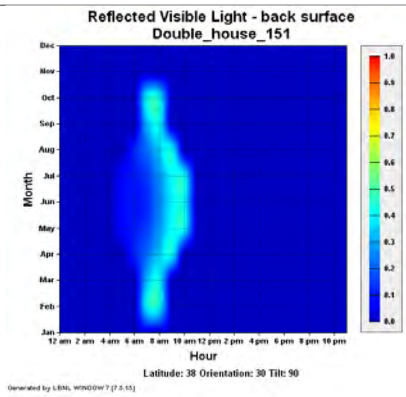
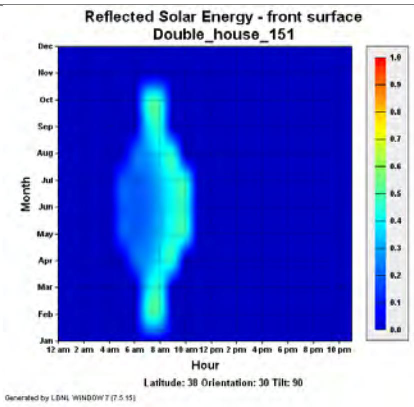
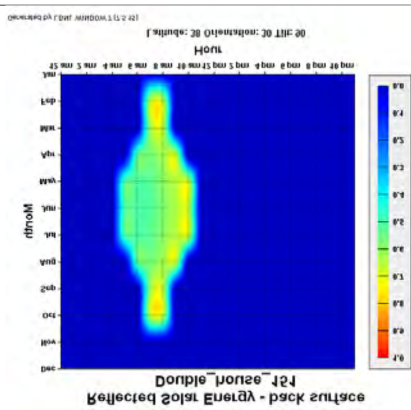


Figure I17. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I13. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.124	0.125	0.122	0.118	0.114	0.106	0.090	0.062	0.027	0.000	0.099
Abs1	0.675	0.680	0.683	0.683	0.678	0.668	0.652	0.600	0.432	0.001	0.644
Abs2	0.025	0.025	0.027	0.028	0.028	0.028	0.030	0.029	0.019	0.000	0.027
Rfsol	0.177	0.170	0.168	0.171	0.181	0.197	0.228	0.309	0.522	0.999	0.220
Rbsol	0.502	0.496	0.493	0.494	0.501	0.512	0.531	0.580	0.710	0.999	0.521
Tvis	0.326	0.330	0.322	0.312	0.301	0.281	0.238	0.162	0.070	0.000	0.261
Rfvis	0.065	0.056	0.054	0.058	0.070	0.090	0.127	0.221	0.463	0.999	0.117
Rbvis	0.075	0.062	0.059	0.064	0.080	0.107	0.153	0.261	0.505	0.999	0.135
SHGC	0.162	0.164	0.162	0.159	0.155	0.148	0.132	0.102	0.054	0.000	0.139

Table I14. Annual optical graphs.

	Front surface	Back surface
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.7.2. Single glazing window

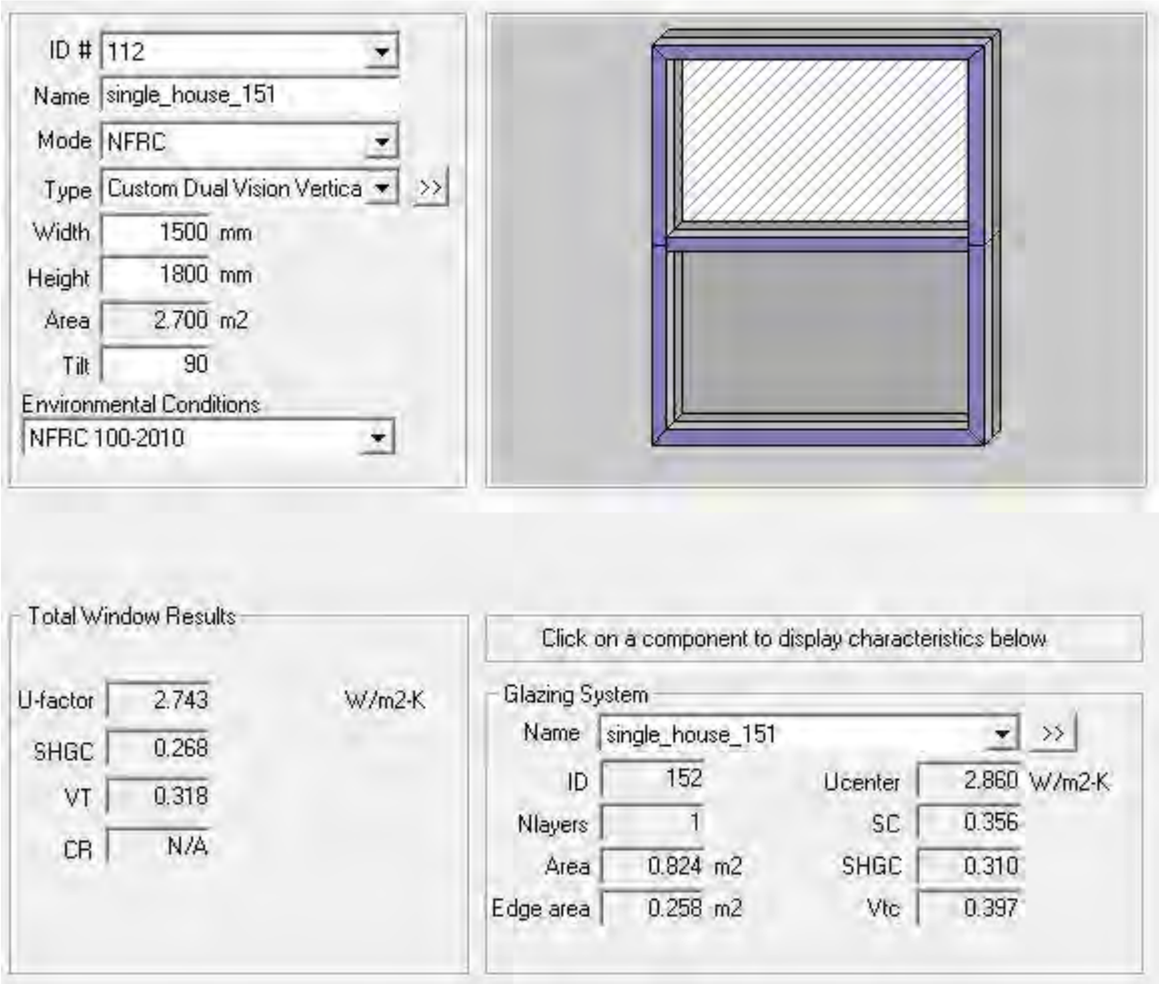
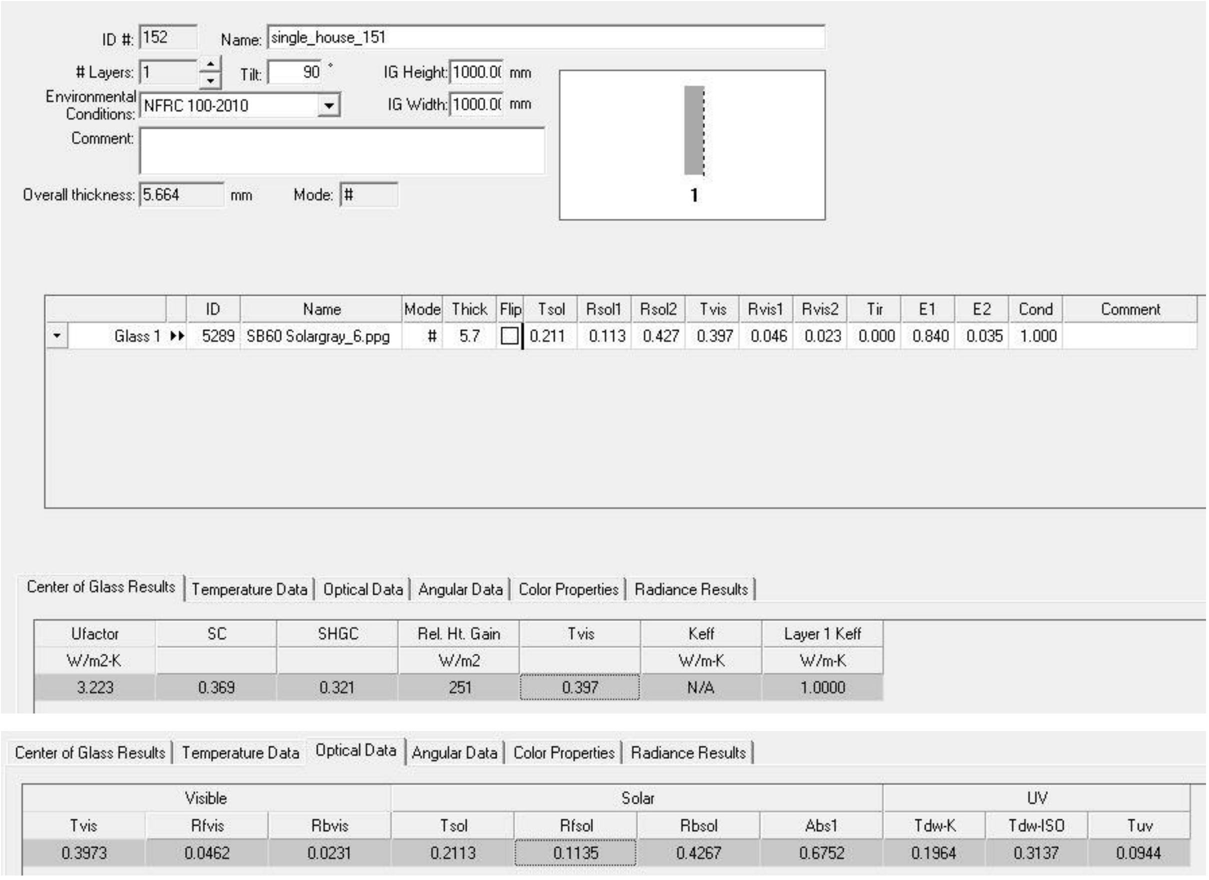


Figure I18. The characteristic of the whole single window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.



	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	5289	SB60 Solargray_6.ppg	#	5.7		0.211	0.113	0.427	0.397	0.046	0.023	0.000	0.840	0.035	1.000	

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff
W/m2-K			W/m2		W/m-K	W/m-K
3.223	0.369	0.321	251	0.397	N/A	1.0000

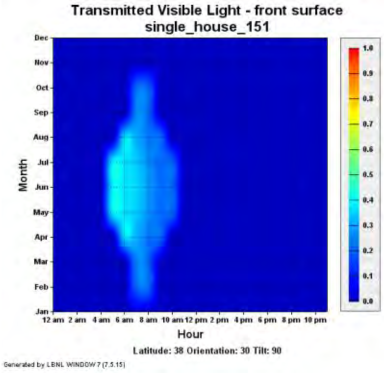
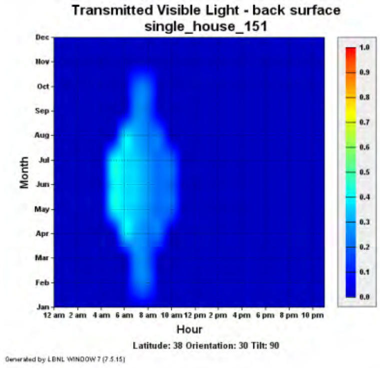
Visible			Solar				UV		
Tvis	Rfvis	Rbvis	Tsol	Rfsol	Rbsol	Abs1	Tdw-K	Tdw-ISO	Tuv
0.3973	0.0462	0.0231	0.2113	0.1135	0.4267	0.6752	0.1964	0.3137	0.0944

Figure I19. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I15 Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.211	0.213	0.210	0.207	0.203	0.196	0.180	0.146	0.088	0.000	0.185
Abs1	0.675	0.681	0.685	0.686	0.680	0.670	0.653	0.601	0.431	0.001	0.645
Rfsol	0.113	0.106	0.105	0.108	0.118	0.135	0.167	0.253	0.481	0.999	0.160
Rbsol	0.427	0.422	0.421	0.423	0.429	0.440	0.461	0.517	0.664	0.999	0.453
Tvis	0.397	0.400	0.395	0.389	0.381	0.368	0.338	0.275	0.165	0.000	0.347
Rfvis	0.046	0.038	0.037	0.040	0.051	0.069	0.104	0.196	0.442	0.999	0.097
Rbvis	0.023	0.015	0.013	0.017	0.028	0.046	0.082	0.177	0.428	0.999	0.076
SHGC	0.321	0.324	0.322	0.319	0.314	0.305	0.286	0.243	0.156	0.000	0.290

Table I16. Annual optical graphs.

<table>
<tr><th></th><th>Front surface</th><th>Back surface</th></tr>
<tr><td>Transmitted visible light</td><td>
</td><td>
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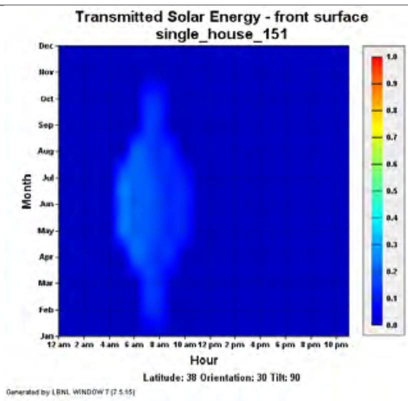
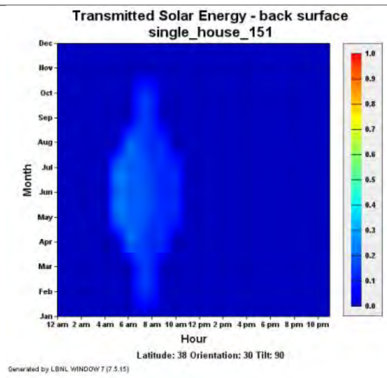
<tr><td>Transmitted solar energy</td><td>
</td><td>
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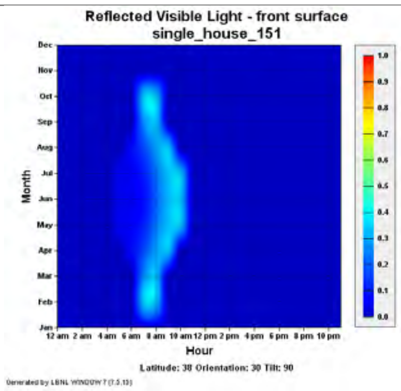
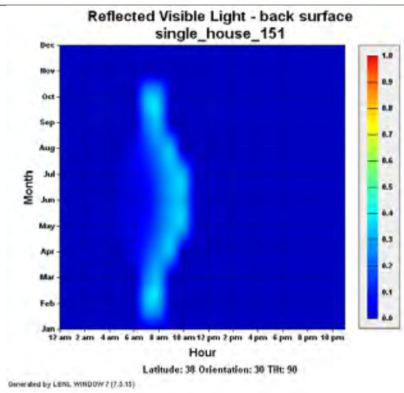
<tr><td>Reflected visible light</td><td>
</td><td>
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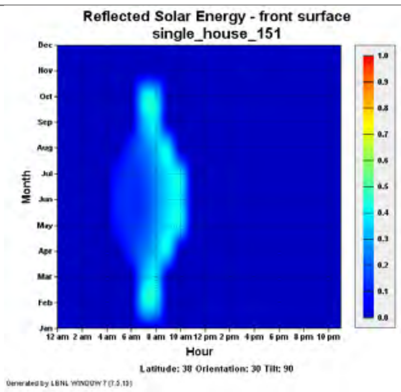
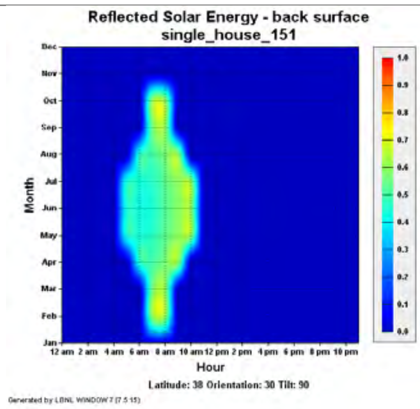
<tr><td>Reflected solar energy</td><td>
</td><td>
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I.8. Case 8. The window of a traditional house (age = 160)

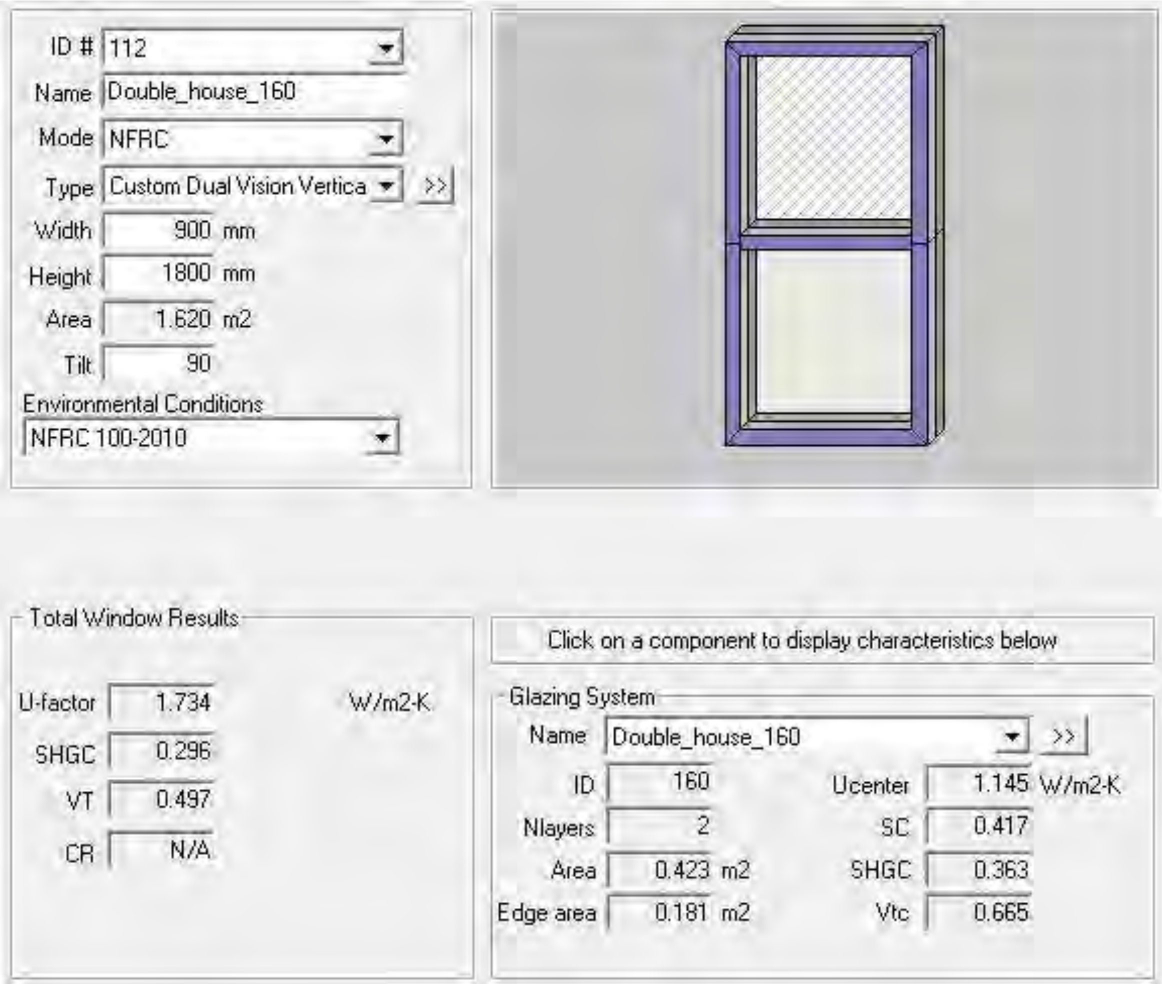


Figure I20. The characteristic of the whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

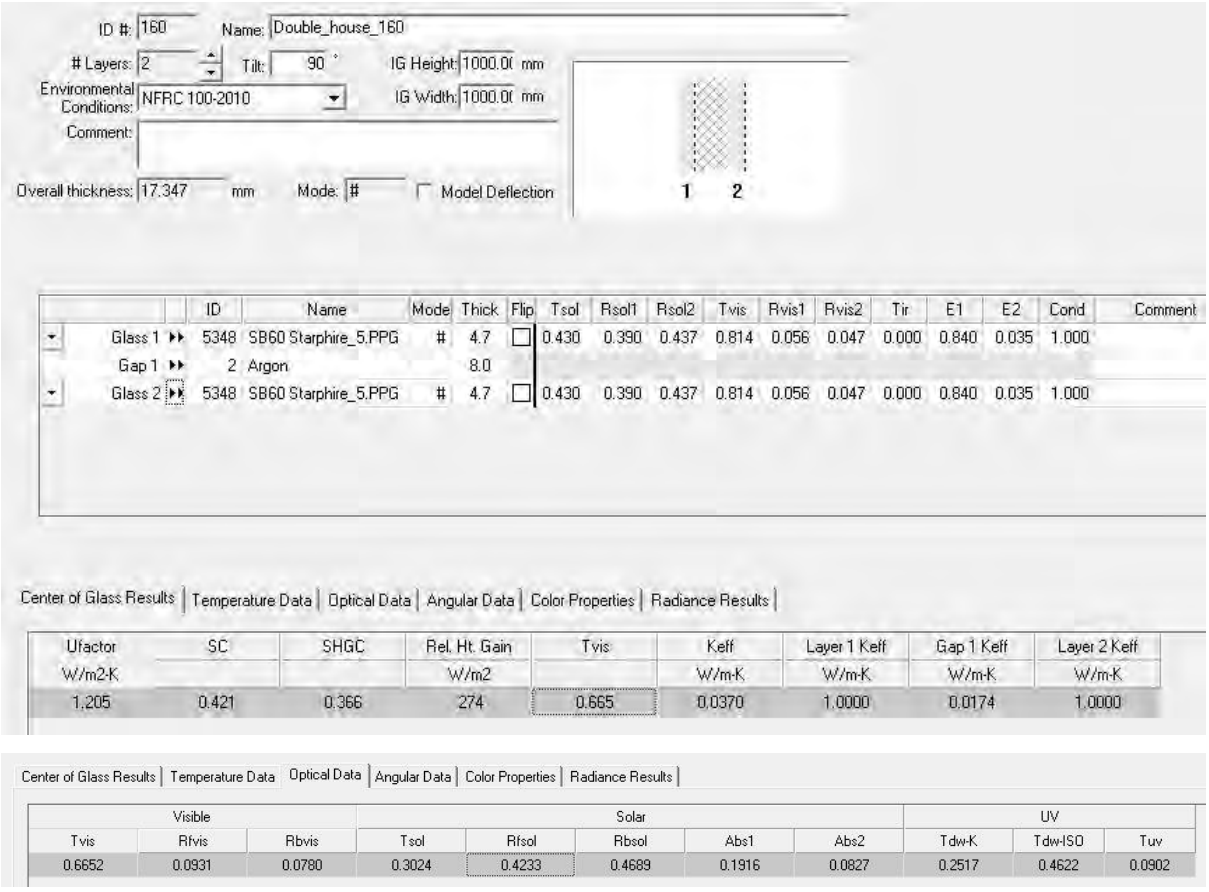
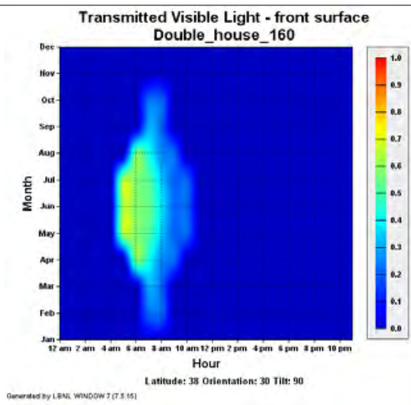
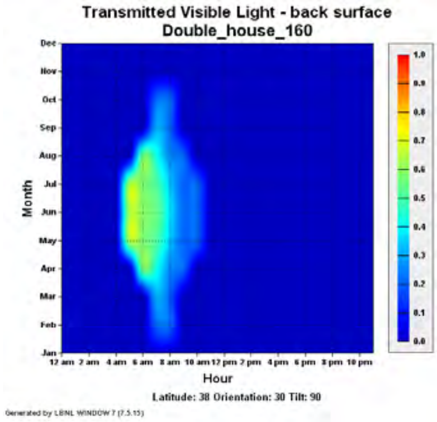
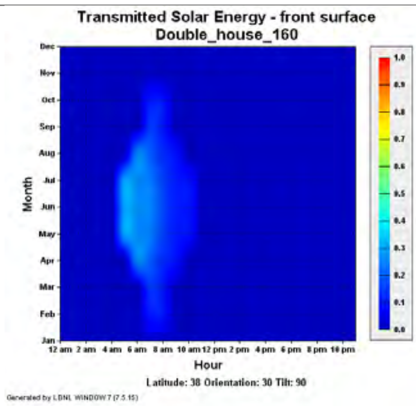
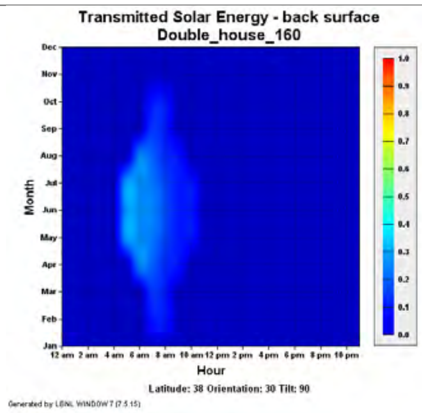
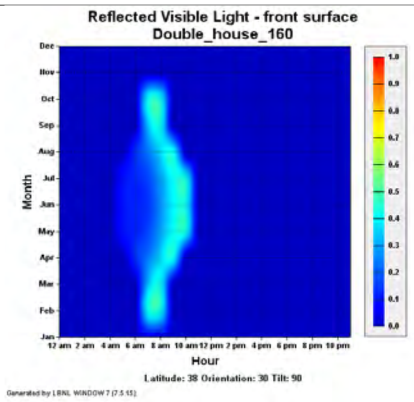
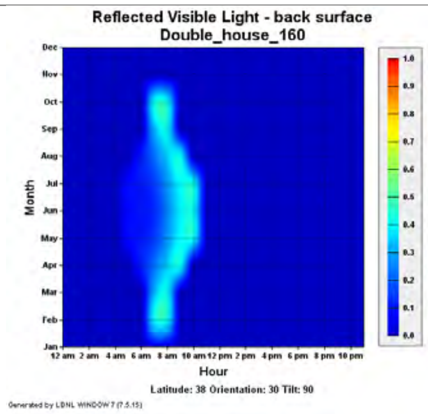
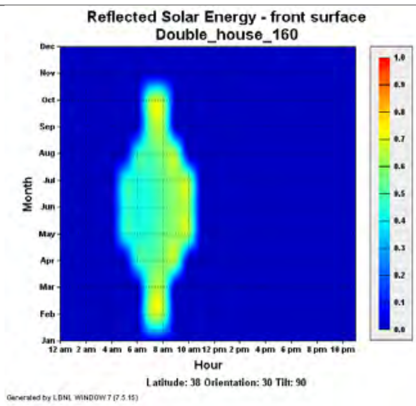
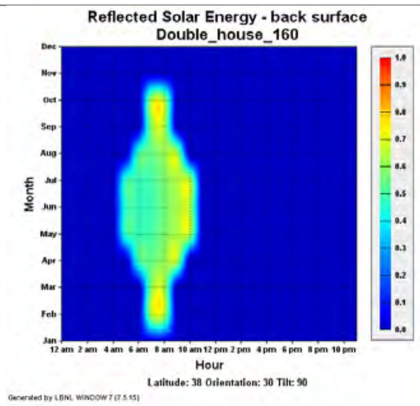


Figure I21. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I17. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.302	0.306	0.298	0.289	0.279	0.260	0.221	0.152	0.067	0.000	0.243
Abs1	0.192	0.193	0.200	0.205	0.207	0.211	0.224	0.238	0.203	0.001	0.210
Abs2	0.083	0.084	0.088	0.090	0.090	0.090	0.091	0.085	0.054	0.000	0.086
Rfsol	0.423	0.416	0.414	0.416	0.425	0.439	0.464	0.525	0.675	0.999	0.452
Rbsol	0.469	0.462	0.460	0.462	0.470	0.484	0.507	0.564	0.703	0.999	0.495
Tvis	0.665	0.674	0.656	0.636	0.613	0.572	0.485	0.331	0.143	0.000	0.533
Rfvis	0.093	0.080	0.077	0.081	0.097	0.123	0.168	0.272	0.511	0.999	0.150
Rbvis	0.078	0.065	0.062	0.066	0.083	0.109	0.155	0.262	0.505	0.999	0.137
SHGC	0.366	0.371	0.365	0.358	0.348	0.330	0.292	0.221	0.113	0.000	0.309

Table I18. Annual optical graphs.

	Front surface	Back surface
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.9. Case 9. The window of a traditional house (age = 164)

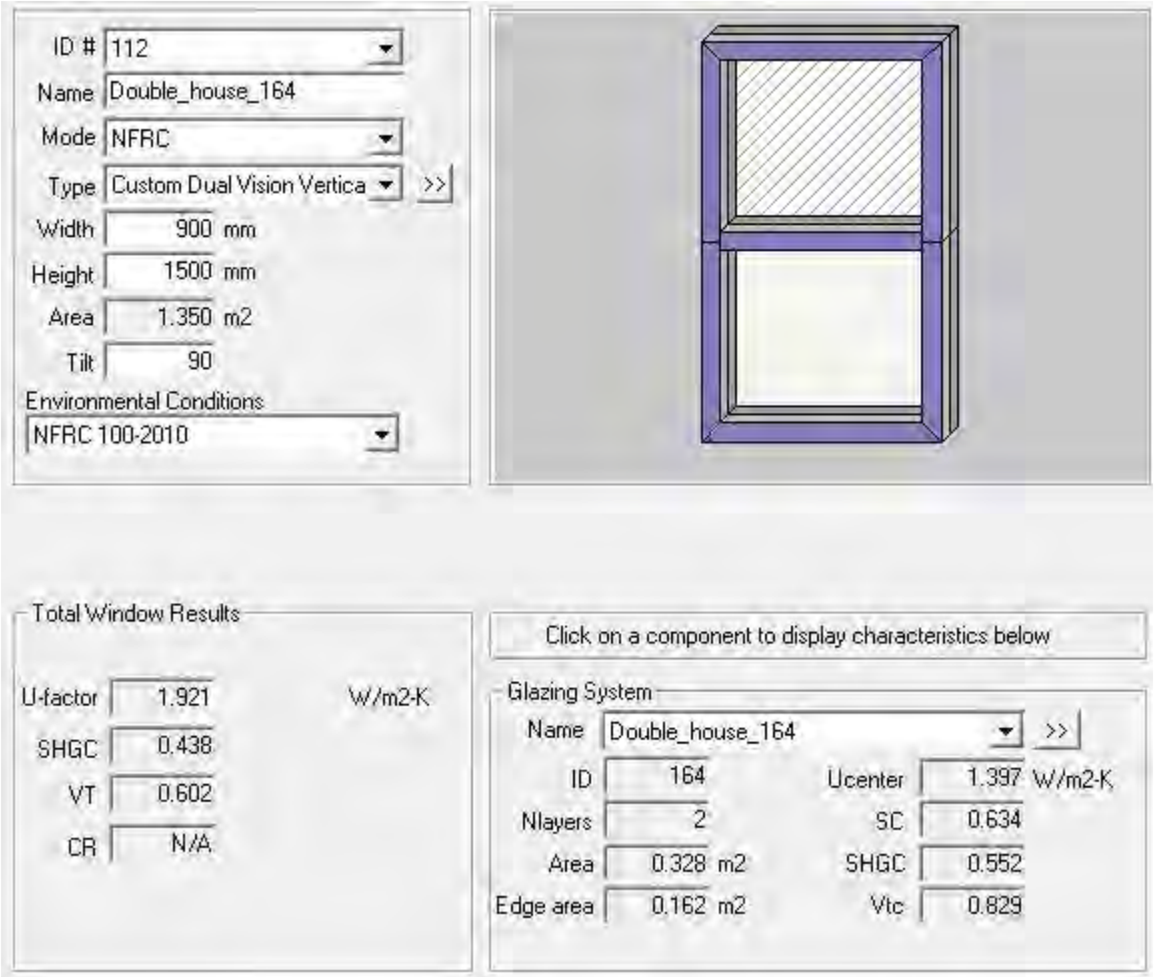
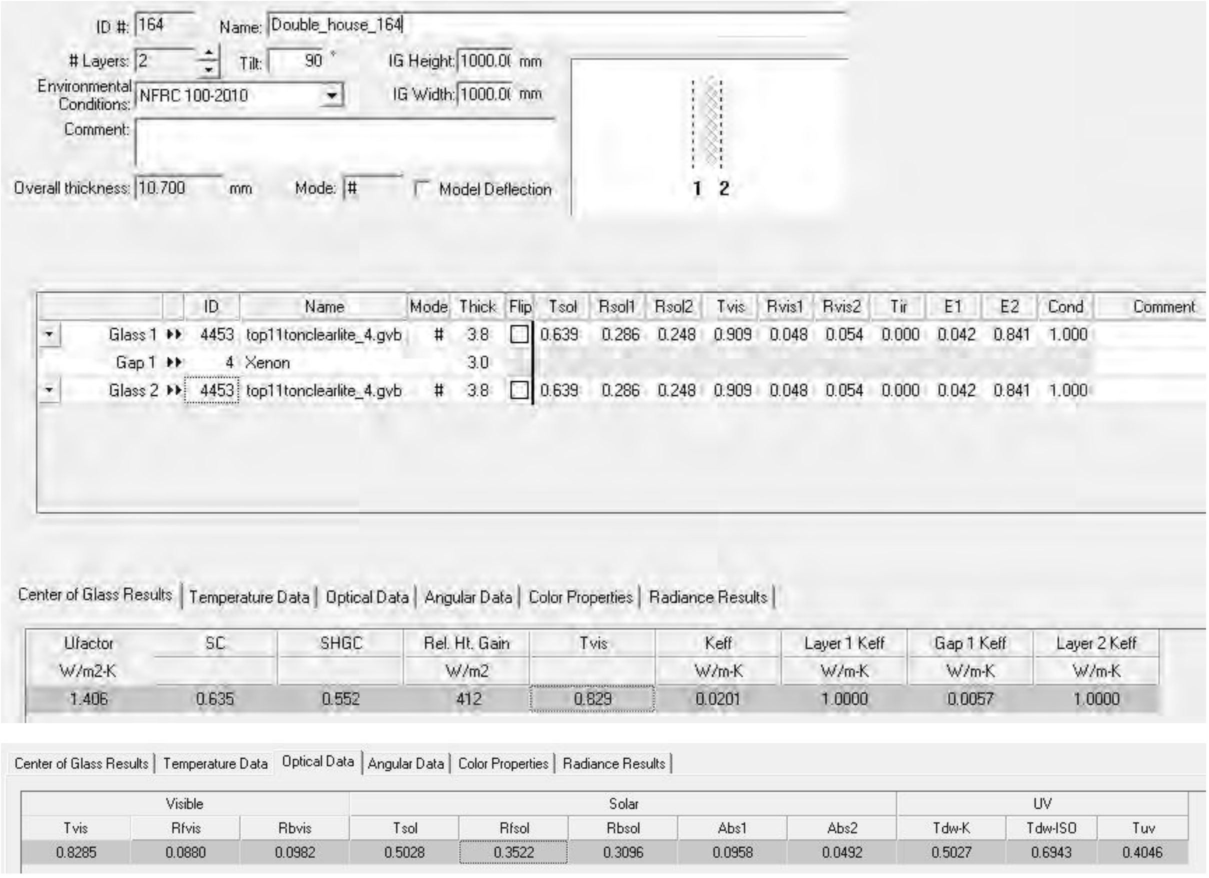


Figure I22. The characteristic of the whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 164 Name: Double_house_164
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 10.700 mm Mode: # Model Deflection
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	4453	top11tonclearlite_4.gvb	#	3.8		0.639	0.286	0.248	0.909	0.048	0.054	0.000	0.042	0.841	1.000	
Gap 1	4	Xenon		3.0												
Glass 2	4453	top11tonclearlite_4.gvb	#	3.8		0.639	0.286	0.248	0.909	0.048	0.054	0.000	0.042	0.841	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.406	0.635	0.552	412	0.829	0.0201	1.0000	0.0057	1.0000

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

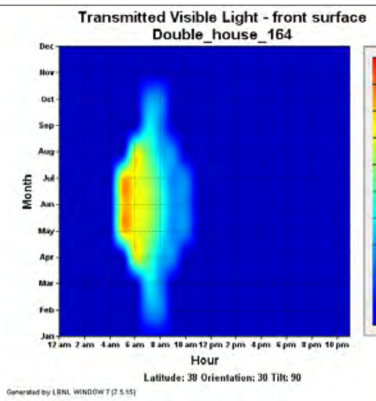
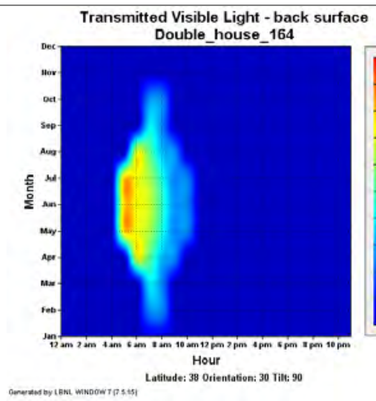
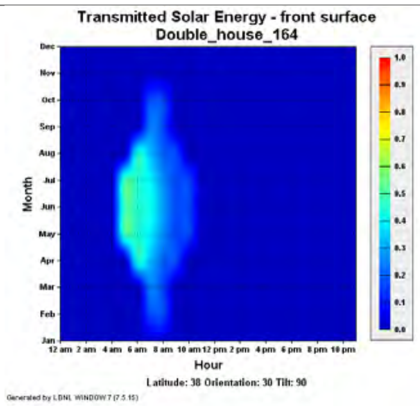
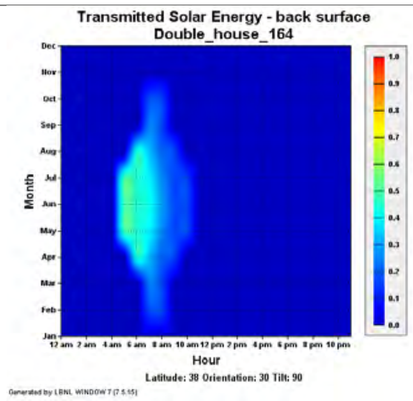
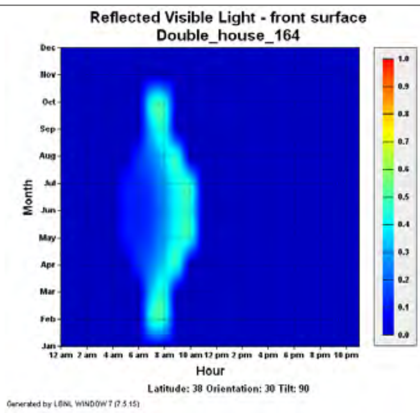
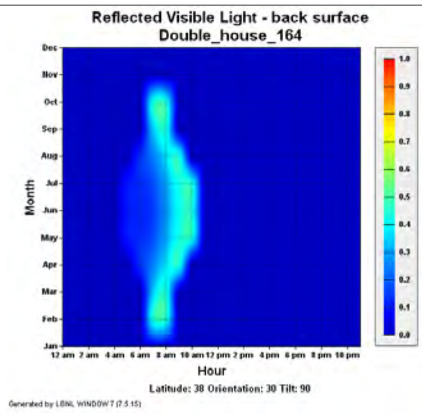
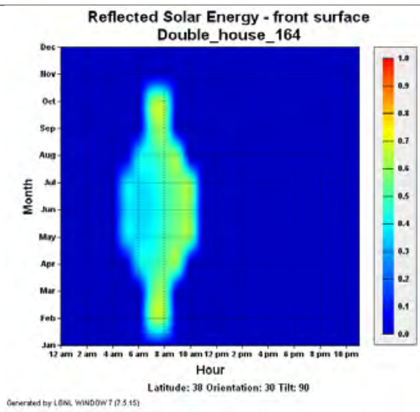
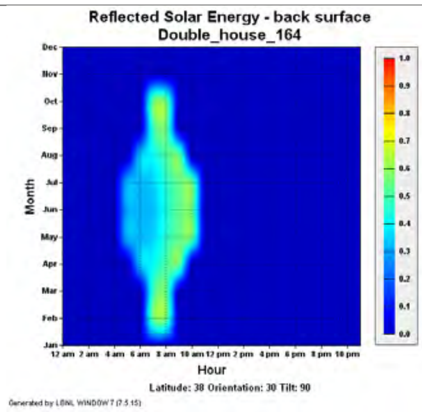
Visible			Solar					UV		
Tvis	Rfvis	Rbvis	Tsol	Rfsol	Rbsol	Abs1	Abs2	Tdw-K	Tdw-ISO	Tuv
0.8285	0.0880	0.0982	0.5028	0.3522	0.3096	0.0958	0.0492	0.5027	0.6943	0.4046

Figure I23. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I19. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.503	0.509	0.496	0.480	0.463	0.433	0.369	0.254	0.112	0.000	0.404
Abs1	0.096	0.097	0.107	0.116	0.120	0.129	0.155	0.192	0.188	0.001	0.134
Abs2	0.049	0.051	0.057	0.062	0.064	0.068	0.079	0.086	0.062	0.000	0.067
Rfsol	0.352	0.343	0.340	0.342	0.352	0.369	0.398	0.467	0.638	0.999	0.385
Rbsol	0.310	0.300	0.297	0.299	0.310	0.328	0.359	0.433	0.615	0.999	0.346
Tvis	0.829	0.839	0.817	0.792	0.763	0.712	0.603	0.412	0.178	0.000	0.663
Rfvis	0.088	0.074	0.070	0.075	0.093	0.121	0.170	0.280	0.522	0.999	0.149
Rbvis	0.098	0.084	0.080	0.085	0.103	0.131	0.178	0.286	0.526	0.999	0.157
SHGC	0.552	0.559	0.553	0.543	0.528	0.502	0.449	0.344	0.182	0.000	0.472

Table I20. Annual optical graphs.

	Front surface	**Back surface**
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.10. Case 10. The windows of a traditional house (age = 169)

I.10.1. Double glazing window

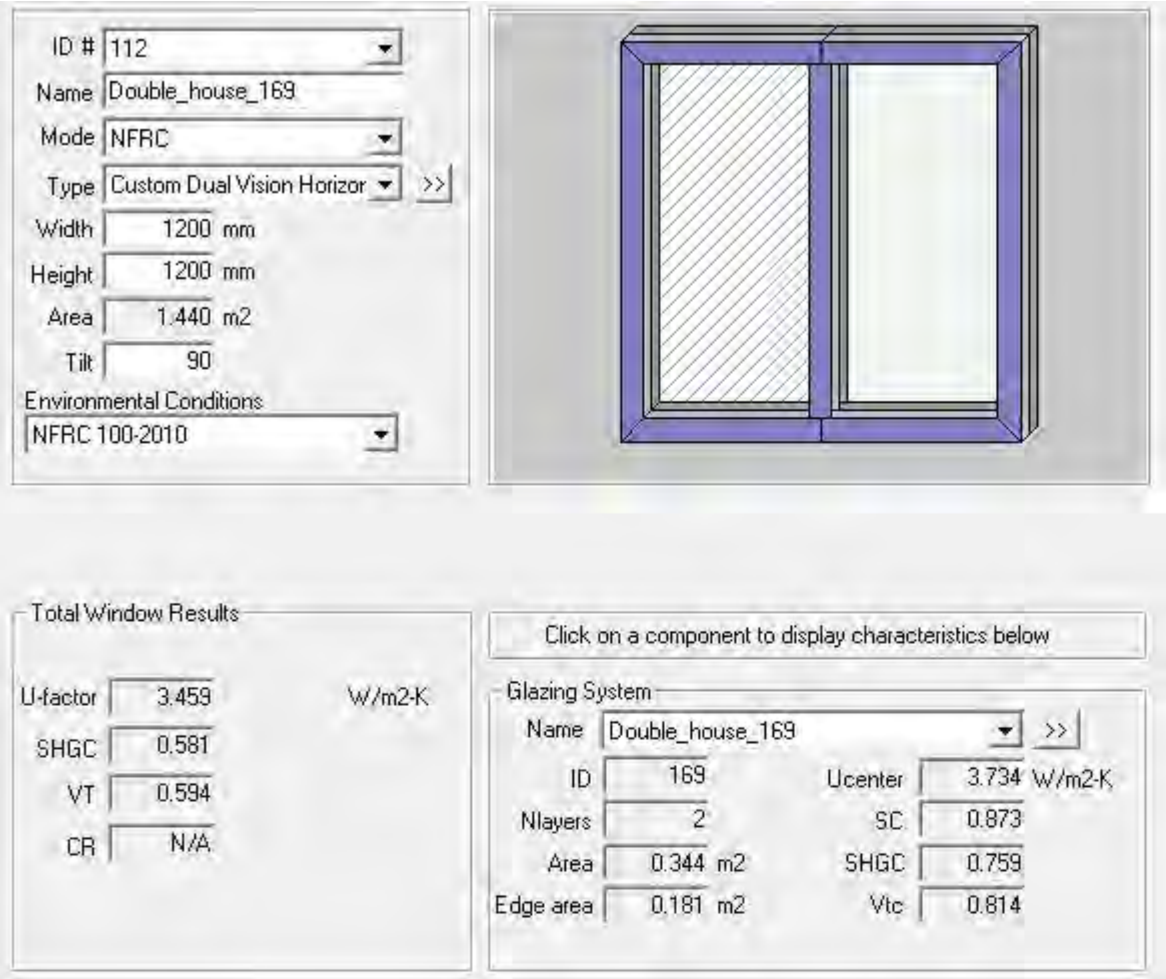
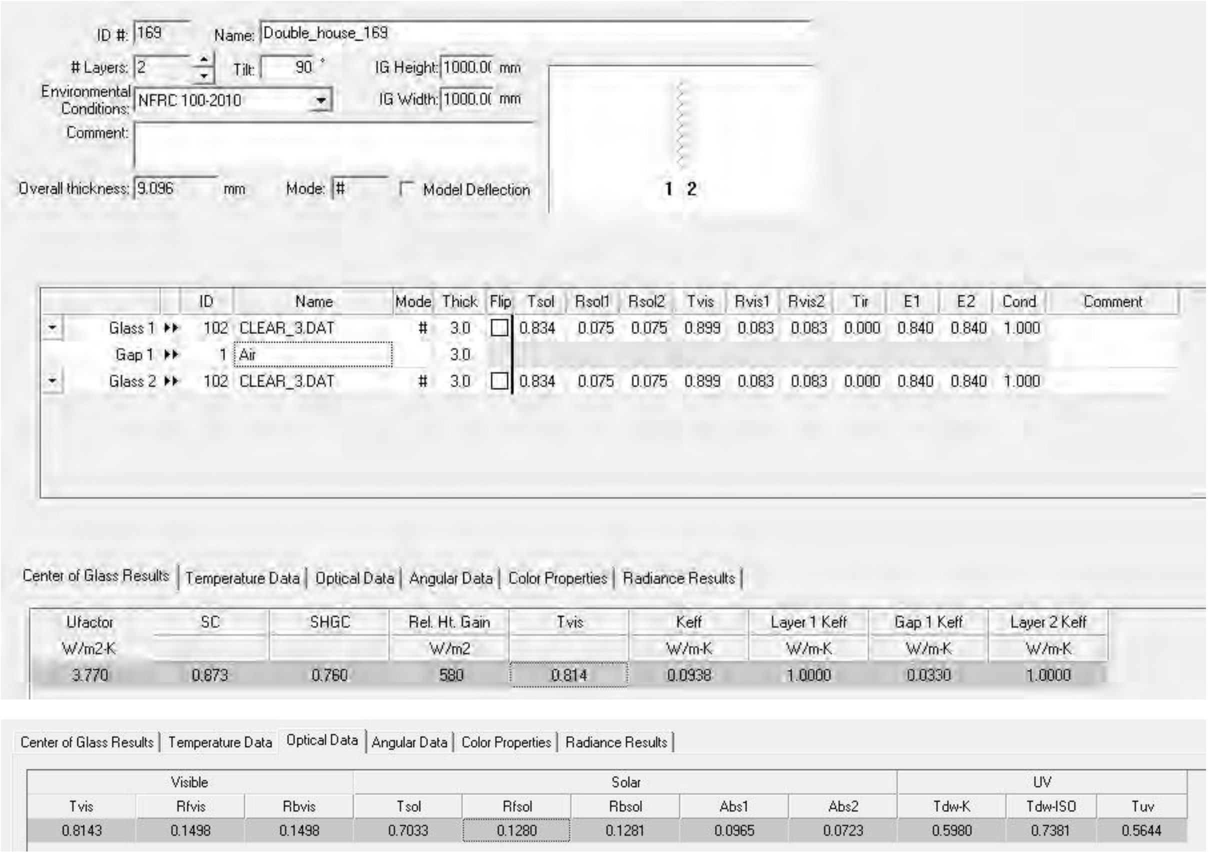


Figure I24. The characteristic of the whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 169 Name: Double_house_169
Layers: 2 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 9.096 mm Mode: # Model Deflection
1 2

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1 ▸▸	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	
Gap 1 ▸▸	1	Air		3.0												
Glass 2 ▸▸	102	CLEAR_3.DAT	#	3.0		0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results |

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
3.770	0.873	0.760	580	0.814	0.0938	1.0000	0.0330	1.0000

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results |

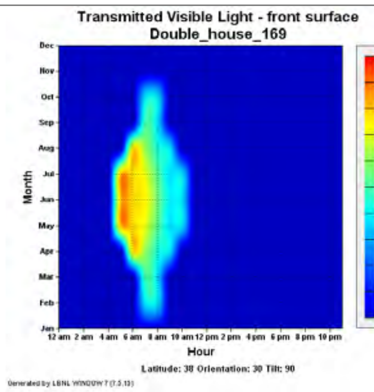
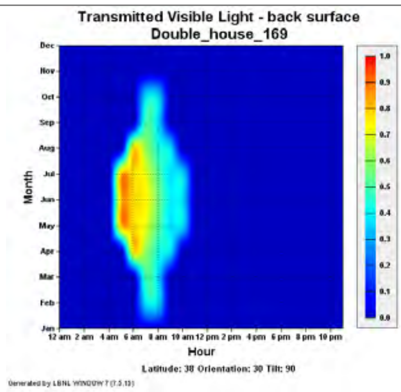
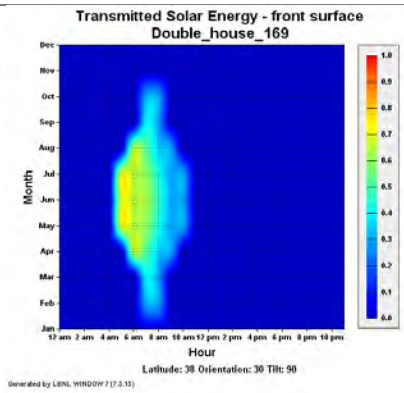
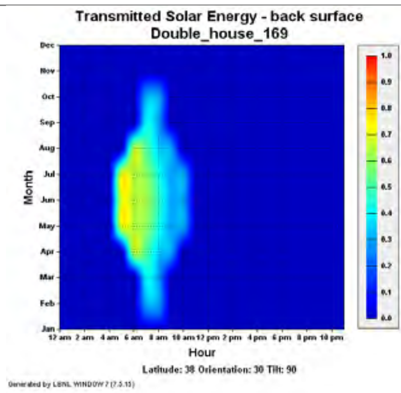
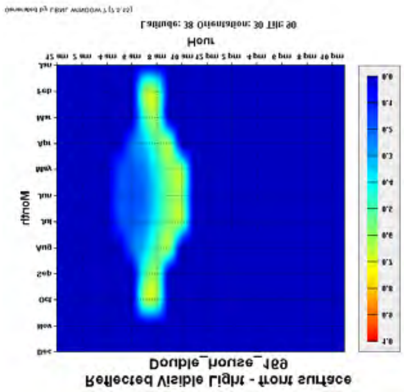
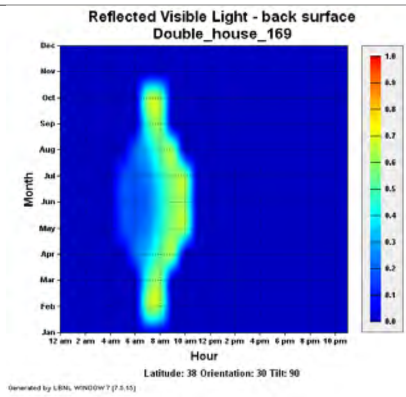
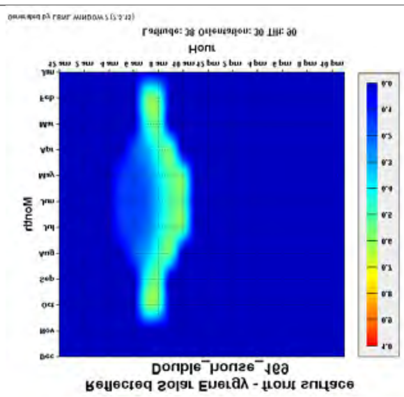
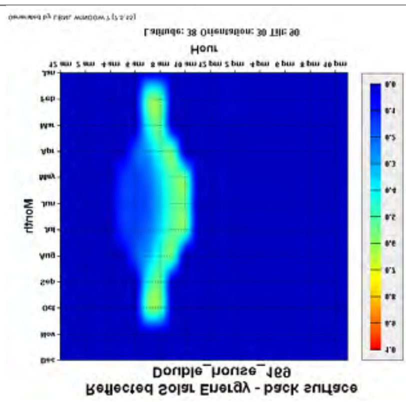
Visible			Solar					UV		
Tvis	Rfvis	Rbvis	Tsol	Rfsol	Rbsol	Abs1	Abs2	Tdw-K	Tdw-ISO	Tuv
0.8143	0.1498	0.1498	0.7033	0.1280	0.1281	0.0965	0.0723	0.5980	0.7381	0.5644

Figure I25. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I21. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.703	0.702	0.699	0.692	0.678	0.646	0.577	0.438	0.208	0.000	0.601
Abs1	0.096	0.097	0.099	0.102	0.106	0.112	0.119	0.127	0.130	0.000	0.110
Abs2	0.072	0.073	0.074	0.075	0.077	0.078	0.077	0.070	0.050	0.000	0.073
Rfsol	0.128	0.128	0.128	0.130	0.139	0.164	0.227	0.365	0.612	1.000	0.206
Rbsol	0.128	0.128	0.128	0.130	0.139	0.164	0.227	0.365	0.612	1.000	0.206
Tvis	0.814	0.814	0.813	0.809	0.797	0.766	0.693	0.537	0.273	0.000	0.712
Rfvis	0.150	0.150	0.150	0.153	0.164	0.193	0.264	0.418	0.682	1.000	0.238
Rbvis	0.150	0.150	0.150	0.153	0.164	0.193	0.264	0.418	0.682	1.000	0.238
SHGC	0.760	0.759	0.757	0.752	0.739	0.709	0.641	0.500	0.260	0.000	0.661

Table I22. Annual optical graphs.

	Front surface	**Back surface**
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.10.2. Single glazing window

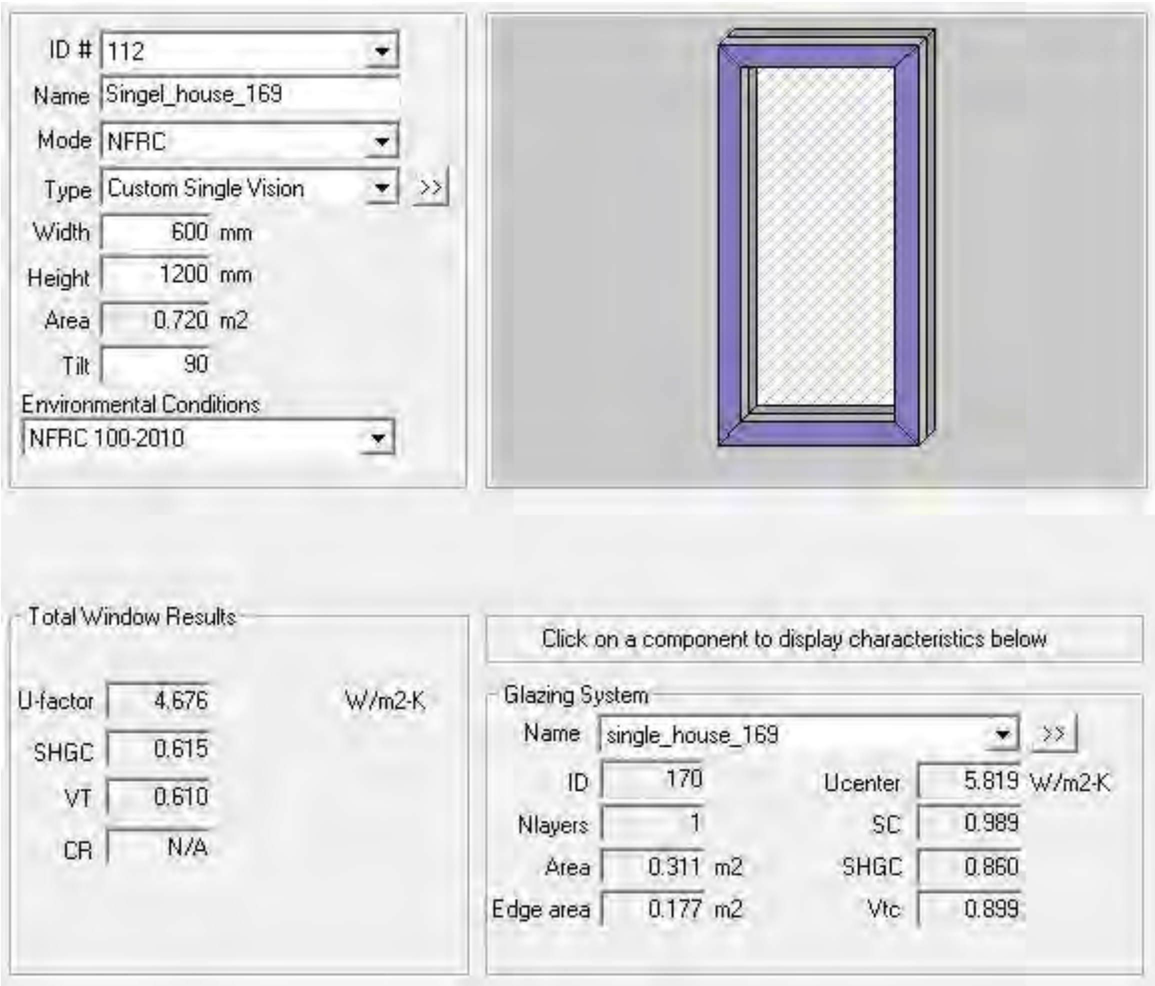


Figure I26. The characteristic of the whole single window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

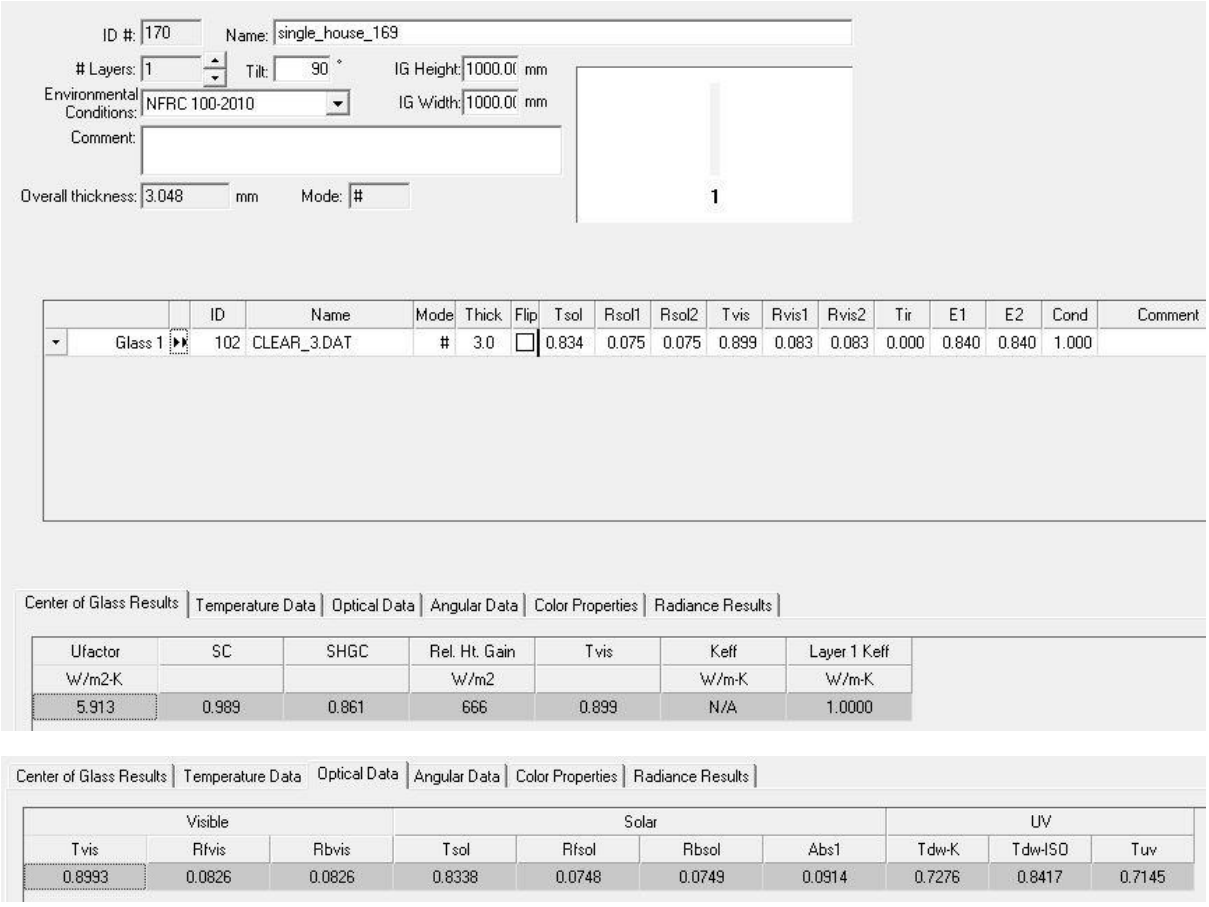
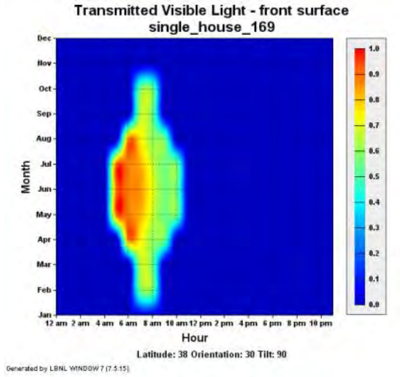
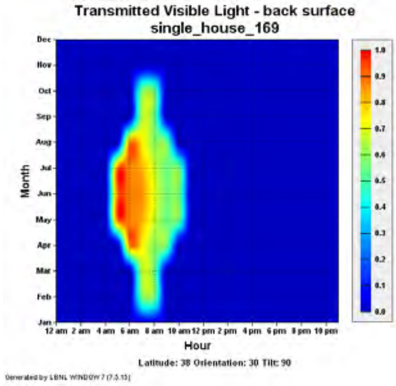
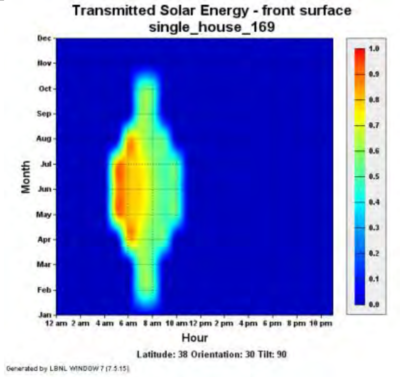
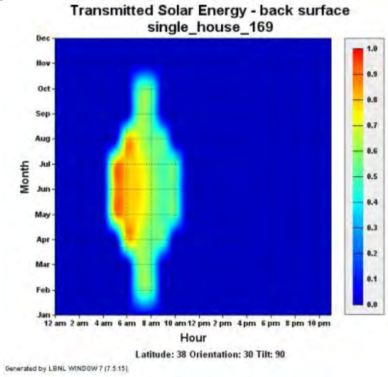
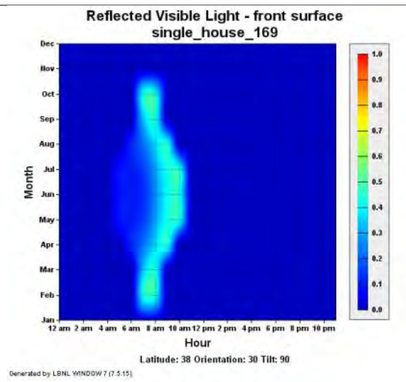
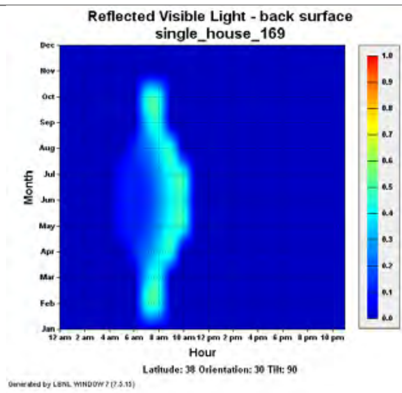
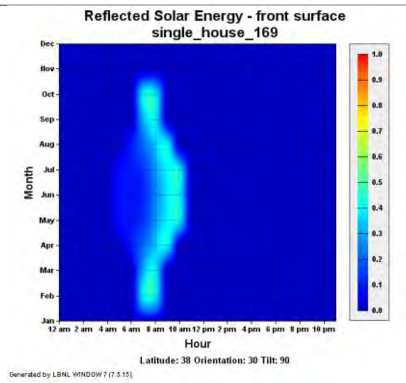
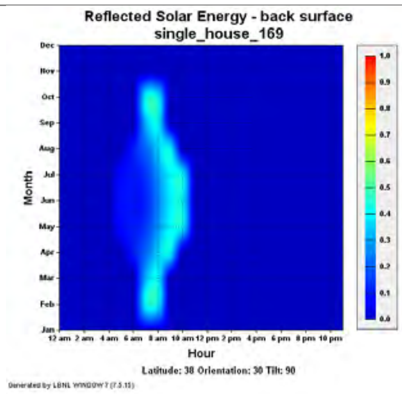


Figure I27. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I23. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.834	0.833	0.831	0.827	0.818	0.797	0.749	0.637	0.389	0.000	0.753
Abs1	0.091	0.092	0.094	0.096	0.100	0.104	0.108	0.110	0.105	0.000	0.101
Rfsol	0.075	0.075	0.075	0.077	0.082	0.099	0.143	0.253	0.506	1.000	0.136
Rbsol	0.075	0.075	0.075	0.077	0.082	0.099	0.143	0.253	0.506	1.000	0.136
Tvis	0.899	0.899	0.898	0.896	0.889	0.870	0.822	0.705	0.441	0.000	0.822
Rfvis	0.083	0.083	0.083	0.085	0.091	0.109	0.156	0.272	0.536	1.000	0.148
Rbvis	0.083	0.083	0.083	0.085	0.091	0.109	0.156	0.272	0.536	1.000	0.148
SHGC	0.861	0.860	0.859	0.855	0.847	0.827	0.781	0.669	0.420	0.000	0.783

Table I24. Annual optical graphs.

	Front surface	**Back surface**
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.10.2.1 Recommended solution

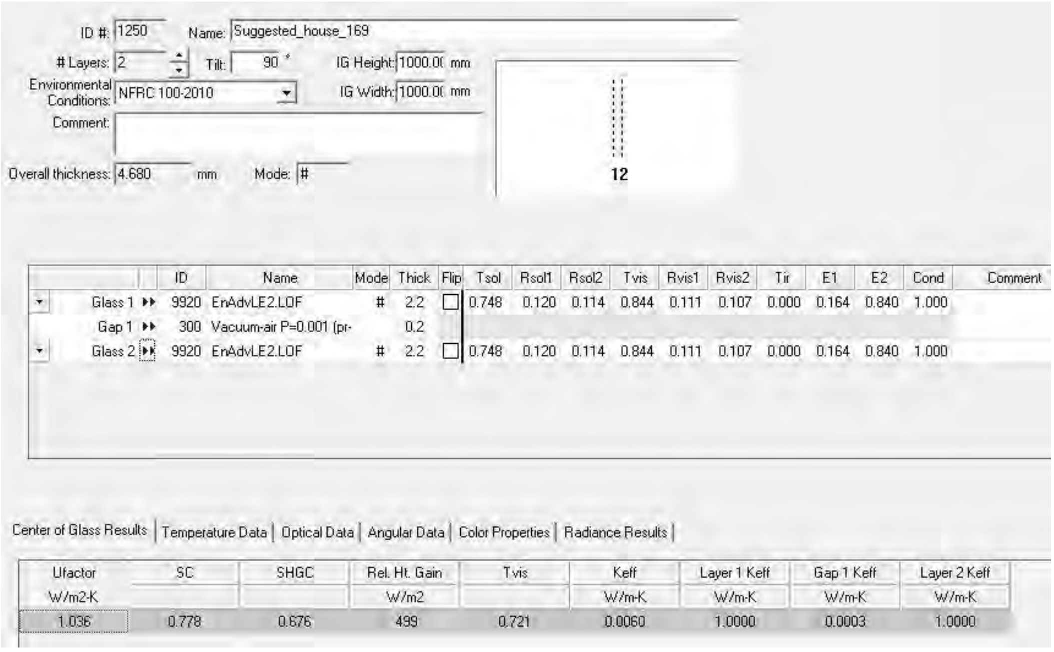


Figure I28. The characteristic of the suggested glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

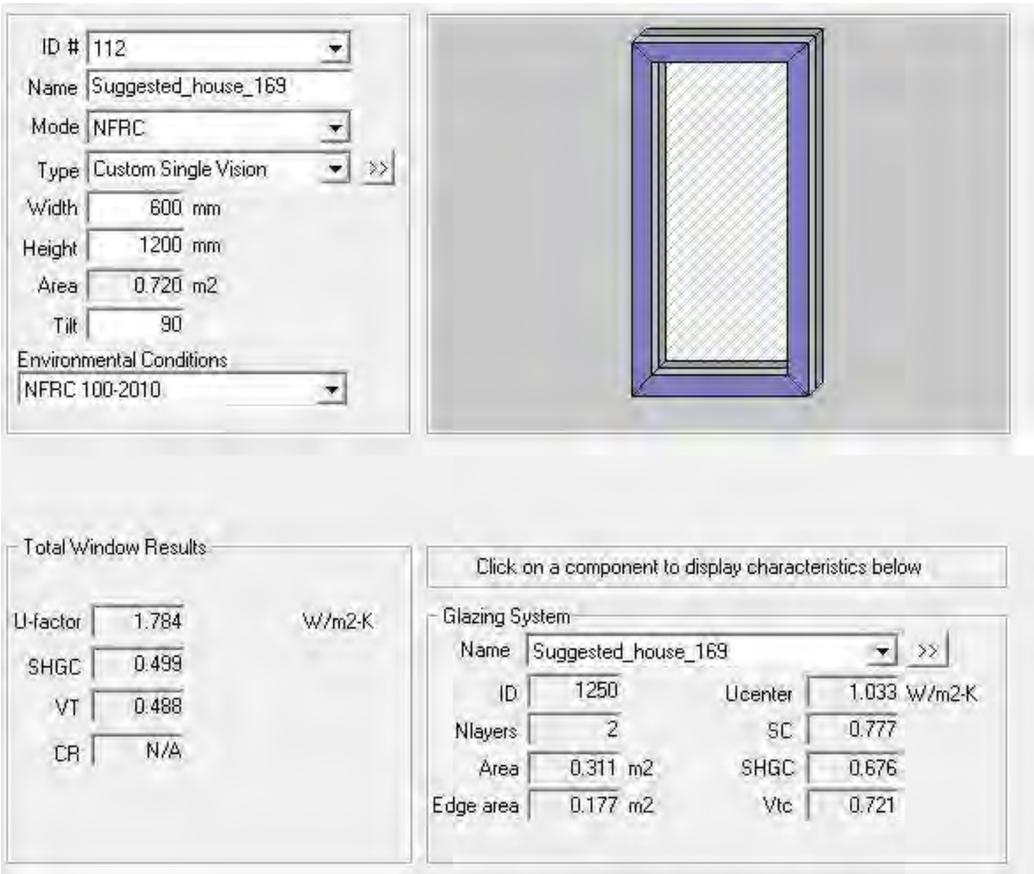


Figure I29. The characteristic of the suggested whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

I.11. Case 11. The windows of a traditional house (age = 171)

I.1.1. Double glazing window

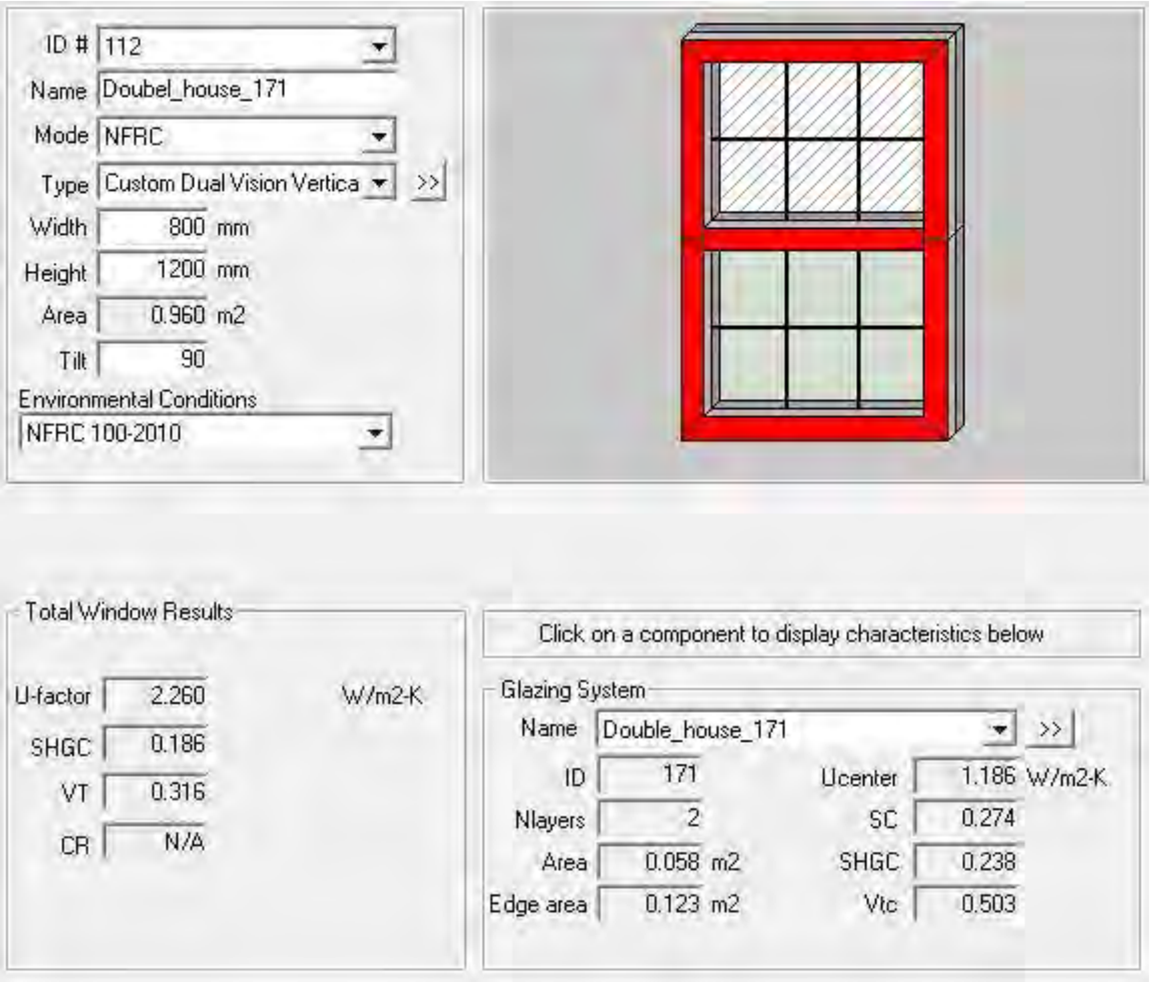


Figure I30. The characteristic of the whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

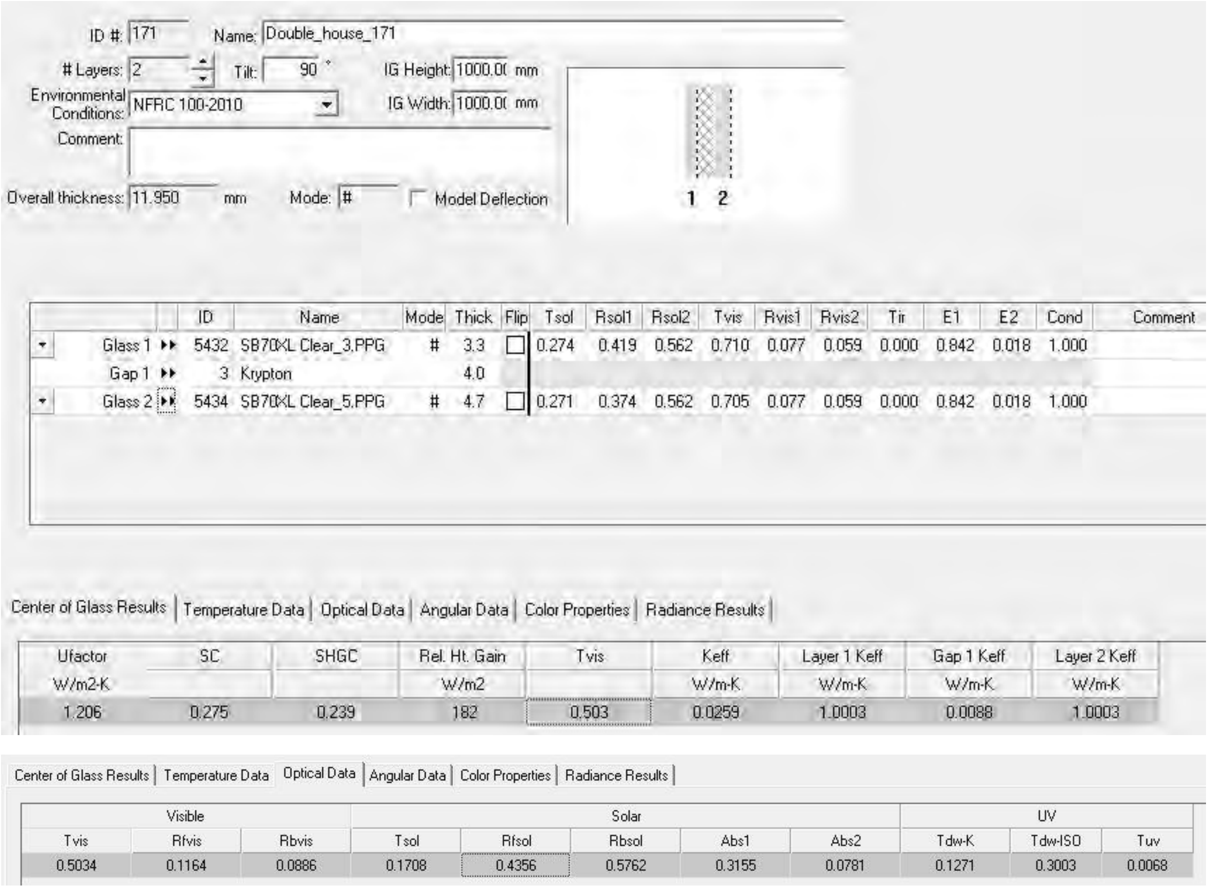
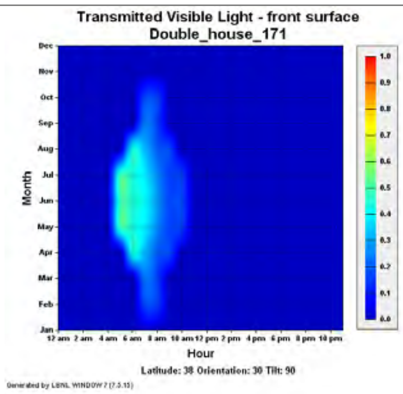
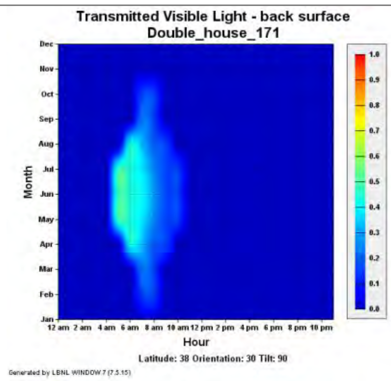


Figure I31. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I25. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.171	0.173	0.168	0.163	0.157	0.147	0.125	0.086	0.038	0.000	0.137
Abs1	0.316	0.318	0.323	0.325	0.324	0.324	0.325	0.316	0.244	0.001	0.315
Abs2	0.078	0.079	0.081	0.082	0.081	0.079	0.077	0.067	0.040	0.000	0.075
Rfsol	0.436	0.430	0.428	0.430	0.438	0.450	0.473	0.531	0.678	0.999	0.463
Rbsol	0.576	0.571	0.570	0.572	0.578	0.588	0.606	0.650	0.761	1.000	0.595
Tvis	0.503	0.510	0.497	0.481	0.464	0.433	0.367	0.252	0.109	0.000	0.403
Rfvis	0.116	0.105	0.102	0.106	0.120	0.143	0.182	0.279	0.511	0.999	0.168
Rbvis	0.089	0.077	0.074	0.078	0.093	0.117	0.158	0.259	0.498	0.999	0.143
SHGC	0.239	0.242	0.239	0.234	0.228	0.217	0.193	0.147	0.077	0.000	0.203

Table I26. Annual optical graphs.

<table>
<tr><th></th><th>Front surface</th><th>Back surface</th></tr>
<tr><td>Transmitted visible light</td><td>
</td><td>
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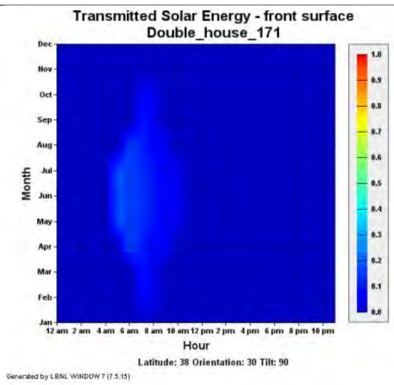
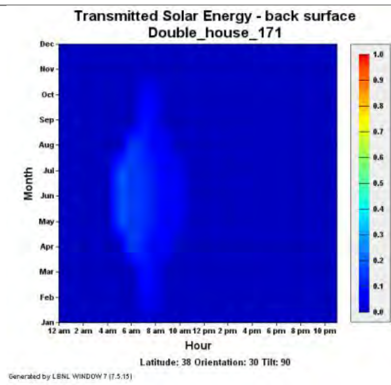
<tr><td>Transmitted solar energy</td><td>
</td><td>
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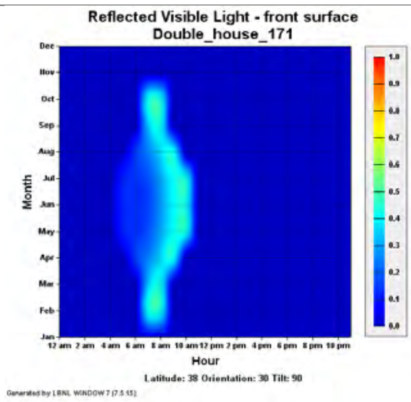
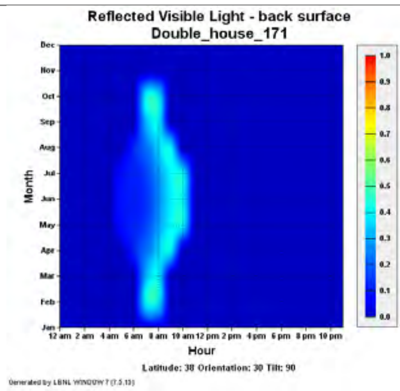
<tr><td>Reflected visible light</td><td>
</td><td>
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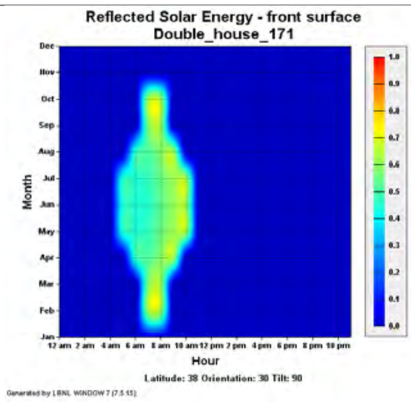
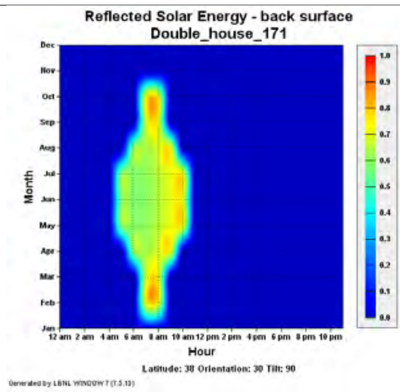
<tr><td>Reflected solar energy</td><td>
</td><td>
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I.11.2. Single glazing window

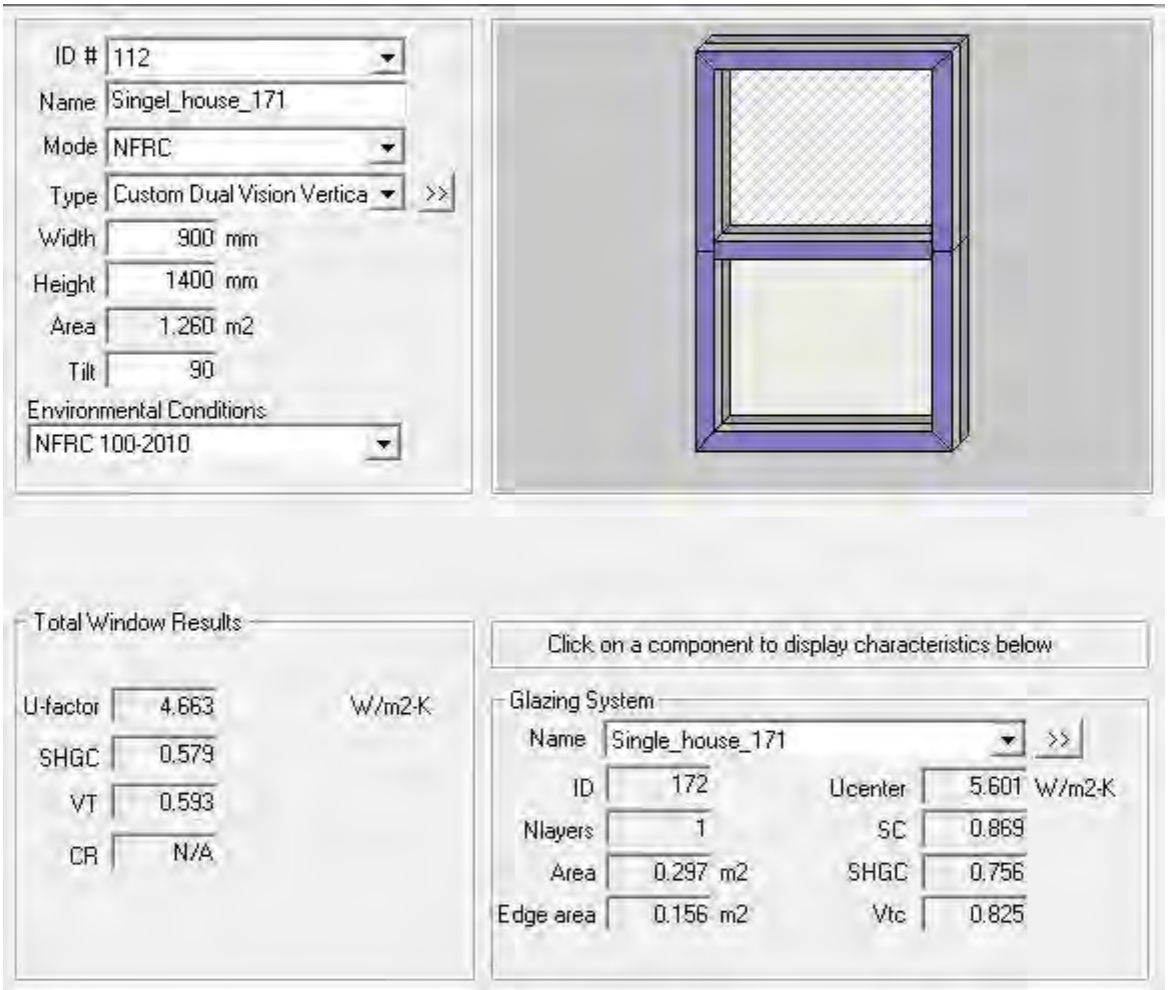
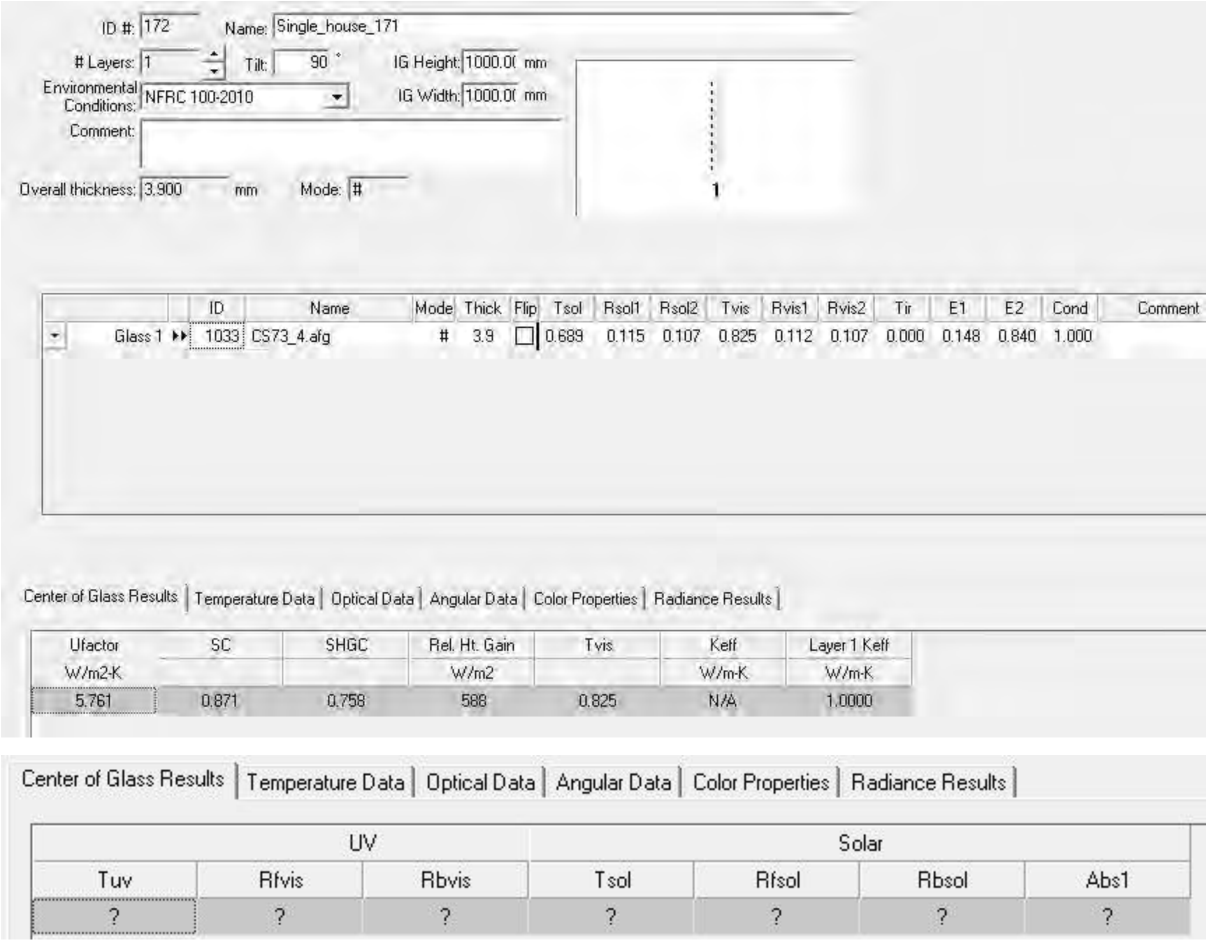


Figure I32. The characteristic of the whole single window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.



ID #: 172 Name: Single_house_171
Layers: 1 Tilt: 90 ° IG Height: 1000.0(mm
Environmental Conditions: NFRC 100-2010 IG Width: 1000.0(mm
Comment:
Overall thickness: 3.900 mm Mode: #

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	1033	CS73_4.afg	#	3.9		0.689	0.115	0.107	0.825	0.112	0.107	0.000	0.148	0.840	1.000	

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff
W/m2-K			W/m2		W/m-K	W/m-K
5.761	0.871	0.758	588	0.825	N/A	1.0000

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

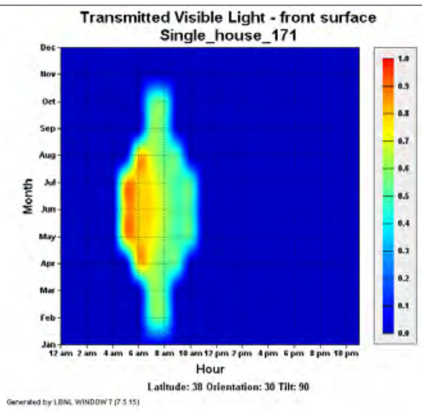
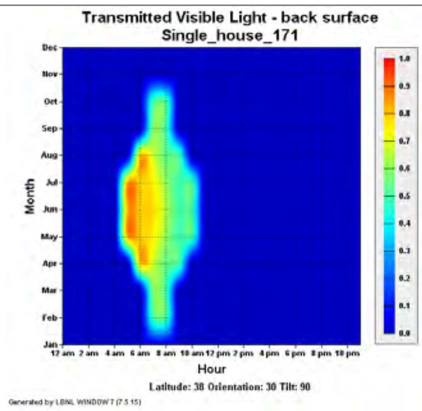
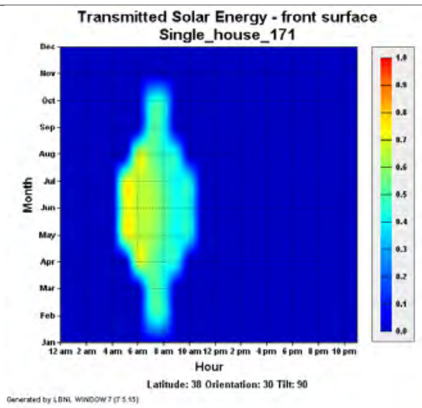
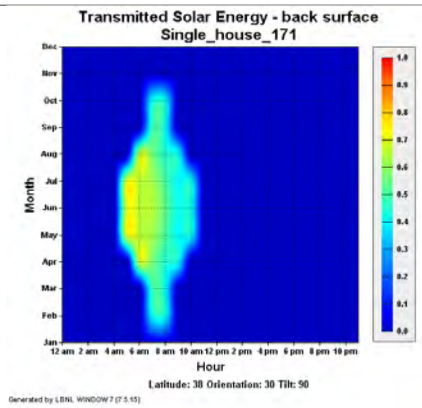
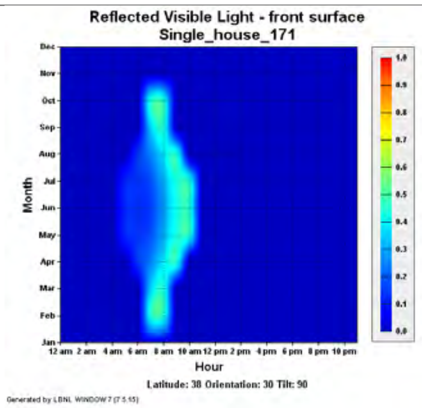
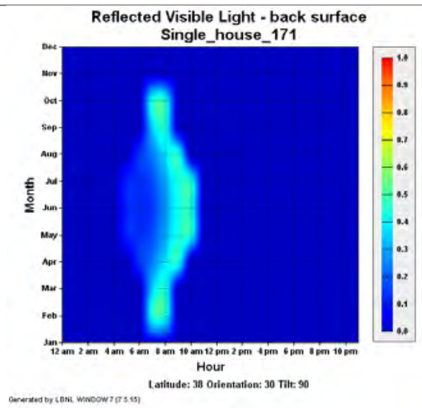
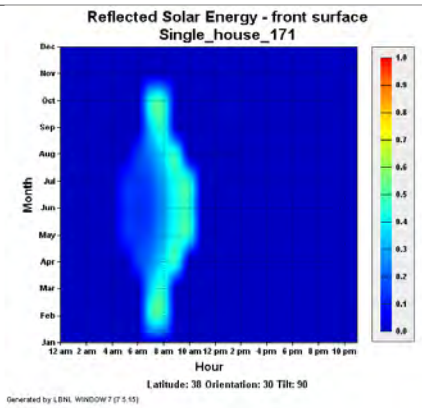
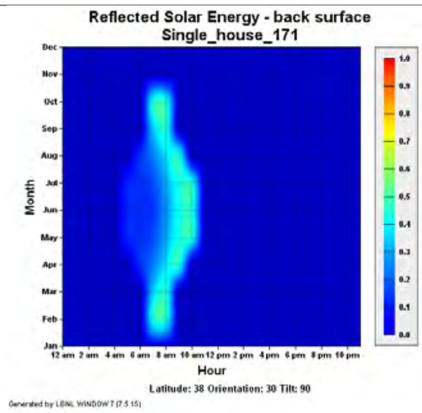
UV			Solar			
Tuv	Rfvis	Rbvis	Tsol	Rfsol	Rbsol	Abs1
?	?	?	?	?	?	?

Figure I33. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

Table I27. Angular properties of the glazing system.

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.689	0.688	0.685	0.681	0.676	0.662	0.620	0.520	0.326	0.000	0.622
Abs1	0.196	0.197	0.200	0.201	0.200	0.199	0.197	0.185	0.137	0.000	0.192
Rfsol	0.115	0.114	0.116	0.118	0.124	0.139	0.183	0.295	0.538	1.000	0.176
Rbsol	0.107	0.107	0.108	0.110	0.116	0.132	0.176	0.289	0.534	1.000	0.169
Tvis	0.825	0.825	0.820	0.816	0.810	0.793	0.743	0.623	0.390	0.000	0.746
Rfvis	0.112	0.111	0.112	0.115	0.121	0.136	0.180	0.292	0.536	1.000	0.173
Rbvis	0.107	0.106	0.108	0.110	0.116	0.132	0.176	0.288	0.534	1.000	0.169
SHGC	0.758	0.758	0.755	0.751	0.746	0.732	0.689	0.585	0.373	0.000	0.689

Table I28. Annual optical graphs.

	Front surface	Back surface
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.11.2.1. Recommended solution

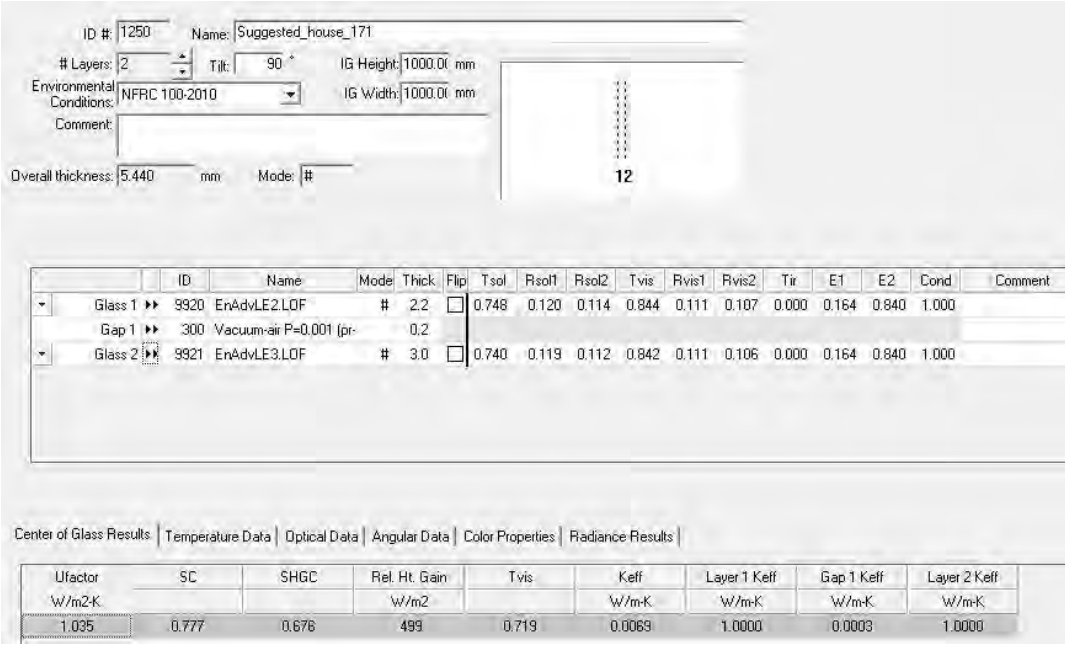


Figure I34. The characteristic of the suggested glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

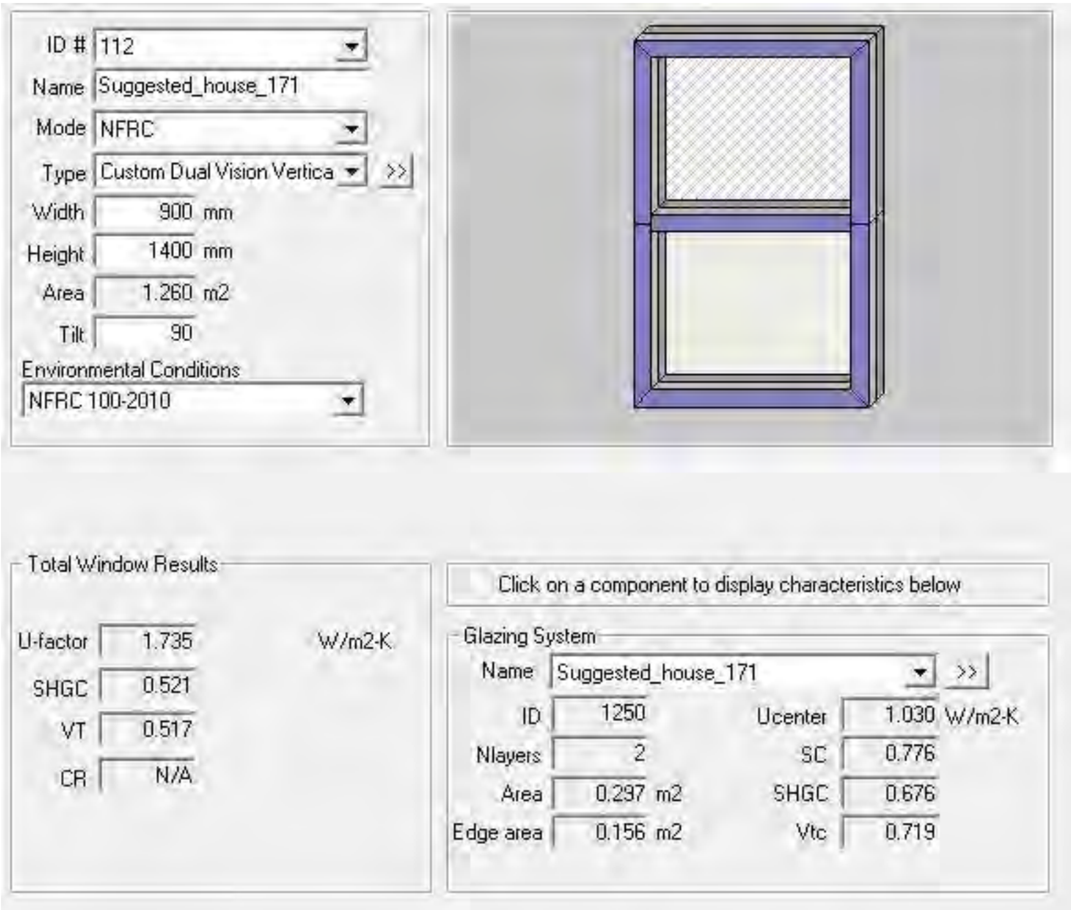


Figure I35. The characteristic of the suggested whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

I.12. Case 12. The window of a traditional house (age = 223)

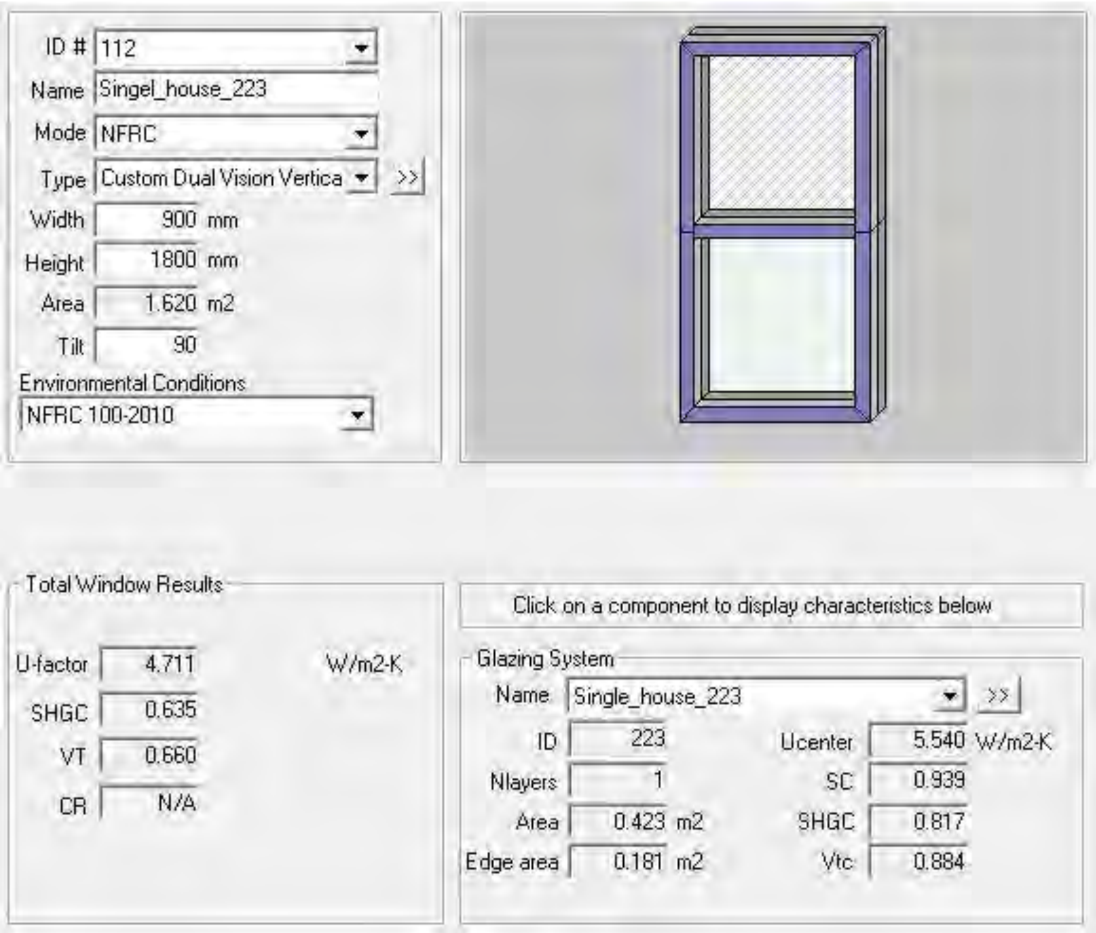


Figure I36. The characteristic of the whole old single window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

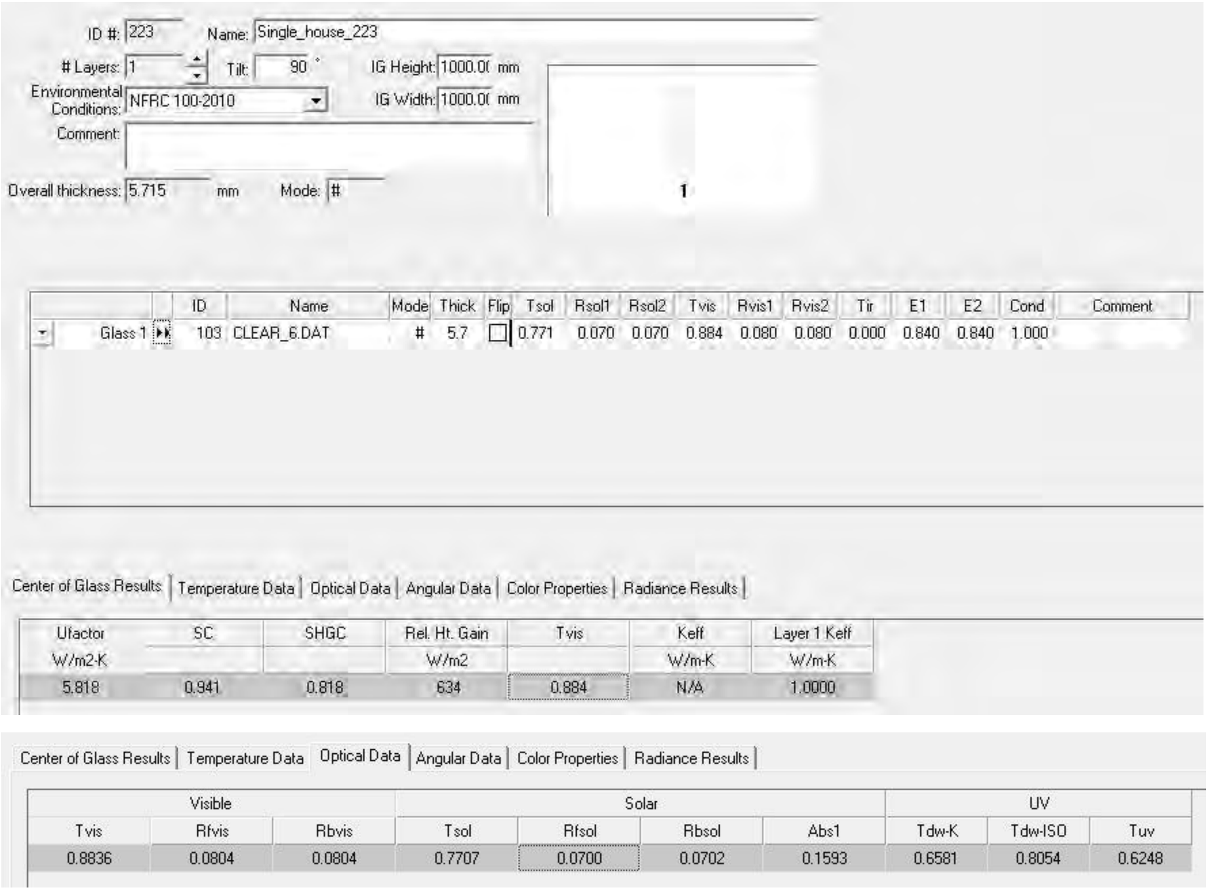
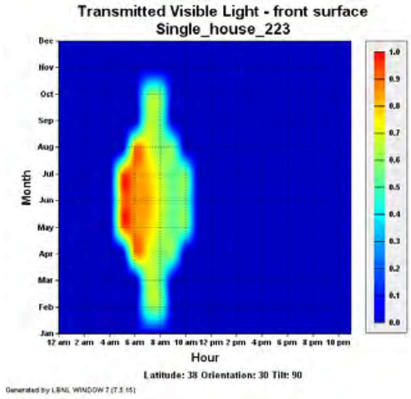
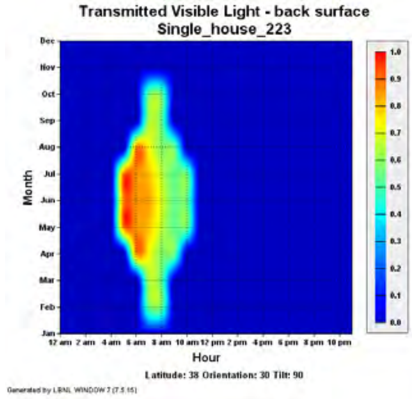
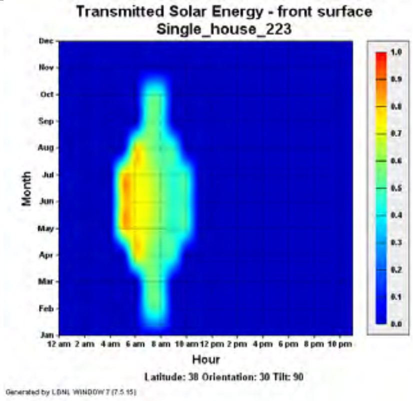
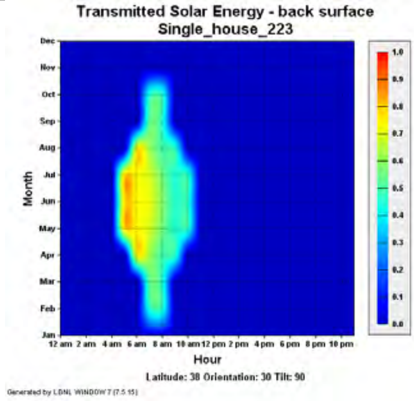
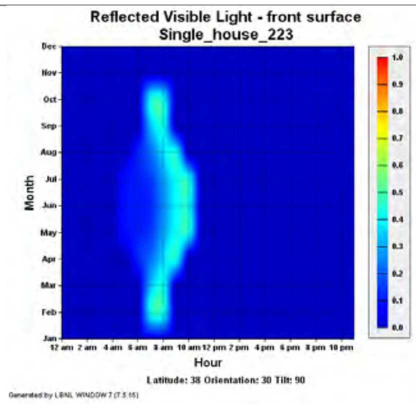
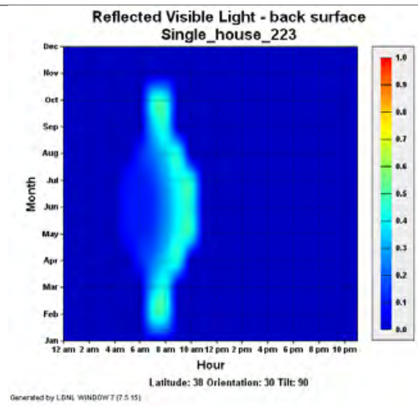
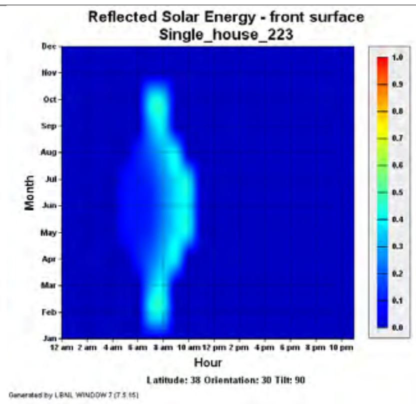
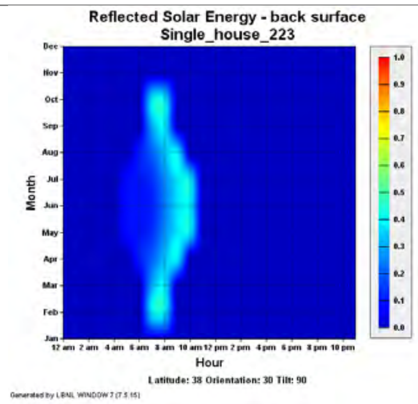


Figure I37. The characteristic of the glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software

Table I29. Angular properties of the glazing system

	0	10	20	30	40	50	60	70	80	90	Hemis
Tsol	0.771	0.770	0.767	0.761	0.750	0.727	0.680	0.575	0.346	0.000	0.689
Abs1	0.159	0.160	0.163	0.167	0.173	0.180	0.185	0.186	0.170	0.000	0.173
Rfsol	0.070	0.070	0.070	0.072	0.077	0.093	0.134	0.239	0.484	1.000	0.128
Rbsol	0.070	0.070	0.070	0.072	0.077	0.093	0.134	0.239	0.484	1.000	0.128
Tvis	0.884	0.883	0.882	0.879	0.872	0.852	0.804	0.688	0.427	0.000	0.805
Rfvis	0.080	0.080	0.081	0.083	0.089	0.106	0.152	0.267	0.528	1.000	0.144
Rbvis	0.080	0.080	0.081	0.083	0.089	0.106	0.152	0.267	0.528	1.000	0.144
SHGC	0.818	0.818	0.816	0.811	0.802	0.781	0.736	0.631	0.397	0.000	0.741

Table I30. Annual optical graphs.

	Front surface	Back surface
Transmitted visible light		
Transmitted solar energy		
Reflected visible light		
Reflected solar energy		

I.12.1 Recommended solution

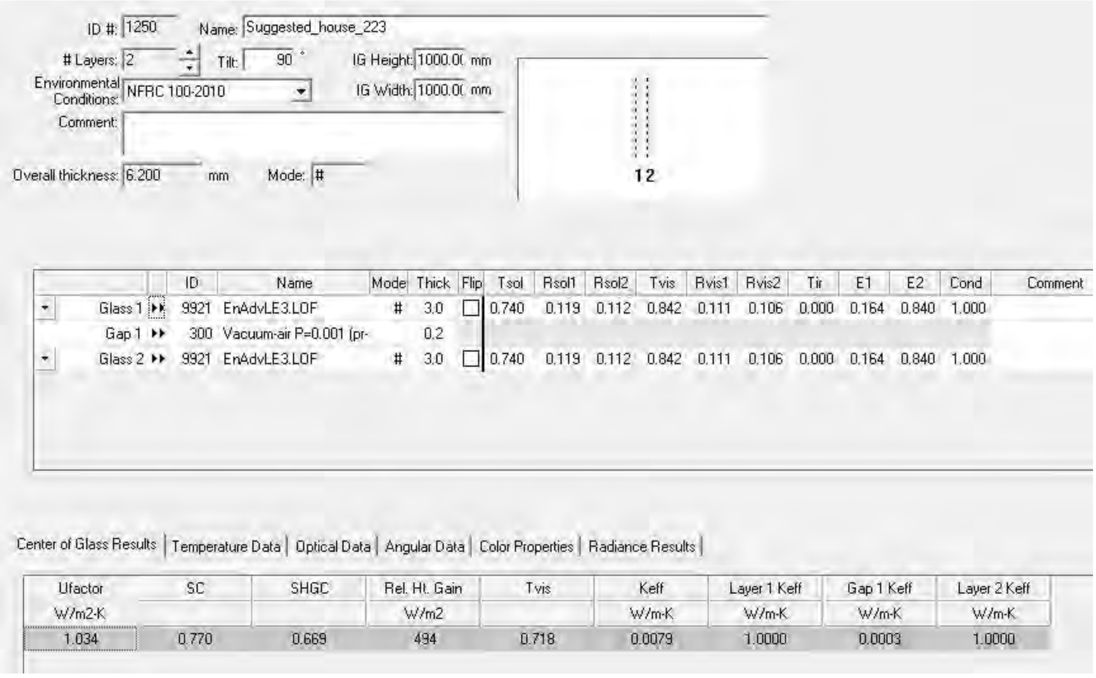


Figure I38. The characteristic of the suggested glazing system that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

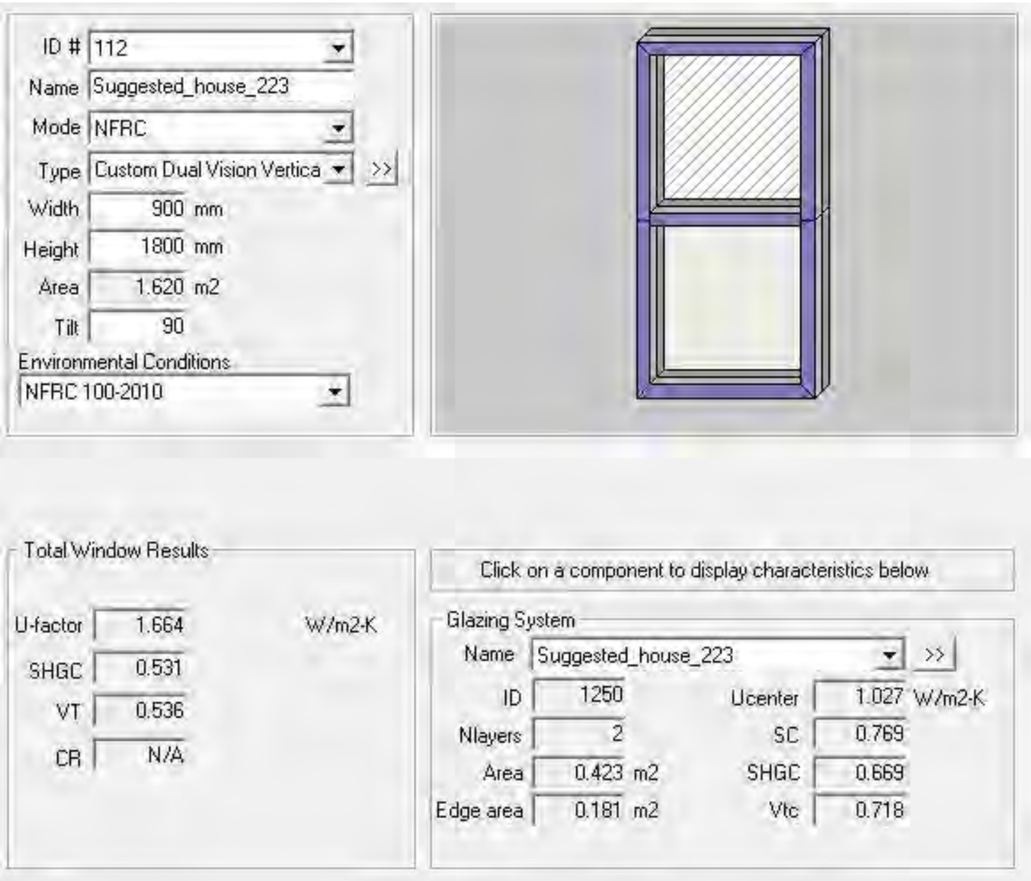


Figure I39. The characteristic of the suggested whole double window that analysed by Lawrence Berkeley National Laboratory (LBNL) software.

Appendix J. Data sources

The most difficult part of the thesis was to find the information especially traditional buildings, First step is to find the primary information from the house agency for example Single Survey Report and technical report of the building, this process need more time as for each building must to call and explain the process and get permission, this information is untrustworthy as I understood in this report, in some cases compared the information from the house agencies and Scottish heritage organization, the agencies exaggerated in the information about energy efficiency and environmental impact rating. Also, this kind of information is just available for the building that decided to sell so, does not cover all the building.

Regards to the main subject of the thesis that is the relevance of the U-values and age, the next step is to find the houses with different ages and proper distribution. According to the Dwellings Technical Bulletin: "The word of the homeowner on its own is not enough to provide proof of dwelling age. Where the knowledge of the homeowner is being used to determine dwelling age, then further evidence based on at least one of the following must be obtained:

- Dwelling style.
- Age plate or plaque indicating dwelling/development year of construction.
- Electricity meter age.;
- Glazing age stamps."

So, the age of the each building checked by two sources, in several cases there are some difference between one to five years.

In order to offer as complete a picture as possible, data was collected on a variety of parameters.

Data sources on building stock including data on whether properties are habitable or uninhabitable, age of buildings, type of buildings, construction type, heritage-protection and architectural type.

J.1 Building stock

Table J1. The details of building components sources

Data Source	Summary of data provided
Listed Building Data	Identification of listed buildings.
Conservation Area Data	Conservation area boundaries.
Home Energy Efficiency-cy Database (HEED(	Provides information on energy efficiency measures that have been installed, property characteristics. Data has been collated from a variety of data sources.
Home Analytics	Property characteristics and potential for energy efficiency measures. Based on probabilities, so accuracy at small scale is limited.
House Condition Surveys	Overview of housing in each nation – includes age, type, energy efficiency measures. Taken from a small sample so limited accuracy.
UK Housing Review 2102	Housing stock and finances.
National statistics websites statistics websites	Variety of statistics including some on housing and fuel poverty.
Building at Risk registers	Historic buildings deemed to be in a state of disrepair.
Fuel poverty and ECO mapping	Identification of geographical areas in fuel poverty, and areas that are eligible for new ECO funding.
Registry sources	Data on ownership and selling of properties.
TABULA	EU project showing domestic and non-domestic properties.
Google Street view	Photographic images of properties, allowing identification of specific properties such as building height and construction.

Other data sources, detailed in other sections, which may be relevant are:

DECADE (Domestic Equipment and Carbon Dioxide Emissions).

Digest of UK Energy Statistics (DUKES).

EPC Register.

Housing Energy Fact File.

MLSOAs, IGZ and LLSOA.

Scotland's 2011 Census – contains data on the type of house, house size and main heating systems (not energy efficiency of buildings).

Historic Scotland Data Services.

Historic Scotland provides an online database of listed buildings and this can also be downloaded as a GIS dataset from the following link:

http://data.historic-scotland.gov.uk/pls/htmldb/f?p=2100:10:0::::CURRENT_GIS:about

J.1.1 Listed Building Data

Data on listed buildings is held by each country within the UK.

J.1.1.1 Historic Scotland Data Services

Listed building Edinburgh and near of it can be found in the following links:

https://data.gov.uk/dataset/listed-buildings-wms1

https://data.gov.uk/dataset/listed-buildings-dataset

https://data.gov.uk/dataset/fife-listed-buildings

J.1.1.2 British Listed Buildings Online

This website combines listed building data from Wales, Scotland and England into a single portal. It extracts data from the datasets held by Historic Scotland and English Heritage (see previous) and in addition it includes online mapping so all the Scottish sites can be viewed 'on the map'.

http://www.britishlistedbuildings.co.uk/

J.1.1.3 Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS)

Scotland's national collection of buildings, archaeology and industry. The Canmore website contains photo-graphs (including aerial photography), drawings and survey information on a variety of important buildings both listed and unlisted. It also include Pastmap, a mapping tool showing the location of each building/monument documented.

http://canmore.rcahms.gov.uk/

http://pastmap.org.uk/

J.1.2 Conservation Areas Data

Information on conservation areas is held by local authorities and Historic Scotland. This is essentially the same data and both are publicly available, but may be provided in different formats. This information is essential to the EFFESUS model. The data held by Historic Scotland is likely to be of most use as it is provided as a GIS shape file.

http://data.historic-scotland.gov.uk/pls/htmldb/f?p=2100:10:0::::CURRENT_GIS:about

Historic Scotland also holds spatial locations of conservation areas for Scotland with links online to the relevant local authority. This will be the same information as held by local authorities.

J.1.2.1 Historic Scotland Data Services (Conservation Areas)

http://data.historicscotland.gov.uk/pls/htmldb/f?p=2100:10:0::::CURRENT_GIS:about4.4 Home Energy Efficiency Database

J.1.3 (HEED Home Energy Efficiency Database (HEED)

HEED has been developed by the Energy Saving Trust on behalf of the UK Government to register the uptake of sustainable energy measures and related survey data throughout the UK housing stock. HEED holds a vast amount of information about the energy efficiency of domestic properties.

http://www.energysavingtrust.org.uk/Organisations/Government-and-local-programmes/Free-resources-for-local-authorities/Homes-Energy-Efficiency-Database

Data includes :

- Property details: building type, full address building age band, insulation levels, building fabric and main heating system (this does not include any information on occupants).
- Recorded energy efficiency installations on a property-by-property basis e.g. those through fuel poverty energy efficiency schemes (Warm Deal, Central Heating Program and Energy Assistance Package) or utility company schemes (EEC, CERT).

Data sources on building age, type and characteristics could be obtained from a variety of sources. HEED may provide the most reliable data for this purpose, but could be complemented with house condition surveys, for instance.

J.1.4 Home Analytics

Home Analytics contains a lot of useful information on stock (e.g. property age, type, number of beds, building footprint (m^2), wall type, loft insulation, glazing type, fuel and heating system).

http://www.energysavingtrust.org.uk/Organisations/Government-and-local-programmes/Home-Analytics-housing-data-and-analysis

J.1.5 House Condition Surveys

Each country in the UK carries out its own survey of domestic housing:

- House Condition Survey (HCS) – Northern Ireland.
- English Housing Survey (EHS).
- Living in Wales Survey (LIWS).
- Scottish House Condition Survey (SHCS).

The House Condition Surveys provide detail on various aspects of domestic housing including age, tenure, size and energy efficiency properties (e.g. level of insulation). Although there are lists of 'buildings at risk'.

J.1.5.1 Scottish House Condition Survey (SHCS)

It is an annual survey of 3,000 homes in Scotland, concerning physical condition and experiences of the occupants. Data includes dwelling age, type, condition, tenure, urban/rural split, fuel use, EPC rating, CO_2 emissions, household income, insulation measures, fuel poverty metrics, Scottish Housing Quality Standard and condition of the dwelling (damp, condensation, disrepair). Data is also compared to previous years to identify trends.

http://www.scotland.gov.uk/Topics/Statistics/SHCS

J.1.6 UK Housing Review 2012

The primary objective of the 20th edition of the UK Housing Review (initially called the Housing Finance Review), is simply to draw together key current financial and related data about both public and private housing in the United Kingdom, and rapidly assemble them in a coherent and accessible format.

http://www.york.ac.uk/res/ukhr/

Data includes tenure, property age, stock condition, private and social housing. Also includes house condition surveys and economics (expenditure, investment and rent)

J.1.7 National statistics websites

There are government websites which hold a large amount of data. There are statistics on fuel poverty and housing which may prove useful. However, a full analysis of these datasets cannot be carried out without knowing exactly what data is required; thus these datasets could be examined if there was missing information in the EFFESUS model.

http://www.statistics.gov.uk/hub/index.html

The site include national statistics on a wide variety of subjects, including 'Business and Energy' and 'Housing and Households'. Within the Business and Energy section there is a Fuel Poverty subsection and this includes an Excel table showing the levels of fuel poverty at the sub local authority level across England.

J.1.7.1 UK National Statistics

http://www.statistics.gov.uk/hub/index.html

J.1.7.2 Scottish Government Statistics

As with the other websites, this provides data on a whole range of topics such as housing, economy, health, transport, etc. The most relevant dataset is likely to be the House Condition Survey.

http://www.scotland.gov.uk/Topics/Statistics/About/NationalStatistics

J.1.8 Buildings at Risk Register

Historic houses which are in a state of disrepair are defined as 'buildings at risk' in lists compiled by each nation. These buildings usually include listed buildings or those located in conservation areas. These lists may be useful to the EFFESUS project to identify specific buildings or even types of buildings in an area.

J.1.8.1 Save Britain's Heritage

This website has a summary and photo of each building, which includes full address and post code.

http://www.savebritainsheritage.org/buildings_at_risk/

J.1.8.2 Buildings at Risk Register (Scotland)

It provides a list and description of 'buildings at risk' in Scotland. These are usually buildings which are listed or located within a conservation area that meet criteria such as suffering from neglect or suffering from structural problems.

http://www.buildingsatrisk.org.uk/

Information on each building includes:

- Name of building.
- Address and postcode.
- Planning authority.
- Reference number.
- OS Grid Reference.
- Historic Scotland reference number.
- Age of building.
- Description.
- Development history.

Buildings can be searched for by postcode or LA area.

It is compiled from a number of sources, including local planners, Historic Scotland, local civic trusts, building preservation trusts, other heritage bodies and the public.

J.1.9 Fuel poverty and ECO mapping

Properties in low-income areas (defined through multiple deprivation indices) are eligible for new Energy Company Obligation (ECO) funding for energy efficiency improvements. These areas can be mapped using data obtained from UK and Scottish Government websites.

J.1.9.1 ECO eligible areas Scotland

Energy Company Obligation (ECO) is a new policy providing funding for energy efficiency measures. One stream of funding (Carbon Saving Communities Obligation (CSCO) is directed at properties in low income areas defined as the bottom 15% of ranked in the Indices of Multiple Deprivation (IMD). These are SIMD areas in Scotland and Lower Layer Super Output Areas (LSOA). Adjoining areas are also eligible.

These areas can be mapped using data available from UK and Scottish Government websites. They highlight areas eligible for ECO funding.

http://www.scotland.gov.uk/Topics/Statistics/SIMD

J.1.9.2 Fuel poverty mapping

Fuel poverty can be mapped spatially (this is not a direct data source, but mapping that could be carried out). For instance, the following fuel poverty map of Edinburgh was created by Changeworks in 2006. This was based on the Scottish Fuel Poverty Indicator (FPI) developed by Energy Action Scotland and Alembic Research using 2001 Census data.

J.1.10 Land registers for Scotland

The Registry of Scotland can provide a range of reports and data on properties in Scotland. This information generally pertains to prices, sales, ownership and boundaries, rather than any details about the property.

http://www.scotlandlandregistry.co.uk/

J.1.11 TABULA

This is an EU project which provides data on domestic and non-domestic properties. Whilst it would be extremely useful data, there is no information provided for the UK (as it was not a project partner).

It provides data on residential properties such as size, age ,energy consumption and potential impact on energy saving improvement. Also takes into account national climatic data. For exemplary buildings, it provides data on visual appearance, commonly found construction elements and their U-values.

http://www.building-typology.eu/ and

http://webtool.building-typology.eu/

J.1.12 Google Street view

Google Street View is extremely useful for gathering or verifying some data on individual buildings. Only characteristics visible from the exterior of the property (and probably only one angle) can be verified and therefore there are obvious limitations. However, this can provide useful information on construction type, height and detail across the country. To gather this data would need the postcode or address of the property.

http://maps.google.co.uk/

In addition, Google Street view (from Google Maps) may be very useful for identifying certain visual characteristics of buildings such as height. However, this would be for specific buildings only.

J.2 Urban district / spatial

This part provides detail on information sources that contain urban district / spatial data on properties, for example within city limits/wards or GIS data.

Other data sources, detailed in other sections, which may be relevant are:

- Digest of UK Energy Statistics (DUKES).
- MLSOAs, IGZ and LLSOA.

J.2.1 National Library of Scotland

The National Library of Scotland holds online copies of maps covering much of the UK.

http://maps.nls.uk/

J.2.2 Office for National Statistics

The Office for National Statistics holds very similar data to the General Registrar for Scotland based on the census.

http://www.ons.gov.uk/ons/index.html

J.2.3 Gazetteers

The gazetteers may be the most useful reference for providing a full list of houses in the UK, although it provides little other data and is not specific to pre-1945 properties. Gazetteers provide a comprehensive address list of buildings across the UK and spatial information on stocks.

J.2.3.1 One Scotland Gazetteer

An address database made up of all 32 individual local authority gazetteers. This includes information from local authorities (such as house number, town and locality) and Royal Mail (post town and postcode). Some local authority data comes through planning applications and building warrant completions, to show when properties are created or demolished.

Data is available either through a web service or as an export (Scottish Data Transfer Format (SDTF) as a CSV file). A subset of data may be supplied to match specific requirements.

http://www.onescotlandgazetteer.org.uk/

J.2.4 Census Data

The most recent census was carried out in 2011; so the information contained in this is up-to-date. It contains information on households such as type of property (flat, semi-detached house etc.), numbers of rooms, main heating systems and tenure and ownership.

J.2.4.1 Scotland's Census data Scotland's 2011 Census

Building energy use and CO_2 emissions data sources that cover building energy use, CO_2 emissions and energy generation. There are a number of sources providing different information on energy. One of the most useful sources will be MSLOAs, IGZ and LLSOA which produce domestic and non-domestic energy consumption for geographical areas. This is also likely to be the best source of data for CO_2 emissions; this can be calculated by multiplying average energy consumption by CO_2 factors for each fuel (available on the DECC website). Above this level, information is only available for local authorities on their CO_2 emissions at National Atmospheric Emissions Inventory.

http://www.scotlandscensus.gov.uk/en/censusresults/

J.3 Building energy use and CO_2 emissions

Other information sources in this part can provide regional or national overviews of energy use and generation; this may be useful as an overview but less useful for integration into the database model for EFFESUS as they do not provide data on a lower resolution. Data sources described in other sections, such as HEED and Home Analytics, will be useful in providing energy efficiency ratings of housing stock which could be cross-referenced against property characteristics.

Table J2. The details of building energy and CO_2 emissions sources

Data source	Summary of data provided
Annex 42 of the Energy Conservation in Building & Community Systems Pro-gram	Simulation model from 1990s on energy use. http://www.ecbcs.org/annexes/annex42.htm#p
BPIE Data HubBPIE Data Hub	EU database showing energy consumption and energy efficiency measures potential. http://www.buildingsdata.eu/
DECADE	Data on domestic electric appliance use. http://www.eci.ox.ac.uk/research/energy/decade.php
Digest of UK Energy Statistics (DUKES)	Non-spatial (aside from some regional data) on energy consumption and production. https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/digest-of-uk-energy-statistics-dukes
EPC register	Collation of EPC data, which shows energy efficiency rating of properties and recommended improvements. https://www.epcregister.com/
Housing Energy Fact File	Comprehensive annual review of energy use in homes. https://www.gov.uk/government/publications/housing-energy-fact-file-2012-energy-use-in-homes
Low Energy Buildings Database (LEB)	Information from 100 retrofit case studies across the UK. http://www.aecb.net/featured/low-energy-buildings/
MLSOAs, IGZ and LLSOA	Domestic energy consumption in geographical areas. https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/mlsoa-and-llsoa-electricity-and-gas-estimates
Energy Consumption in the UK (ECUK)	Overview of energy consumption in the UK. https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/energy-consumption-in-the-uk

Other data sources, detailed in other sections, which may be relevant are:

- Home Energy Efficiency Database (HEED) – records of energy efficiency measures installed through previous schemes and property characteristics.
- Home Analytics - property characteristics including energy efficiency, based on probabilities.
- House Condition Surveys – dwelling characteristics, including some detail of energy efficiency levels such as insulation levels.

J.4 Climate zoning

Detail on climatic data sources such as rainfall levels, wind-driven rain sunshine and temperature. Aside from the NOABL wind speed database and UKCIP data, most of the information sources seek to provide reasonably similar information e.g. weather from the past 20 - 30 years for particular areas within the UK. Weather Analytics provides the greatest density of data as it is for 35km x 35km squares. CIBSE may be very useful for calculating overheating in buildings ,and some of its data will be sourced from the Met Office. UKCIP provides data on predicted weather under various climate change scenarios. This would be useful in estimating heat requirements for buildings in the future, and would therefore be relevant to the EFFESUS model as well.

Table J3. The details of climate zoning sources

Data source	Summary of data provided
CIBSE TRY & DSY Hourly Weather Datasets	Weather data for 14 locations in the UK for past 23 years http://www.cibse.org/index.cfm?go=page.view&item=1300
NOABL Wind Speed Data-base	Average wind speed for 1km square for three given heights http://www.rensmart.com/Weather/BERR
SAP and RdSAP Regional Climate Data	Regional weather information http://www.bre.co.uk/sap2009/page.jsp?id=1642
UK Climate Impact Program (UKCIP)	Weather in predicted climate change scenarios http://ukclimateprojections.defra.gov.uk/
UK Met Office (UKMO)	Hold all data from UK weather stations http://www.metoffice.gov.uk/climate and http://data.gov.uk/metoffice-data-archive
Weather Analytics	Global data for past 30 years. Data can be obtained for 35km2 areas. http://www.weatheranalytics.com

Other data source, detailed in other sections, which may be relevant is Home Analytics, which includes likelihood of exposure to wind driven rain (which would affect certain insulation methodologies) and wind speed at 10m above ground level.

J.5 Pre-1945 properties

Key to EFFESUS is identifying pre-1945 stock. The most useful information to help understand where pre-1945 building are and their scope for energy efficiency improvements will come from combining a number of existing resources such as the Gazetteer or Census data, maps from the National Library of Scotland, data on listed buildings and data on conservation are-as. In some cases, Household Condition Surveys may also be useful for this .

The main limitation faced is finding out which homes are likely to be of the correct age range (i.e. 1945 and older). There are a few ways with the given data to infer where clusters of older properties exist. These may be :

- A lack of central heating.
- Hard to heat properties.
- Where there are a number of listed buildings in the area or the presence of a conservation area.
- Where certain housing types (e.g. terraced houses) are prevalent.
- Using the pre-1945 maps available at the National Library of Scotland.

Such information could be sourced from data sources concerning energy efficiency such as Home Analytics, MSLOAs and HEED. However none of these indicators are going to be completely reliable and any data would probably provide an indication of where to initially investigate .

Using a GIS approach could also be used to recognize where properties that are pre-1945 that need energy efficiency improvement are located. By mapping data it would be possible to gain a visual understanding of where likely properties could be found and then this map could be interpreted by people with local knowledge to refine the accuracy of the search for suitable properties. In any area there is likely to be a variety of building ages although some areas will have extremely high concentrations of pre-1945 buildings .

For the information on heritage protection (i.e. listed buildings and conservation areas) are essential to include in EFFESUS since it is focused on historic properties. This data can be obtained from national or local authorities but should essentially be the same data.

J.6 Combining data sources

With a suitable GIS system it should be possible to map out the areas of any particular region where the energy efficiency of properties was poor. This could be through using information from the MLSOA energy data or HEED and to overlay data on listed properties and conservation areas. HEED and the EST's Home Analytics database would give good indications of energy efficiency in any locality and the listed building databases can show property locations .

Changeworks has some experience of this as it developed fuel poverty mapping at the data zone and census output area level and the techniques required for matching data are likely to be similar .

There was no single data source that provided all the data that might be needed to identify pre-war buildings which might benefit from energy efficiency improvements. However, combined data sets there is plenty of information that might be combined using GIS to show where these buildings may be found.