SIMPLIFIED MODEL TO DETERMINE THE ENERGY DEMAND OF EXISTING BUILDINGS. CASE STUDY OF SOCIAL HOUSING IN ZARAGOZA, SPAIN

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The refurbishment of residential buildings is fundamental to fulfil the EU's CO_2 emissions and energy savings objectives. Social housing estates built during the Spanish post-war period are vulnerable areas in Spanish cities that require public economic investment for their urban regeneration, and to refurbish their buildings. Public economic resources must centre on the buildings that most require these actions, which are precisely those with a higher energy demand. This article proposes a simplified model to predict heating and cooling energy demands of buildings with no insulating material layer in their envelopes, which was conducted based on the case study of social housing buildings built in the Spanish city of Zaragoza between 1945 and 1975. The model obtained herein predicts the cooling and heating energy demands of buildings from only knowing a few inputs that are easily obtained, and is useful for the energy characterisation of large residential stocks without the need of dynamic simulation.

Keywords: energy demand; building envelope; refurbishment; social housing

1. Introduction

The residential building sector in the EU is responsible for more than 21% of all energy consumed [1]. Nowadays, regulations require new energy-saving buildings to be built. However, in some countries like Spain, fewer new buildings are being built, and efforts must be made to fulfil energy refurbishment objectives.

To fulfil the greater energy efficiency and lower greenhouse gas emissions objectives, energy improvements must be made to existing buildings as they will remain on the market for many years to come. In Spain, most of the existing building stock, i.e., 56% of all buildings [2], were erected before the 1979 Basic Building Regulations on Thermal Conditions in Buildings (NBE-CT, in Spanish) [3] came into force. These regulations were the first in Spain on taking measures to make energy savings to be applied to new buildings in the residential sector. Current regulation, the Basic Document "Energy Saving HE1- Limitation of the energy demand" of the Technical Building Code [4], indicates requirements for newly constructed buildings, as well as for works of considerable magnitude to be done on existing buildings. Nevertheless, no legislation exists that obliges existing buildings to be refurbished, which is why public organisations must promote the renewal of the existing building stock. Efforts should be made to limit energy consumption by refurbishing buildings to reduce the energy they consume and to make them comparable to newly constructed buildings. Besides, it makes sense to prioritise buildings with a higher energy demand as they will be the ones to make more savings and higher profitability.

Refurbishing buildings in the urban regeneration context helps fulfil energy savings objectives, cut CO_2 emissions and revitalise the areas where they are located. The Europe 2020 strategy consists in five main objectives that Member States have to fulfil by 2020 in the following areas: employment, R&D, climate change and sustainable energy, education, and fight against poverty and social exclusion [5]. Urban regeneration contributes to two of these objectives: on the one hand, climate change and urban sustainability since refurbishing buildings, as indicated herein, reduces energy consumption and cuts greenhouse gas emissions; on the other hand, fight against poverty and social exclusion as neighbourhoods affect families and children [6] [7].

From Europe, investments in renewing the existing building stock are being urged [8], and in Spain the Refurbishment, Regeneration and Urban Renewal Act refers to obtaining and updating maps and censuses of deteriorated areas or buildings in need of refurbishment [9]. This is why making information available about diagnosing building stocks to the EU and Public Administrations in Spain is so important.

Public economic investments in urban refurbishment and regeneration must centre on the most unfavourable areas and, among them, the buildings that most require such actions. In Spanish cities, deteriorated areas generally concentrate in old quarters, and also in the old housing estates built during the Spanish post-war period. In the Spanish city of Zaragoza, the old workers districts have begun to be studied, known as Urban Estates of Interest (UEI). These estates are groups of buildings constructed during the protection regime period that covered 1945-1965, now characterised by high-density buildings, poor-quality buildings, poor-quality environment in public places and selective population loss [10]. Most of the buildings have load-bearing walls and therefore their façades are significantly massive. Neither the façades nor the roofs have a layer of insulating material since they were built before any thermal regulating existed in Spain. It has to be stated that sporadic investments have been made to refurbish and regenerate these UIE with excellent results [11], but the economic conditions that promoted them have changed.

Nowadays, public investments are limited and should focus on buildings that most require them. For refurbishments promoted by public organisations, or those financed with public resources, to address buildings with a greater energy improvement capacity, we need to know their energy consumption and potential savings. Given the large number of existing blocks and the difficulty of studying each one in detail, a simplified evaluation methodology is proposed to estimate energy demand in primary energy terms ($kW \cdot h/year \cdot m^2$) to give priority to certain refurbishments over others.

Our study objective was to develop a simplified method that predicts the heating and cooling energy demand of social housing buildings that considers the thermal inertia of the non-insulated elements of the envelope, at the scale of housing block, by only knowing some variables of buildings that are easily obtained, without the need of simulating them since this would be very time-consuming. This model is useful for the Public Administration in Spain, and it will also be of help in other European countries with this construction typology, since they will count with a simple method to quickly obtain objective information about the energy demand of a large stock of residential buildings, which will be helpful in prioritising their refurbishment.

2. State of the art

In this study the energy demand of buildings in primary energy terms (kW·h/year·m^2) is the energy-related criterion used to give priority to the refurbishment of certain buildings over others. Other parameters could also be used, such as the energy consumption, the CO_2/year·m^2 emissions associated to such energy consumption, or the energy classifications that derive from the former. These three other alternative parameters are energy consumption-based parameters.

The studies pursuing the energy characterisation of existing building stocks rely mostly on consumption-based parameters. Some of these studies in the literature propose evaluation methodologies to estimate annual energy consumptions that start with overall energy consumptions data and share them among buildings according to specific building typology parameters. For example, in the studies that analyse the whole building stock in Europe, the energy consumption and CO_2 emissions of such a large and heterogeneous set of data is shared among buildings according to statistical-based data related to country, climate zone, building typology or age [12] [13]. The studies at city scale estimate the energy consumption of the built stock according to statistical data about building typology, envelope thermal characteristics, heat production units, energy carriers and use of renewables [14] [15]. In any case, these energy consumption-based studies have the disadvantage that, as calculations are based on proportionally sharing the official energy consumptions according to the building, envelope or installation typologies, specific residential block factors such as orientation or social factors affecting energy consumption are ignored.

User behaviour –a social factor– is considered key to energy efficiency of existing buildings [16] as well as orientation. For this reason, the studies that proportionally share energy consumptions according to statistical census data are not considered appropriate for the objective of this paper since our aim is to find a method to predict energy efficiency for a given building typology (old social housing) requiring sufficient precision to differentiate behaviours at the residential block scale. Whereas the previously mentioned studies provide rough energy data about country- or city-scale residential building stocks, our intention is to provide more accurate data about a given residential typology that is found in European cities and has been identified as a key residential typology to be refurbished due to its high consumptions [17].

Energy poverty in Spain is a genuine and growing problem [18]. The percentage of homes unable to maintain a suitable temperature increased by 22% from 2012 to 2014, and is now estimated at 11% [19]. It is reasonably assumed that this percentage is higher in vulnerable areas. Energy demand decreasing strategies work better for people suffering from energy poverty than consumption decreasing ones [20]. Besides energy poverty, building’s heating and cooling systems will also affect energy consumption, and there is no available and reliable data about this matter for the residential stock in Spain. So conducting a study into the energy characteristics of buildings by means of their energy demand, that is, the energy they require for their interiors to be comfortably enjoyed by occupants, was considered a more appropriate measure than using any energy consumption-related parameter. Demand depends basically on climate and the building’s characteristics, and is independent of the performance of heating systems and social factors. This is why it was considered a more reliable criterion.

Various models have been designed to forecast the heat demand of buildings. They use regression models to predict the energy demand of residential buildings [21] [22] [23], office buildings [24] or commercial buildings [25]. The energy prediction models are based on extended databases obtained by dynamic simulations. The inputs for the models include building shape factors, building orientation aspects, building construction characteristics, windows ratios, and climate. These models have been developed to support early design stages of new buildings whose envelopes have insulating material. In the case of building refurbishment, especially in post-war social housing, the thermal envelope is not insulated and thus the model must include different inputs. Most of these buildings have a great thermal inertia that taken into account together with heat transfer coefficients are the most important quantitative parameters for designing energy-efficient exterior walls and roofs [26].

Therefore, the novelty of this paper consists of using an energy demand criterion to characterize the existing building stock –instead of the most commonly used energy consumption related ones– and of including as input data for the prediction model the thermal inertia of the building envelope with no insulating material.

3. Methodology

Simulation tools were used from which demand data were obtained. To calculate energy demand, the General Option Technical Building Code Energy Savings (CTE DB HE) Method was used, formalised through the Unified LIDER-CALENER (HULC by its Spanish acronym) software application tool, version 20151113 (0.9.1431.1016), of compulsory use in Spain since 14 January 2016. This tool was used instead of other simulation software because it is the official tool employed in Spain. The heating and cooling energy demands for a sample of buildings were obtained by the HULC tool using the climate data from the study area, Zaragoza, and its geometric and building definition parameters.

A model was designed with these data with which the heating energy demand of the other blocks can be obtained by only knowing a series of variables with available information. A multiple linear regression model was defined using independent variables to predict the behaviour of a dependent variable.

4. Case study

Europe denounces the situation of districts in which social, economic and environmental problems concentrate [27], which have been identified as social housing estates built after 1945, among others. In Spain, these are blocks of social housings built during the postwar period. In the city of Zaragoza, some of these blocks of buildings have been declared as UEI by the 2001 Urban Land-Use Plan of Zaragoza as regards certain protection measures.

For this study 19 UEI were chosen by applying selection criteria: they had to be protected by the UEI regime, be built during the 1945-1975 period, and be considered vulnerable districts. This study excluded single family housing because its high revaluation does not enable it to be included in the vulnerability concept. The selected 19 UEI comprise 7,981 homes distributed among 228 blocks. Most have between three and six storeys, and there are 12-storey flats.

5. Model variables

A model was developed which, by means of a series of variables that intervene in a building's energy demand, obtains energy demands in primary energy terms (kW·h/m^2·year). The factor that intervenes the most in energy demand of buildings is climate zone. In our particular case, the climate zone remains constant as all the buildings are located in the city of Zaragoza.

The described model firstly addressed the ability to obtain the heating energy demand of buildings. Nonetheless, the model for cooling energy demand was also run, with satisfactory results.

The sections below examine the proposed independent variables to be considered to estimate demand. With a series of buildings used as case study, these independent variables were related with the heating energy demand, a dependent variable, to establish a relation that could be applied to the other blocks (Figure 1).

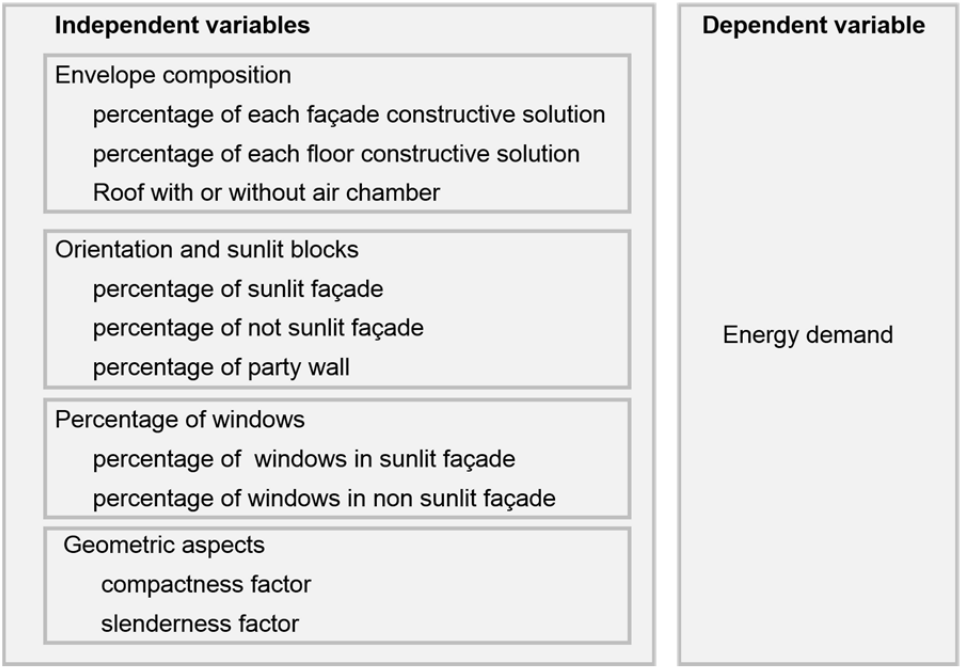

Figure 1. Model variables considered in the study.

5.1. Envelope composition

To quantify the thermal behaviour of the envelope of the Urban Blocks, the static and dynamic behaviours of each construction solution were studied.

A former study [28] made an initial evaluation of the construction solutions of opaque envelope elements of housing blocks, and compared them with the requirements of current Spanish regulations (the CTE). This section employed the construction solutions and nomenclature presented herein, which are not repeated to simplify.

As the buildings are old social housing types, their exterior walls are not thermally insulated, and solutions would be massive for many cases. This is why the thermal inertia of some of these walls is important and is, therefore, a differentiating element among the various types of existing walls. Of the distinct properties to quantify the thermal inertia of walls, we used thermal lag, which refers to the time that heat takes to cross a layer of material. In order to characterise the dynamic behaviour of walls, the method described in standards UNE-EN ISO 13786:2011 and UNE-EN ISO 6946:2012 [29] was followed. As we were dealing with old, and virtually crafted, materials, the thermal conductivity, density and specific heat values were chosen and taken from Spanish sources [3] [30] [31].

Originally, the exterior carpentry of the studied housing was wood. There have been occasions on which users have replaced this solution with other materials and other glass compositions. The work by [28] accounted for 17 different kinds of windows and verified the existence of a homogeneous distribution throughout all the studied blocks and estates. In order to determine energy demand as a simplification method, all the windows on the studied buildings, which offered poor energy performance, were considered original. It was reasonable to assume that each block would have a percentage of windows of each kind. However, this could distort the results depending on the direction that the façades faced where windows were found as to them having better energy performance and sunlight.

The windows that we considered to develop the physical vulnerability indicators were, therefore, poorly sealed wooden windows, with an air permeability of 100 m^3/hm^2 to

100 Pa, and a window frame percentage of 20%. Glass was 4 mm single-glazed, with a thermal transmittance of 5.70 $W/m^2 \cdot K$ and a solar heat gain coefficient of 0.87. Data were obtained from the official Spanish Construction Elements Catalogue.

a) Façades

The buildings that formed part of the UEI presented 15 types of different façades. Figure 2 depicts the construction solutions according to their energy performance. There were three clearly different groups according to static and dynamic behaviours.

In order to create groups which façade behaviours were to be divided into, the demands for new buildings in the first regulation on energy savings to be passed in Spain, NBE CT79, was taken as a criterion because no case fulfilled the criteria in today's regulation (the CTE) on refurbishing buildings. The figure shows the limit that the CTE sets, 0.66 $W/m^2 \cdot K$, and that set out in NBE CT79 1.20 or 1.60 $W/m^2 \cdot K$, depending on whether the façade is light or heavy.

For the reference thermal lag limit, the work by [32] set it at 8 hours to group better performing walls. These authors indicated that a value from 6.5 was acceptable. Both these limits are shown in Figure 2.

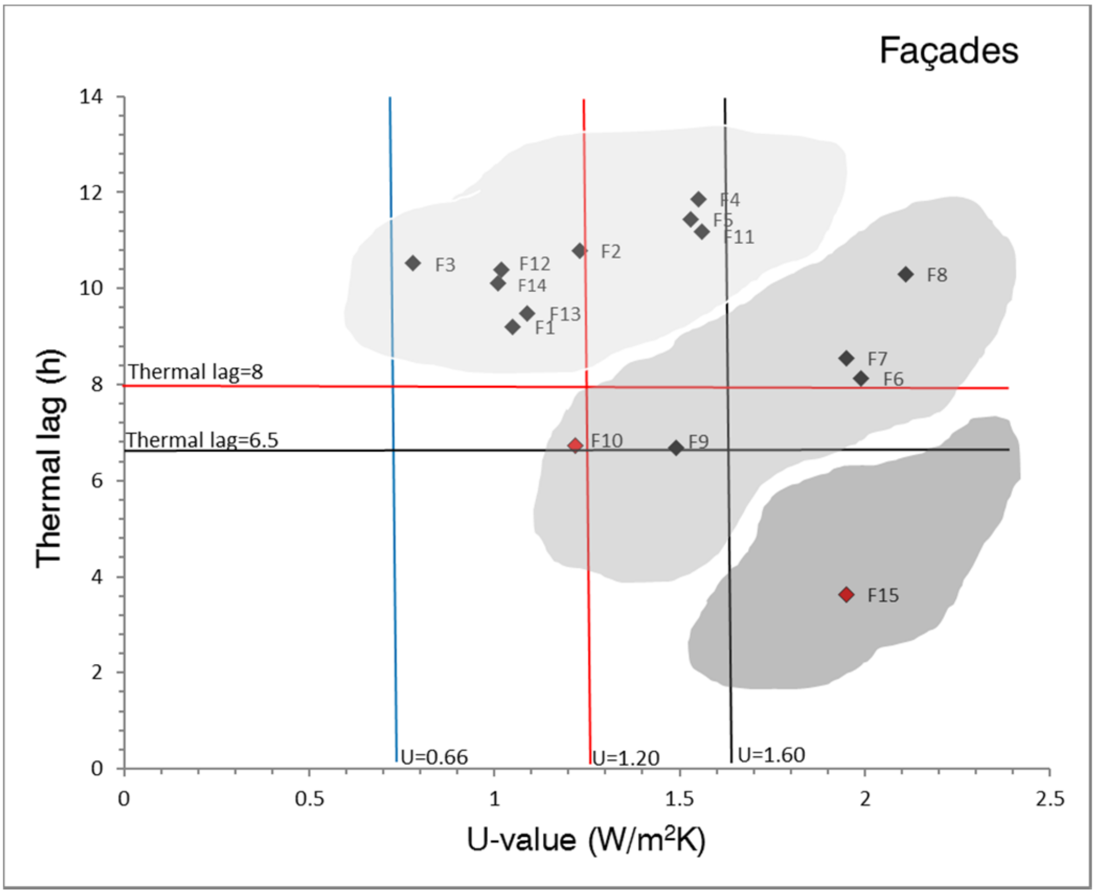

Figure 2. Scatter plot of the energy properties of the different façade types. Following NBE-CT79 criteria, the red marker represents light façades and the black marker denotes heavy façades.

Groups of façades were formed as follows: the first group corresponded to the façades whose blind side had lower transmission values than those set in Regulation NBE CT79, but with thermal lag values above 8 hours. Although transmission values were high, these walls presented considerable inertia that would compensate for exterior thermal variations, and would presumably offer better performance for all the construction solutions in the blocks. The second group presented a higher transmission value than that indicated in the regulation, but a high thermal lag value; or vice versa; i.e, a lower transmission value than that set out in the regulation, but a thermal lag value under 8 hours. The third group encompassed façades which, in this case, were of only one type for which transmission values were over those set out in the Basic Standard. Its thermal lag values were under 8 hours, and even below 6.5 hours. Therefore, the formed groups of façades were, from better to worse thermal performance, the following:

Façade group 1	F1, F2, F3, F4, F5, F11, F12, F13, F14
Façade group 2	F6, F7, F8, F9, F10
Façade group 3	F15

b) Roofs

The blocks had nine different types of roofing solutions. Their roofs presented deficient energy performance for transmission values, which were higher than those required by NBE CT 79, and for thermal lag values. However, roofs were divided to set a transmission limit of 2 W/m^2·K, which coincides with the dividing of roofs that had a non-ventilated air chamber and those without this air chamber.

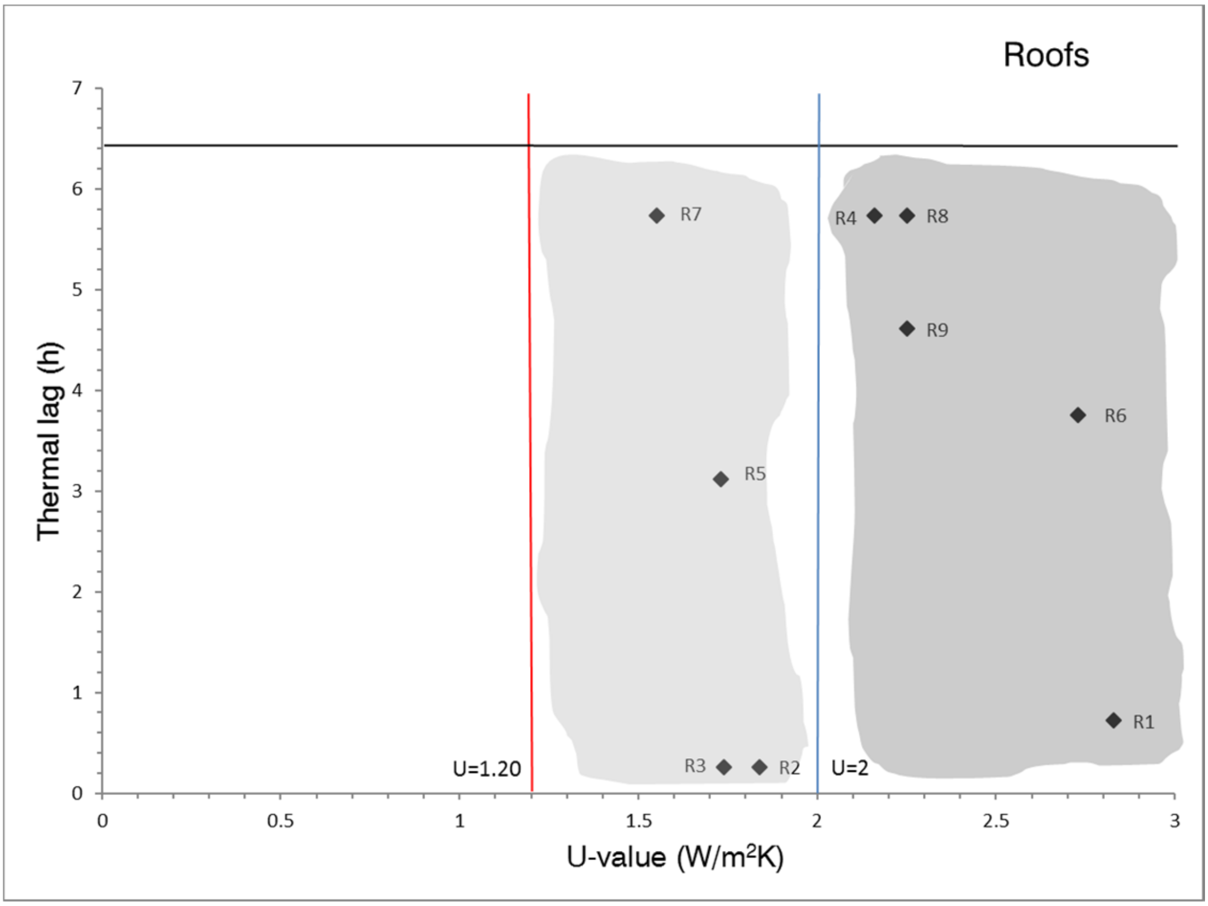

Figure 3. Scatter plot of the dispersal in the energy properties of the different roof types

Therefore, the roofs of the UEI were divided between those with a non-ventilated air chamber and those with a well-ventilated air chamber. From better to worse thermal performance, we obtained (Figure 3):

Roofs with a non-ventilated air chamber	R2, R3, R5, R7
Roofs with a well-ventilated air chamber	R1, R4, R6, R8, R9

c) Floors

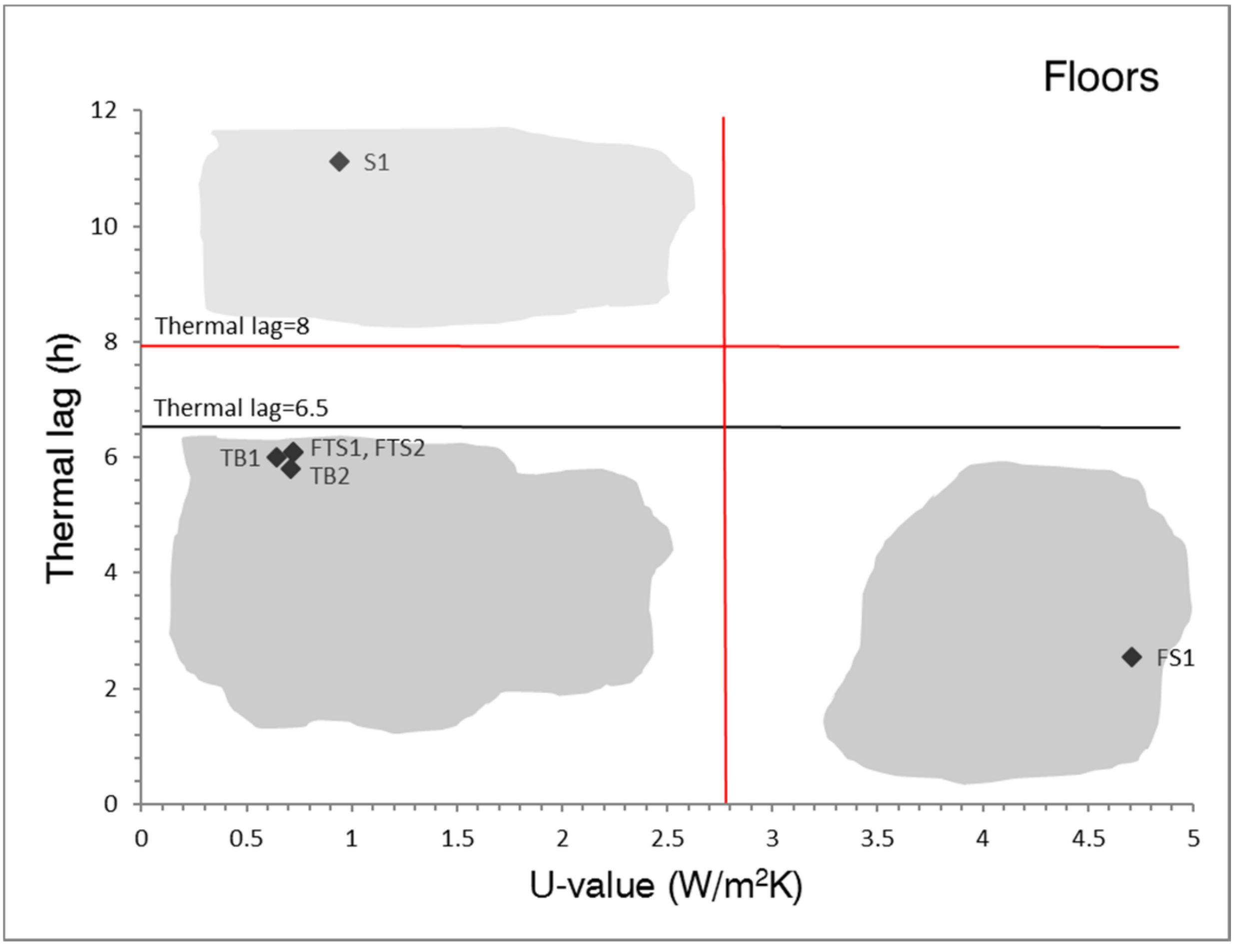

Figure 4. Scatter plot of dispersal in the energy properties of different floor types

The housing blocks had six different floor types. Floors were divided into three groups according to their energy performance. In Figure 4 we can clearly see these three groups. The first is made up of only solution S1, and has a low thermal transmission value and a high thermal lag value. It is the floor with the best thermal performance. The group formed by floors TB1, TB2, FTS1 and FTS2 share a low thermal transmission value and a low thermal lag value. Finally, floor FS1 has a high thermal transmission value and a low thermal lag. It is the worst energy performing floor.

Floor group 1	S1
Floor group 2	TB1, TB2, FTS1, FTS2
Floor group 3	FS1

5.2. The blocks'orientation and sunlight

To obtain this variable, it was necessary to define orientations that came as close as possible to the real situation in the city of Zaragoza, which simplified the task of orientating a building or detecting the "best or worst" orientation of an already existing building. Therefore, the intention was to obtain an approach that facilitated diagnosing sufficiently or insufficiently sunlit façades. Three orientations were defined according to the following criteria: sufficiently sunlit, insufficiently sunlit and averagely sunlit. The limit between the three of them was obtained by studying different levels of incidence of solar radiation on the buildings façades and linking the percentages of building façades with such a solar radiation level during the cool season with energy demand for heating.

5.3 Percentage of windows

Glass is a passive system that directly captures solar radiation, which it transfers inside buildings as a direct form of heat. As it is a poor thermal-performing element in both static and dynamic terms, because of its high thermal transmission and its low thermal lag, it can also be the point at which heat escapes from buildings. To define the heating energy demand, two variables related to the percentage of windows in buildings were distinguished: percentage of windows in sufficiently sunlit façades and percentage of windows in insufficiently sunlit façades.

The percentage of windows in the blocks was determined by consulting the original construction projects, subsequent refurbishment projects and by taking data in situ, depending on each case. The window dimensions formed by the window frame and glass were recorded.

The setback of the spaces for windows was not taken as a variable. However, this dimension depends on the façade solution, which is a variable. Therefore, the setback of windows goes implicitly hand in hand with the façade construction composition variable.

A building may be oriented in such a way that part of its façade is sufficiently sunlit, but does not have spaces for windows to capture solar radiation. This is why we considered the variable percentage of windows to better explain our model, which had to be divided into two: percentage of window spaces on a sufficiently sunlit façade and percentage of window spaces on an insufficiently sunlit façade. In the former, these spaces allow sunlight to be captured and make full use of this energy. The latter are the equivalent to window spaces on a northerly facing façade. So they are unable to make full use of the sun entering through them and only produce energy losses.

5.4 Geometric aspects

Buildings' geometric and volumetric aspects greatly determine their energy losses and, therefore, their energy demand.

The floor area of the blocks is another factor. However, as the percentage of each façade was calculated in each orientation, and the width of each buildings type was similar as they shared similar construction characteristics, surface area was indirectly taken into account.

To define the shape of buildings, we can resort to two definitions:

- Compactness: compactness indicates the energy losses that a building has given its geometric shape. It is defined as the surface of the sphere that could contain the same volume as the building, between the building's outer surface, without counting interior patios. It gives values of between zero and one; the closer to 1, the fewer energy losses through the building envelope the building has. It gives an idea of buildings'concentration of masses and shape because, as this is a ratio, the same shapes give us the same compactness, although volumes are different.

- Slenderness: a building's slenderness represents its length vertically. It is calculated by the ratio between the whole building height and the mean storey's surface area radius, understood as the mean value of all its storeys [33]. The higher the slenderness value is, the more the building will be submitted to climate exposure.

6. Energy demand as a dependent variable

To determine the dependent variable (the heating energy demand), the HULC simulation software was used. Buildings' heat storage capacity does not only depend on façade properties, but also on the thermal inertia of interior elements like floor slabs and interior partitioning. Internal masses were simplified to conduct this study. The energy simulation run with HULC only took into account the vertical partitioning walls between dwellings.

Simulating them all made no sense because the objective was to seek a simplified model to predict the heating energy demand with some variables without having to run an energy simulation of them all. Several simulations covered the widest spectrum of variables.

Table 1 shows the selected blocks and their heating energy demand, calculated by the HULC tool. There were 26 cases to study in all. The first column indicates the letters of the name of the housing estates they were located in. The second column includes the block's name, which falls in line with the nomenclature used to undertake the study (not shown to simplify). The third column is the obtained heating demand.

Estate	Block	Heating demand kW·h/m^2•year
AC	MN	114.87
AC	DE	117.38
AC	BC	115.82
AC	O	113.4
AC	H	109.21
AR	D	130.78
AR	E	141.57
VE	F	59.16
VE	A	61.04
PVR	C	84.17
AD	F	107.24
T	F	110.75
OZ	E	86.43
P	F	70.52
BEV	X	133.65
BEV	AF	98.85

AG	B	104.08
AS	L	115.35
AS	Q	103.08
SJ	OP	58.79
P	Nord	64.56
SR	East block	85.75
AS	Tower	87.99
BEV	Tower 1	103.25
T	Tower 2	68.63
T	Tower 3	86.11

Table 1. Heating demands in kW·h/m^2•year of the UEI blocks calculated with HULC. Name of Estates: AC: Andrea Casamayor; AR: Alférez Rojas; VE: Vizconde Escoriaza; PVR: Puente Virrey Roselló; AD: Arzobispo Domenech; T: Torrero; OZ: Ortiz de Zárate; P: Picarral; BEV: Balsas de Ebro Viejo; AG: Agustín Gericó; AS: Aloy Salas; SJ: San Jorge; P: Picarral; SR: Santa Rosa.

As we can observe in Table 1, the heating energy demand varied between the different UEI, and even within the same estate. Three blocks of the Andrea Casamayor (AC) estate were simulated with the Unified Lider-Calener tool using the same constructive solutions and equal geometric aspects. Nevertheless, a 2% difference appeared between the highest and lowest demands due to sunlight. Likewise, a 3% difference was found between two simulated blocks from the Vizconde Escoriaza (VE) estate, and an 8% difference in Aloy Sala (AS) and one of 26% in Balsas de Ebro Viejo (BEV) were obtained. These differences were due to each block's orientation and, therefore, also to the solar radiation that façades and window spaces received.

7. Determining a model for the simplified calculation of heating energy demand

Multiple linear regression is a statistical mathematical model that predicts the value of a dependent variable –Y– by the linear combination of the independent variables –xi–. A multiple regression model is presented as follows:

$$Y= m_0 + m_1x_1 + m_2x_2 + m_3x_3+\ldots+ m_nx_n \qquad (1)$$

where m is the coefficient and x is the variable.

The explanatory variables of the model must be adapted to be introduced into the multiple linear regression model. The values of the used matrix are shown in Table 2. Columns F1 and F2 indicate the façade fraction formed by each constructive solution. There are three façade groups. However, one of the variables is dependent on the other two, which is why only two of the variables must be introduced into the model so they are independent and so no correlation appears among them that could distort the regression model. The roof and floor columns were completed in the same manner.

Façades can be sufficiently sunlit, insufficiently sunlit and averagely sunlit. The sum of these three percentages comes to 100, and one is dependent on the other two. As in previous cases, only two independent variables are introduced into the model and, in this case, the percentage of sufficiently sunlit façade was chosen –SSF-, and the percentage of insufficiently sunlit façade –ISF-.

The other variables were introduced with a numerical value: percentage of window spaces on façades, percentage of dividing walls, compactness factor and slenderness factor. The percentages for sunlit façades, and for window spaces and dividing walls, were rounded off to whole numbers to simplify calculations.

Table 2 shows the matrix of the 26 studied buildings that allowed the model to be determined. The first column indicates the initials of the estate where the block that is the study object is located. The second column indicates the building, and the other 12 columns reflect the independent variables. The last column denotes the dependent variable, heating energy demand, calculated by the simulation method. Multiple regression was calculated by the SPSS software package, version 21, and by Excel.

Estate	Block	F1	F2	FL1	FL2	R	% w SSF	% w ISF	% SSF	% ISF	% dw	C	S	Energy demand heating (HULC) kW·h/m^{2}year
AC	MN	1	0	1	0	0	20	20	36	59	0	0.57	0.75	114.87
AC	DE	1	0	1	0	0	22	19	31	64	0	0.57	0.75	117.38
AC	BC	1	0	1	0	0	20	20	36	59	0	0.57	0.75	115.82
AC	O	1	0	1	0	0	10	21	7	93	0	0.76	0.8	113.4
AC	H	1	0	1	0	0	19	17	43	50	0	0.63	0.75	109.21
AR	D	1	0	0	0	0	15	10	38	62	0	0.57	0.82	130.78
AR	E	1	0	0, 22	0	0	17	12	55	34	0	0.62	0.81	141.57
VE	F	1	0	1	0	1	11	13	50	50	0	0.61	0.60	59.16
VE	A	1	0	1	0	1	0	13	0	50	0	0.61	0.60	61.04
PVR	C	1	0	0	1	1	17	17	11	70	0	0.41	0.44	84.17
AD	F	1	0	1	0	0	10	10	7	7	0	0.63	0.74	107.24
T	F	0	1	0	1	1	0	9	3	52	4	0.63	0.77	110.75
OZ	E	0	1	1	0	0	9	9	40	50	0	0.69	0.77	86.43
P	F	0	1	1	0	0	0	18	0	100	0	0.51	0.53	70.52
BEV	X	0	1	0	1	0	0	0	11	11	0	0.71	0.82	133.65
BEV	AF	0	1	0	1	0	22	20	42	58	0	0.66	0.77	98.85
AG	B	0	1	0	1	1	14	8	49	48	3	0.54	0.56	104.08
AS	L	0	0,78	0	1	1	35	25	43	50	0	0.64	0.82	115.35
AS	Q	0	0,78	0	1	1	29	25	50	50	0	0.64	0.82	103.08
SJ	OP	1	0	1	0	1	14	14	35	50	0	0.57	0.59	58.79
P	Nord	1	0	1	0	1	14	13	23	73	0	0.37	0.42	64.56
SR	East Tower	0	1	1	0	0	17	15	30	64	0	0.50	0.65	85.75
AS	Tower	0	1	0	1	0	27	20	29	55	0	0.62	0.90	87.99
BEV	Tower	0	1	0	1	0	22	20	33	29	0	0.64	0.95	103.25
T	Tower 2	1	0	1	0	1	0	9	8	50	0	0.56	0.90	68.68
T	Tower3	1	0	1	0	1	15	15	35	35	6	0.66	0.96	86.11

Table 2. Matrix of the variables for the multiple linear regression model to obtain the simplified formula to calculate heating energy demand. Name of Estates: AC: Andrea Casamayor; AR: Alférez Rojas; VE: Vizconde Escoriaza; PVR: Puente Virrey Roselló; AD: Arzobispo Domenech; T: Torrero; OZ: Ortiz de Zárate; P: Picarral; BEV: Balsas de Ebro Viejo; AG: Agustín Gericó; AS: Aloy Salas; SJ: San Jorge; P: Picarral; SR: Santa Rosa. Variables: F: façade, FL: floor; R: roof; w SSF: windows space sufficiently

sunlit façade; w ISF: window spaces insufficiently sunlit façade; SSF: sufficiently sunlit façade; ISF: insufficiently sunlit façade; dw: dividing wall; C: compactness; S: slenderness.

7.1 Obtaining expressions

To determine the regression model, the values of the coefficients of each variable were calculated, as was an independent term (Table 3). The multiple linear regression model expression used to determine the heating energy demand of the UEIs is shown below:

Heating energy demand = 470.29–322.73 Façade 1 – 364.18 Façade 2 – 4.81 Floor 1 + 30.83 Floor 2 – 61.80 Roof– 0.19 window spaces FSS – 2.16 window spaces FIS + 0.30 FSS + 0.20 FIS + 6.39 dividing wall -11.75 Compactness -2.19 Slenderness (2)

Variable	F1	F2	FL1	FL2	R	%w SSF	%w ISF	%FSS	%FIS	%dw	C	S	IT
DC	-322.73	-364.18	-4.81	30.83	-61.8	-0.19	-2.16	0.3	0.2	6.39	-11.75	-2.19	470.29

Table 3. The regression model's coefficients of the indicator heating energy demand. HD: Heating energy demand; IT: Independent term

7.2 Validating the multiple linear regression model

The model was checked after calculating the simplified expression to determine the heating energy demand. The determination r^2 coefficient was analysed, which indicates the model's goodness-of-fit, and is a good indicator of the percentage of variability of the dependent variable explained by the model. The value of this coefficient lies between 0 and 1; the closer it comes to 1, the better it explains the model. The r^2 obtained for this model was:

$$r^2=0.9151$$

The determination coefficient came quite close to 1, especially when we consider that the model is a simplified one run to estimate the energy performance of buildings because a simulation tool should be used to know the exact energy demand value. The model explained 91.51% of the heating energy demand variability.

Another factor that was checked was the F-statistics, which allowed the verification of whether the variables employed for the regression model really explained the value of the analysed demands. If there was no relation between the independent variables and the dependent variable, then the F-statistics value was lower than the ${}_{critical}F$-value, obtained from the distribution tables.

$$F=11.67$$

The ${}_{critical}F$-value obtained for the previous regression model, with 12 and 11 degrees of freedom, and 95% confidence level, was 4.56×10^{-5}. As the obtained F-value was 11.67, which was much higher than the ${}_{critical}F$-value, this indicated that the obtained variables well explained the heating energy demand. The expression of the model obtained to calculate the heating energy demand was considered valid.

7.3 Error of the model

The percentage of error indicates the uncertainty interval of estimated demand. After calculating the expression to calculate the heating energy demand for the blocks under study, the obtained results were checked. The formula obtained and described earlier was applied to the blocks simulated with HULC, and both lots of results were compared.

Of the 26 simulated buildings chosen to determine the model, Table 4 indicates the demand obtained with HULC as $kW \cdot h/m^2 \cdot year$, the demand calculated with the expression indicated in the previous section, the subtraction of both values, and the percentage that this subtraction represents of the demand calculated by HULC.

Estate	Block	Heating demand (HULC) kW·h/m^{2}year	Heating demand calculated with the formula	Absolute difference	Percentage of Error
AC	MN	114.87	110.06	4.81	4.2%
AC	DE	117.38	111.35	6.03	5.1%
AC	BC	115.82	110.06	5.76	5.0%
AC	O	113.4	105.57	7.83	6.9%
AC	H	109.21	116.33	-7.12	-6.5%
AR	D	130.78	138.50	-7.72	-5.9%
AR	E	141.57	131.64	9.93	7.0%
VE	F	59.16	67.37	-8.21	-13.9%
VE	A	61.04	54.42	6.62	10.8%
PVR	C	84.17	88.22	-4.05	-4.8%
AD	F	107.24	113.72	-6.48	-5.9%
T	F	110.75	112.00	-1.25	-1.1%
OZ	E	86.43	92.42	-5.99	-6.9%
P	F	70.52	75.33	-4.81	-6.8%
BEV	X	133.65	132.33	1.32	1.0%
BEV	AF	98.85	104.38	-5.53	-5.6%
AG	B	104.08	91.19	12.89	12.4%
AS	L	115.35	106.79	8.56	7.6%
AS	Q	103.08	111.49	-8.41	-8.1%
SJ	OP	58.79	60.62	-1.83	-3.1%
P	Nord	64.56	66.52	-1.96	-3.0%
SR	East Block	85.75	80.23	5.52	6.4%
AS	Tower	87.99	99.10	-11.11	-12.6%
BEV	Tower 1	103.25	95.68	7.57	7.3%
T	Tower 2	68.63	65.40	3.23	4.7%
T	Tower 3	86.11	91.72	-5.61	-6.4%

Table 4. Values obtained for the heating energy demand, expressed as kW·h/m^2•year, calculated by HULC. The obtained heating energy demand values, expressed as kW·h/m^2•year, calculated with the obtained demand formula (2), the absolute difference, and the percentage of error, for the UEI blocks chosen to determine the model. Name of Estates: AC: Andrea Casamayor; AR: Alférez Rojas; VE: Vizconde Escoriaza; PVR: Puente Virrey Roselló; AD: Arzobispo Domenech; T: Torrero; OZ: Ortiz de Zárate; P: Picarral; BEV: Balsas de Ebro Viejo; AG: Agustín Gericó; AS: Aloy Salas; SJ: San Jorge; P: Picarral; SR: Santa Rosa.

The mean percentage of the mean error value of the demand results, expressed as an absolute value, was 6.28%.

The main absolute difference corresponded to Block B of the AG estate, with an absolute difference of 12.89 kW·h/m^2·year. According to the demand values calculated with the obtained formula, the best result corresponded to Block D of the AR estate with 138.50 kW·h/m^2·year, and the lowest value went to Block A of VE with 54.42 kW·h/m^2·year. The difference between both values was 84.08. The relation between the largest absolute difference, which was 12.89, and the difference between the highest and the lowest obtained calculated demand value, which was 84.08, was 15.3%, which was the relative error.

The highest percentage of error corresponded to Block F of VE, with a difference of 13.9%. The percentage of error is a relative measure of the importance of the error made when predicting, and compared to the real value that is the object of predicting. It is a more accurate measure than the error's own value because this value itself does not sufficiently inform.

In view of the data, the absolute error, the relative error and the percentage of error were considered small, and the model was considered valid.

7.4 Influence of explanatory variables on the model

The model obtained to calculate the heating energy demand in the UEI in a simplified manner assigned a coefficient to each explanatory variable that determined the influence of each variable. These coefficients are provided in Table 6. Here we can see that façade composition was the variable that most strongly influenced demand, followed by roof composition. To a lesser, but significant extent, influence of floors appeared.

Morphological aspects also significantly influenced, firstly compactness and, to a lesser extent, slenderness. Sunlight and the percentage of window spaces were poorly represented in this model. The percentage of window spaces on an ISF was slightly represented, and the rest gave coefficients below 1.

8. Cooling energy demand

Temperatures in Zaragoza are high in the hottest months. So conducting a study into cooling energy demand was considered of interest. Although the variables selected for the model intended to obtain heating demand, they were also checked for the cooling demand. This was done by generating a matrix in which the independent variables were those described in Section 4, and the dependent variable was the cooling energy demand calculated by the HULC software. The resulting matrix is found in Table 5.

Estate	Block	F1	F2	FL1	FL2	R	% w SSF	% w ISF	% SSF	% ISF	% dw	C	S	Cooling demand (HULC) kW/m^2·year
AC	MN	1	0	1	0	0	20	20	36	59	0	0.57	0.75	11.20
AC	DE	1	0	1	0	0	22	19	31	64	0	0.57	0.75	11.10
AC	BC	1	0	1	0	0	20	20	36	59	0	0.57	0.75	11.20
AC	O	1	0	1	0	0	10	21	7	93	0	0.76	0.8	11.46
AC	H	1	0	1	0	0	19	17	43	50	0	0.63	0.75	11.51
AR	D	1	0	0	0	0	15	10	38	62	0	0.57	0.82	16.43
AR	E	1	0	0.22	0	0	17	12	55	34	0	0.62	0.81	15.86
VE	F	1	0	1	0	1	11	13	50	50	0	0.61	0.60	9.18
VE	A	1	0	1	0	1	0	13	0	50	0	0.61	0.60	8.73
PVR	C	1	0	0	1	1	17	17	11	70	0	0.41	0.44	12.95
AD	F	1	0	1	0	0	10	10	7	7	0	0.63	0.74	16.05
T	F	0	1	0	1	1	0	9	3	52	4	0.63	0.77	13.32
OZ	E	0	1	1	0	0	9	9	40	50	0	0.69	0.77	6.34
P	F	0	1	1	0	0	0	18	0	100	0	0.51	0.53	8.08

BEV	X	0	1	0	1	0	0	0	11	11	0	0.71	0.82	19.50
BEV	AF	0	1	0	1	0	22	20	42	58	0	0.66	0.77	12.45
AG	B	0	1	0	1	1	14	8	49	48	3	0.54	0.56	11.83
AS	L	0	0.78	0	1	1	35	25	43	50	0	0.64	0.82	15.41
AS	Q	0	0.78	0	1	1	29	25	50	50	0	0.64	0.82	16.35
SJ	OP	1	0	1	0	1	14	14	35	50	0	0.57	0.59	10.92
P	Nord	1	0	1	0	1	14	13	23	73	0	0.37	0.42	5.90
SR	East block	0	1	1	0	0	17	15	30	64	0	0.50	0.65	8.53
AS	Tower	0	1	0	1	0	27	20	29	55	0	0.62	0.90	12.84
BEV	Tower 1	0	1	0	1	0	22	20	33	29	0	0.64	0.95	14.59
T	Tower 2	0	1	0	1	1	0	9	8	50	0	0.56	0.90	10.22
T	Tower 3	0	1	0	1	1	15	15	35	35	6	0.66	0.96	11.06

Table 5. Matrix of the variables for the multiple linear regression model to obtain the simplified formula to calculate the demand of r. Name of Estates: AC: Andrea Casamayor; AR: Alférez Rojas; VE: Vizconde Escoriaza; PVR: Puente Virrey Roselló; AD: Arzobispo Domenech; T: Torrero; OZ: Ortiz de Zárate; P: Picarral; BEV: Balsas de Ebro Viejo; AG: Agustín Gericó; AS: Aloy Salas; SJ: San Jorge; P: Picarral; SR: Santa Rosa. Variables: F: façade, FL: floor; R: roof; w SSF: windows space sufficiently sunlit façade; w ISF: window spaces insufficiently sunlit façade; SSF: sufficiently sunlit façade; ISF: insufficiently sunlit façade; dw: dividing wall; C: compactness; S: slenderness.

To determine the regression model, the values of the coefficients of each variable and one independent term are calculated, which are found in Table 6. The multiple linear regression model expression to determine the cooling energy demand of the UEI was as follows:

$$\text{Cooling energy demand} = 47.34 - 27.09\ \text{Façade 1} - 30.34\ \text{Façade 2} - 4.46\ \text{Floor 1} - 0.35\ \text{Floor 2} - 3.35\ \text{Roof} + 0.02\ \text{window spaces SSF} - 0.11\ \text{window spaces ISF} - 0.03\ \text{SSF} - 0.05\ \text{ISF} + 0.13\ \text{division wall} + 3.45\ \text{Compactness} - 0.78\ \text{Slenderness} \tag{3}$$

Variable	F1	F2	FL1	FL2	R	%w SSF	%w ISF	% SSF	% ISF	%dw	C	S	IT
HC	-27.09	-	-4.46	-0.35	-3.35	0.02	-0.11	-0.03	-0.05	0.13	3.45	-	47.34

		30.34										0.78	

Table 6. The regression model's coefficients of the indicator cooling energy demand. HC: heating energy demand. IT: independent term.

8.1 Checking the multiple linear regression model

The model was checked after calculating the simplified expression to determine the cooling energy demand. The coefficient of determination r^2 was analysed, which indicated the model's goodness-of-fit, and was a good indicator of the percentage of variability of the dependent variable, which was explained by the model. The r^2 value obtained for this model was:

$$r^2=0.8927$$

The coefficient of determination came quite close to 1, especially when we consider that it is a simplified model to explain 89.27% of cooling energy demand variability.

Another checked factor was F-statistics, which allowed us to verify whether the variables employed for the regression model really explained the value of the analysed demands.

$$F=9.01$$

The $_{critical}F$-value obtained for the previous regression model, with 12 and 11 degrees of freedom and 95% confidence level, was 0.00018. As the obtained F-value was 9.01, which was higher than the $_{critical}F$-value, this indicated that the obtained variables well explained the cooling energy demand. The model of the equation obtained to calculate the cooling energy demand was considered valid.

8.2 Error of the model

Of the 26 studied buildings chosen to determine the model, Table 7 indicates the demand obtained with HULC, in $kW/m^2 \cdot year$, the demand calculated with the expression indicated in the previous section, the subtraction of both values, and the percentage that this subtraction represents compared to the demand calculated with HULC.

Estate	Block	Demand (HULC) kW/m^2 year	Demand calculated with the formula	Absolute difference	Percentage of error
AC	MN	11.20	11.08	0.12	1.0%
AC	DE	11.10	11.13	-0.03	-0.3%
AC	BC	11.20	11.08	0.12	1.0%
AC	O	11.46	10.64	0.82	7.2%
AC	H	11.51	11.82	-0.31	-2.7%
AR	D	16.43	16.23	0.20	1.2%
AR	E	15.86	16.12	-0.26	-1.6%
VE	F	9.18	8.55	0.63	6.8%
VE	A	8.73	10.08	-1.35	-15.5%
PVR	C	12.95	12.77	0.18	1.4%
AD	F	16.05	15.90	0.15	0.9%
T	F	13.32	14.93	-1.61	-12.1%
OZ	E	6.34	9.54	-3.20	-50.4%
P	F	8.08	6.75	1.33	16.4%
BEV	X	19.50	18.21	1.29	6.6%
BEV	AF	12.45	12.82	-0.37	-3.0%
AG	B	11.83	11.01	0.82	6.9%
AS	L	15.41	16.00	-0.59	-3.8%
AS	Q	16.35	15.77	0.58	3.5%
SJ	OP	10.92	8.89	2.03	18.6%
P	Nord	5.90	7.64	-1.74	-29.5%
SR	East block	8.53	8.09	0.44	5.1%
AS	Tower	12.84	13.27	-0.43	-3.4%
BEV	Tower 1	14.59	14.44	0.15	1.0%
T	Tower 2	10.22	9.82	0.40	3.9%
T	Tower 3	11.06	10.39	0.67	6.0%

Table 7. The values obtained for the cooling energy demand, expressed as kW/m^2•year, calculated by HULC. The values obtained for the cooling energy demand, expressed as kW/m^2•year, calculated with the obtained demand formula (3), the absolute difference, and the percentage of error for the blocks of the UEI chosen to determine the model.

Table 6 indicates the highest percentage error in Block E in the OZ estate. Although the absolute difference was 3.20 kW/m^2·year, this represents a percentage of 50.4%. Nevertheless, the mean percentage value of the mean error in the demand results as an absolute value was 6.28%. The main absolute difference also corresponded to Block E in the OZ estate.

However, for the cooling demand values calculated with the obtained formula, the highest result went to block X in the BEV Estate, with 18.21 $kW/m^2\cdot$ year, and the lowest value was for block F in the Picarral Estate with 6.75 $kW/m^2\cdot$year.

9. Discussion

The most important factor that determines a building's energy demand is the climate zone where it is located. When this input is constant because the whole building stock under study is situated in a single climate zone, it gets more difficult to get a high reliability level in the prediction models. However, we have found that by a thorough study of the envelope construction characteristics, the model is sufficiently reliable.

In our case, of residential buildings without insulating material layer, the consideration of the thermal inertia of the envelope together with its U-value is a key factor for the success of the prediction model. This simplified model predicts the energy demand in aged buildings without insulating material layer, for both heating and cooling, with a sufficiently high level of trust (91,51% for heating and 89,27% for cooling), allowing to quickly estimate energy demand with the use of easy to access input data, for social housing at the building block scale. The results of this paper for the studied typology show that indeed the input regarding the construction characteristic of the envelope is the most important one when climate zone is constant.

The model allows to distinguish levels of energy demand at block scale. This fact differentiates it from the models in the literature and it represents an important advantage, as refurbishment policies in Spain are developed at residential block scale. This way, within one single UEI, the blocks with the worst energy behavior can be easily identified by Public Administration.

10. Conclusions

This paper presents a simplified model to predict the energy demand of social housing buildings constructed without insulating material layer in a given climate zone as support in the prioritisation of their refurbishment by the Public Administration.

The inputs that were found to most influence the heating energy demand are of a construction kind, with a weight of 61,7%, followed by morphological aspects, with 1,1%. Sunlight and the percentage of window spaces barely influence their performance, only by 0,2%. Indeed the construction characteristics were so influential that they outdid all the others.

The obtained model allowed the heating energy demand to be predicted with a series of explanatory inputs. The sources in which we found these inputs were the original building projects and on site observations. Morphological aspects and the percentage of window spaces can be calculated by using information from the building project, the cadastre and by making onsite observations. It is necessary to use a tool like the Ecotect Analysis software to calculate sunlight, and to know what solar radiation reaches façades. For future research works, the possibility of eliminating this variable is proposed as it is highly time-consuming and barely influences the obtained model.

The number of simulated buildings was sufficient to establish energy performance differences in the studied set of buildings given their construction and morphological homogeneity. However, the number of buildings to simulate should be increased if this model is to be transferred to determine energy efficiency indicators on a larger scale.

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