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Case study

Evaluation thermal of the building envelope: Rehabilitated building versus non-rehabilitated

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ABSTRACT

When an energy rehabilitation of a building is planned, the aim is to achieve a significant energy saving. However, how to assess these savings can be difficult. A first idea may be monitoring the building before and after rehabilitation, but the climatic conditions can differ, which may mislead the conclusions. In this work, this problem was avoided by monitoring two similar buildings for a year, one of them energy retrofitted and the other not, sited in the same location (Zaragoza, Spain) and also with the same orientation and geometry, same climate, inner conditions as similar as possible but different materials in the enclosures: rehabilitated and original. This accurately compares energy consumption between the rehabilitated building and the non-renovated building. The yearly energy savings achieved were 58.42 % with the rehabilitation.

1. Introduction

In 2020, buildings accounted for approximately 28 % of global energy-related emissions [1], while in the EU, emissions related to buildings reached 36 % [2]. These figures reach 40 % [3] in the U.S. and 42 % [4] in the United Kingdom. As a result, global CO_2 emissions related to buildings reached 9 $GtCO_2$ in 2020 [5].

According to the Government of Spain [6], 28.73 % of the energy consumed in the country is due to the residential sector, and of this percentage, almost 57 % corresponds to the consumption of fossil or renewable fuels to satisfy the energy demand of Spanish homes. Forty-three percent of the remaining consumption is satisfied with electricity [6].

In addition, Spain has an old building stock, where 34 % of the houses were built more than 50 years ago. The city of Zaragoza in Spain in 2022 has 525,508 homes built, of which 39.16 % were built more than 50 years ago [7], as is the case of the building that will be analysed in this article. These data motivate energy rehabilitation. Basically, of the thermal envelope of these buildings that were

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built when there was still no thermal regulation in Spain. The first was approved in 1979 [8].

As indicated by Cambridge Econometrics [9], improving the energy efficiency of a home through rehabilitation measures, such as increasing insulation, can substantially contribute to the efforts of a home to live a more ecological and environmentally friendly life, in addition to creating more comfortable homes at a more affordable operating cost and potentially increasing the value of the property [10,11].

However, the reality is that the rates of renovation of buildings in the EU remain low, approximately 1 % per year [12].

To improve this rate, the European Commission published in October 2020 a new strategy called the "Oleada de rehabilitación para Europa" ("Surge of rehabilitation for Europe") [13], which aims to double, at a minimum, the annual rates of energy rehabilitation and increase its scope.

In Spain, with the Plan de recuperación y resiliencia de España (Recovery and Resilience Plan of Spain), within the framework of Next Generation EU [14,15], it is planned to dedicate 3400 million euros [15,16] to rehabilitate more than one million buildings energetically until the year 2030 [17] and convert them into with high energy efficiency real estate. The objective is a reduction in primary energy demand of at least 30 %.

One of the challenges to achieving this is to make the owners of buildings aware of the long-term benefits of rehabilitation and another to offer knowledge of the constructive solutions that can be implemented.

One way to find efficient solutions is the energy simulation of buildings. In this field, Hashempour [17] offers a complete, accurate and updated literature review on the different methods and tools for optimizing the energy performance of existing buildings. Kolaitis [18] performs a comparative evaluation of internal versus external thermal insulation systems to achieve energy efficiency and Ucar [19] studies the optimal insulation thickness for facades.

Another solution is the measurement of the thermohygrometric conditions in the renovated buildings and with the experience offer new alternatives to achieve thermal comfort in buildings with a low energy cost. Having data and field measurements allows us to obtain much more precise data [20], thus being able to understand in greater detail the real behaviour of these buildings.

In the literature there are different experimental studies that show the potential for energy savings with rehabilitation. These have been carried out in the social housing sector, such as those carried out in Madrid [21] or in Bilbao [22], both in Spain. Also, in Spain (Seville) in the residential sector, 4 homes were monitored [23] to analyse the effect of the level of insulation and natural ventilation. Swinton [24] analyses the effect of external insulation in 16 buildings in Ottawa, Canada and Curado in Portugal [25]. Studies have also been carried out on the behaviour of different insulating materials in construction, such as those carried out in test cells by L. Cabeza [26] or Soubdhan [27] or the use of new insulation materials. phase change (PCM) in buildings [28–31]. There are also studies in the office sector, such as the one carried out in 25 buildings in Germany [32], in historic buildings, such as those studied in France [33] India [34], UK [35] or Spain [36], in low-energy buildings in Switzerland [37], in Romania [38], in universities in Spain [39,40], France [41], in schools in Luxembourg [42] or Slovenia [43].

A deficiency that has been detected in these studies is the reference used to give the results of the savings achieved after rehabilitation.

The percentages of improvement in the energy performance of a building that are achieved by carrying out rehabilitation vary depending on the climatic conditions and other factors that depend on the urban context in which it is located. To understand this possible adjustment that determines whether the improvement actions included in the rehabilitation allow the characteristics of a building with almost zero consumption to be achieved, the present study empirically evaluates the behaviour of the building before and after the rehabilitation.

The data generated during a year of monitoring two buildings that share the same location conditions (Zaragoza, Spain), climatology, orientation, geometry and form factor, construction solutions of the exterior envelope, as well as the interior conditions and the same use and building occupancy, allow us to analyze a comparison of energy consumption between both scenarios: rehabilitated and non-renovated building. The results allow us to know the adjustment of the percentage of energy savings achieved in comparison with current regulatory requirements. In a context in which new capacities for evaluating energy consumption in urban areas are being developed, the novelty of this study lies in the fact that the results obtained serve to improve the adjustment of these simulations, since their value has been obtained by applying empirical methods. comparing a real building with the same characteristics.

2. Features of the studied building

2.1. Building characteristics

The dwellings under study are located in one of the blocks that make up the Urban Complex of Interest of Balsas de Ebro Viejo, located in the Picarral neighbourhood, in the city of Zaragoza, Spain [44]. This is an example of public urbanization (Obra Sindical del Hogar y Arquitectura [45]) made to house workers from nearby industrial zones [46]. The area was designed by the architects A. Allanegui, F. García Marco, J. Guindeo, JL de la Figuera and L. Monclús in 1964 and built between 1964 and 1975. The architects chose an orthodox superblock solution with a central core of facilities.), surrounded by residential typologies in towers and slabs, in line with hygienist criteria [47].

The residential complex of Balsas de Ebro Viejo consists of 1530 buildings and combines open spaces with blocks of different heights - five towers of B + 11 (ground floor + 11 floors) and linear blocks of B + 4 (ground floor + 4 floors), facilities and several ground-floor buildings for shops. Currently, the neighbourhood lacks the activity with which it was conceived and requires a boost to revitalize it. In addition, all homes are obsolete in terms of accessibility and energy efficiency.

The case study was built in 1969. The block consists of two buildings, Oroel 2 and Oroel 4 (Fig. 1). The first of them rehabilitated and the second of them adjacent and without having undergone modifications since its construction.

This set has been chosen for this research because it allows us to adequately study the impact of energy rehabilitation on the energy consumption of homes by having two buildings equivalent in orientation, layout and construction materials of origin, with the difference that one of them has been thermally isolated (rehabilitated with EIFS) and the other has not. This offers conditions that allow rigorous comparison of energy consumption and thermal behaviour between original and renovated homes.

In its initial state (Fig. 2), it is a property that has a ground floor plus four floors, all of them for residential use. In the central axis of the ground floor is the access that leads to the staircase, from which you can access the different floors. Initially, the building did not have an elevator.

Two symmetrical apartments are located on each of the floors. Each of the apartment has a living room, three bedrooms, kitchen, bathroom and/or cloakroom, entrance and hallway (Fig. 3).

The intervention carried out has been carried out in building C/Peña Oroel 2 in Zaragoza (Spain) and aims to execute energetic rehabilitation in the envelope of the building, maintaining the original aesthetics and incorporating innovative and modern materials.

To decide the rehabilitation actions to be carried out in the building, the energy needs of the non-renovated building have been evaluated with the Spanish government's CE3X [48] computer application for the energy certification of existing buildings. This estimates a heating demand of 97.6 kWh/m^2 (energy classification F).

CE3X allows simulations of the building's thermal behaviour when different solutions are incorporated. Allows for thermo-economic optimization of the measurements. The following options studied to try to reduce the estimated heating:

- Rehabilitation of the envelope placing an exterior insulated finishing system (EIFS) of the three facades of the building. The RockWool REDArt System was used [49]. This insulation is formed by rock wool of 80 mm, with a density of 150 kg/m^3 in the outer face and 95 kg/m^3 in the inner layer. The pillars that stand out have been covered with the same system. With this improvement, it is estimated that heating demand will decrease by 25.3 %. Estimated consumption 73.2 kWh/m^2.
- Addition of thermal insulation under the roof, a 120 mm rock wool blanket is used, covered on one side with Kraft paper that acts as a vapour barrier. This action represents a decrease in heating demand of 6.3 %. Estimated consumption 91.8 kWh/m^2
- For the carpentry, double sliding windows with double glass and without breakage to the thermal bridge are placed on the north and south facades (U_{Inital}= 4.07 W/m^2K, $U_{Renovated}$= 2.51 W/m^2K). The door of the balcony (south façade) and the kitchen window (north façade) are replaced by new carpentry, with double glass and a thermal bridge break, as in the new volume where the elevator is located (U_{Inital}= 4.18 W/m^2K, $U_{Renovated}$= 3.14 W/m^2K). With this improvement, a decrease in heating demand of 2.8 % is estimated. Energy consumption 95.2 kWh/m^2

Table 1 shows the initial and final insulation of the building. The new enclosures comply with the thermal insulation of buildings Spanish regulations (CTE [50]).

The Fig. 4 shows some images of the renovated building.

After thermal and economic analysis of the proposed improvements, the implementation of all three is chosen. The set achieves a reduction in heating demand of 38.8 %. Estimated consumption 60 kWh/m^2 (new energy rating of the rehabilitated building D).

A complete thermographic study of the building was carried out to verify the correct execution of the EIFS installation on the envelopes [52]. Fig. 5 shows the optimum result in the thermal insulation achieved in the façade compared to the building non-rehabilitated, the thermal bridges have been removed.

2.2. Indoor conditions

In the study of the energy consumption of a building, the type of materials used in construction, the external climate, but also the indoor conditions and the user of the home, are important, as indicated by Zhun Yu [53] and C. Boomsma [54]. In a comparative

Fig. 1. Case studies: Oroel n°2 and Oroel n°4 (
Source: Google Maps).

Fig. 2. View of the building (Oroel n°2) before rehabilitation. South (left) and North (right) facades.

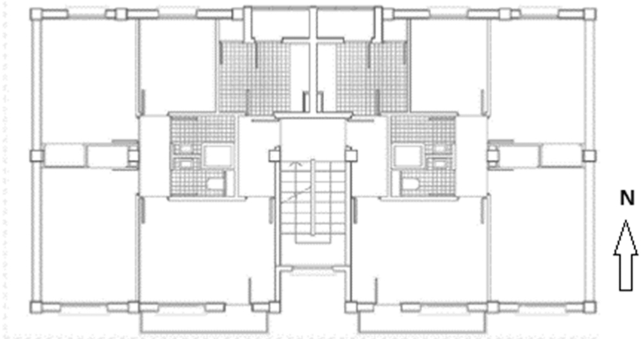


Fig. 3. Type floor of the building non-rehabilitated.

savings method it is important to take this. It is considered important to conduct a social study of the residents of the buildings (Oroel 2 and Oroel 4). The aim is to collect and study the information regarding the occupation of the dwellings (number and age range of the residents) to subsequently analyse the differences and similarities of the residences under study, considering both the characteristics of occupation and the location of the apartment in the building (top floor or mezzanines, orientation, etc.). It is necessary that the apartments that are compared have equivalent social and energetic characteristics. With the data collected in Table 2, the following studies and the selection of the apartment to be monitored are proposed:

- Analysis of energy savings in heating consumption with natural gas. For this, 4 apartments are selected: Oroel 2-4th R, Oroel 2-3rd R, Oroel 4-4th R and Oroel 4-4th L. These have a natural gas boiler and a gas metre that allows monitoring. The objective is to analyse the energy consumption of the rehabilitated apartment (Oroel 2-4th R and Oroel 2-3rd R) and without rehabilitation (Oroel 4-4th R and Oroel 4-4th L) and within the rehabilitated floors., the differences between the undercover and an intermediate dwelling (Oroel 2-4th R, Oroel 2-3rd R).
- Analysis of energy savings in heating consumption with electricity. For this, Oroel 2-4th L and Oroel 2-3rd L are selected, which use electric heating whose consumption can be monitored with the electric energy metre.
- Analysis of the comfort conditions of the apartment. For this, Oroel 2-4th R, Oroel 2-3rd R, Oroel 4-4th R, Oroel 4-4th L, Oroel 2-4th L and Oroel 2-3rd L are selected. The parameters monitored will be the temperature, relative humidity and concentration of CO_2 in the environment.

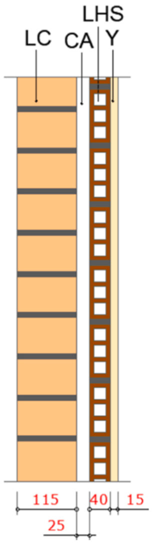
3. Methods: experimental work

The method used to analyse the real influence of the insulation of the envelope on the consumption and comfort of the homes is the installation of a complete set of sensors. Monitoring allows us to have a historical data of the thermodynamic and energy variables of the buildings that quantify the air quality conditions inside of the dwelling and its thermic behaviour [55,56].

The installed sensors record the following parameters:

- Electric energy consumption.
- Consumption of natural gas.

Table 1
Comparison of the opaque envelope and roof thermal transmittance values for both the initial and renovated states [51].

<table>
<tr><th colspan="2">Initial state</th><th colspan="2">Renovated state</th></tr>
<tr><th>Opaque envelope
U = 1.67 W/m²K</th><th>Roof
U = 1.67 W/m²K</th><th>Opaque envelope
U = 0.35 W/m²K</th><th>Roof
U = 0.28 W/m²K</th></tr>
<tr>
<td>
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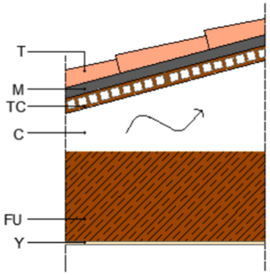
<td>
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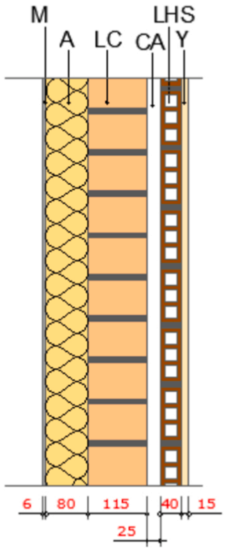
<td>
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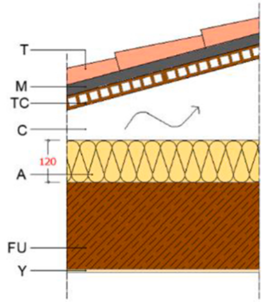
<td>
</td>
</tr>
<tr>
<td>(LC) Facing brick (5 ×11.50 ×25 cm)
(CA) Air chamber (2.50 cm)
(LHS) Hollow brick (4 cm)
(Y) Gypsum plaster (1.50 cm)</td>
<td>(T) Ceramic tile
(M) Cement mortar (3 cm)
(TC) Ceramic Slab (4 cm)
(CA) Air chamber (2.50 cm)
(FU) One-way slab
(Y) Gypsum plaster (1.50 cm)</td>
<td>(M+A) (EIFS) using the REDArt system. RockSATE Duo insulation consists of 80 mm rock wool with a thermal conductivity of 0.04 W/mK.
(LC)Facing brick (5 ×11.50 ×25 cm)
(CA)Air chamber (2.50 cm)
(LHS) Hollow brick (4 cm)
(Y)Gypsum plaster (1.50 cm)</td>
<td>(T) Ceramic tile
(M) Cement mortar (3 cm)
(TC) Ceramic Slab (4 cm)
(CA) Air chamber (2.50 cm)
(A) 120 mm. rock wool with thermal conductivity 0.04 W/mK.
(FU) One-way slab
(Y) Gypsum plaster (1.50 cm)</td>
</tr>
</table>

Fig. 4. View of the building (Oroel 2) after rehabilitation. South (left) and North (right) facades (Photo: Iñaki Bergara).

Fig. 5. Comparative thermographic and optical images of the north façade of a rehabilitated and non-rehabilitated building.

- Indoor comfort conditions: temperature, humidity, CO_2 concentration.
- External environmental conditions: temperature, humidity, CO_2 concentration.

The data of the variables are monitored for one year to be able to analyse the behaviour of the building and thus to investigate the effect of EIFS insulation on energy consumption and on the comfort of residents during all seasons. The data are recorded every 1 min, and an average is performed every 15 min A recording frequency in the range of 10 to 15 min is appropriate for building monitoring [57].

3.1. Monitoring aims and measured setup

This section includes the list of equipment selected for monitoring the apartments.

For the selection process, the characteristics and dimensions of the building, the range of the wireless signal of the equipment, the particularities of the metres and the economic cost of the set of equipment necessary to monitor the variables under study have been taken into account. Additionally, avoiding the possible inconvenience to residents caused by the installation of equipment inside their homes has been sought.

All the electricity metres in the building are of the CERM1 type [58], which have communication of the consumption history and communication of the consumption in real time through optical pulses (through the communication protocol IEC 62056–21), opting for this method to perform the automatic reading of electricity consumption. For the transmission of data to the monitoring equipment, an Optosense unit is connected to each metre (Table 3).

Regarding natural gas supply metres, the homes have the Kromschroeder BK-G4M equipment [60], which allows optical communication for the transmission of consumption data. For the reception of these, a Relaysense unit is incorporated (Table 3).

Table 2
Social profile and occupation/heating and cooling equipment of apartments.

Building: Oroel 4		Floor	Building: Oroel 2	
Left (L)	**Right (R)**		**Left (L)**	**Right (R)**
2 Adults R 30 years gas boiler & air conditioning Oroel 4-4th L	2 Adults R 40 years gas boiler Oroel 4-4th R	**4th**	1 Adult, 2 child R 40, 10 years electric heating by heat pump Oroel 2-4th L	1 Adults (+1 carer) R 80 years gas boiler Oroel 2-4th R
empty gas boiler X	1 Adults R 70 years gas boiler X	**3rd**	3 Adults R 30 years electric heating by radiators Oroel 2-3rd L	1 Adults R 40 years gas boiler Oroel 2-3rd R
3 Adults R 20, 45, 70 years gas boiler	2 Adults R 70 years X	**2nd**	2 Adults R 50 years gas boiler & air conditioning	1 Adults (+1 carer) R 80 years gas boiler
2 Adults R 40, 70 years gas boiler	2 Adults R 70 years electric heating by radiators	**1st**	1 Adult, 2 child R 40, 10 years gas boiler	2 Adults R 70 years electric heating by radiators
empty X	2 Adults, 1 child R 40, 10 years gas boiler	**ground floor**	1 Adult R 70 years X	empty gas boiler

Once the type of gas metre to be monitored and the electrical consumption communication system were determined, different combinations of sensors were studied to monitor all the variables required for this work. After evaluating different solutions taking into account the economic cost and technical characteristics (scope, autonomy, precision, etc.), the complete solution offered by the distributor Cliensol Energy S.L. was chosen [59]. Since it covers all the technical needs related to monitoring and at the same time, by obtaining all the devices from the same supplier, delivery times and costs associated with transport are reduced. This, in addition to centralizing access to the measured data from a single platform, facilitating its management and avoiding additional costs due to the subscription to different data management platforms. The operating diagram of the monitoring system is shown in Fig. 6.

3.2. Data processing

The energy consumption data, as well as the temperature, humidity and CO_2 concentration that are measured and recorded by the devices installed in the buildings, are transmitted through a GPRS connection to a remote server managed by an energomonitor, accessible to through the website https://app.energomonitor.com.

The energomonitor website presents the data in the form of graphs and allows them to be exported in table format, in which the numerical values of the variables recorded over time are found.

To manage the data obtained and to be able to easily and rigorously visualize values and trends of interest, the acquisition and treatment of the same has been automated using Microsoft PowerBi software [61], which allows us to establish a series of programming with which to treat the data and later visualize them, creating interactive graphs. The advantage offered by this software is that once the data acquisition, processing and visualization program is created, the addition of the new data captured is an automatic process. This allows, in addition, to publish the results on an accessible web page.

4. Results and discussion

As indicated by C. Alonso [62], the energy consumption of premises differs greatly between different periods, so carrying out annual monitoring allows us to obtain complete data to quantify the energy demand.

The results obtained the annual monitoring, by examining the behaviour of the building (temperatures and heating consumption) in different time periods are presented in this section: short moments of time (characteristic weeks)., seasonal behaviours or overall

Table 3
Monitoring equipment energy consumption and comfort conditions in homes.

Model	Type of device	Precision [59]	Hardware amount
Airsense	Temperature sensor, relative humidity and CO_2	Thermometer: ± 0.4 °C Relative humidity: ± 4 %RH CO_2 ± 50 ppm, ± 3 % of measure	7
Relaysense	Gas consumption sensor	1 W	4
Plugsense	Plug electrical consumption sensor	1 W	3
Optosense	Electricity consumption sensor in meter	1 W	6
Energobox	Signal receiver. Gateway	–	3
Router	Router with connection GRPS	–	3

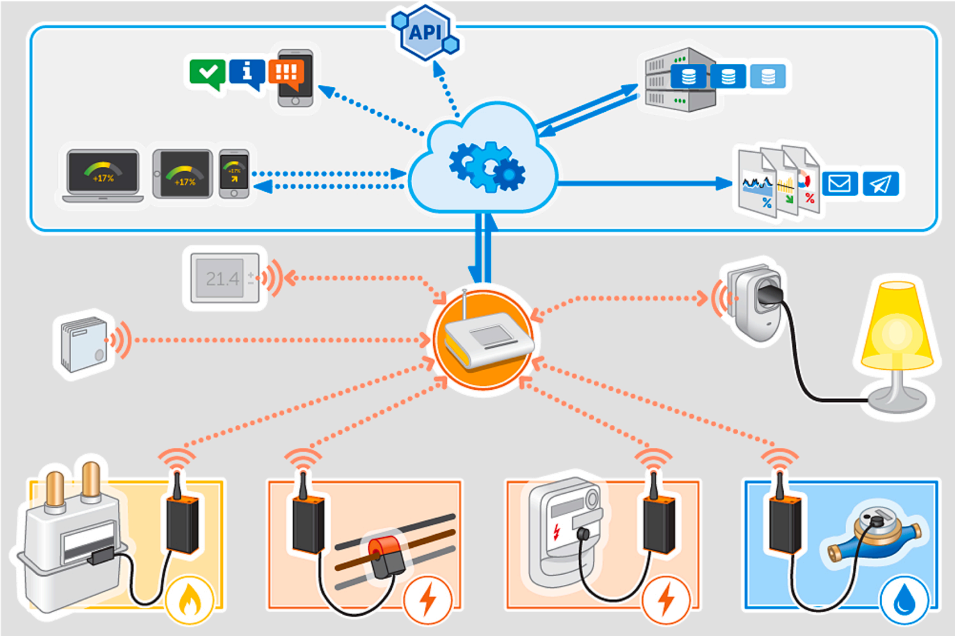


Fig. 6. Monitoring system operating diagram [59].

savings in energy consumption of households.

4.1. Behaviour of dwellings in cold weeks

Fig. 7 represents the temporal evolution of the exterior temperature, as well as the interior and gas consumption for three characteristic apartments (Oroel 2–4th R, Oroel 2–3rd R, and Oroel 4–4th L). The temperature values [°C] are represented as a line, whose

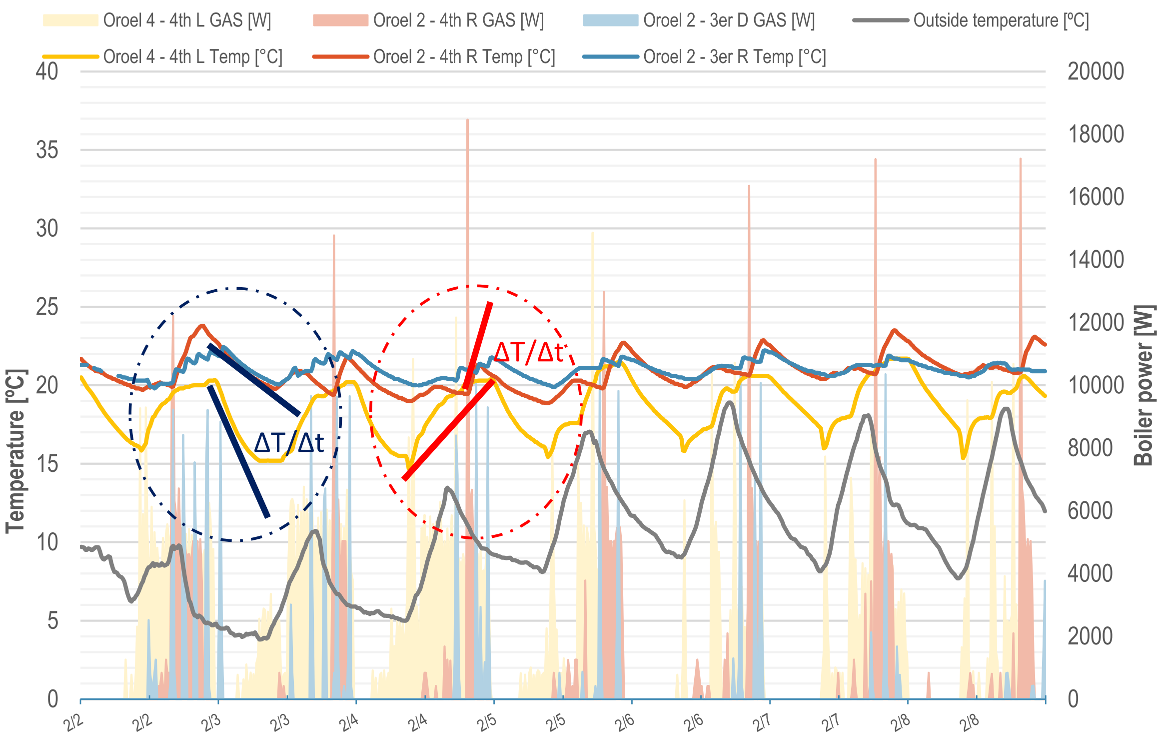


Fig. 7. Evolution of the temperatures and the power supplied by the boiler for a cold week.

scale is represented on the left vertical axis. The power supplied by the boiler [W] is associated with the bars represented in the lower zone, whose scale is associated with the right vertical axis. The area contained under the bar graphs corresponds to the energy consumed in the form of natural gas. This type of graph will be used in the following points:

A winter week representative of cold periods was selected, specifically that of February 2 to 8, 2019, where the average outdoor temperature was 10.23 °C (minimum temperature 3.80 °C and maximum temperature 18.9 °C).

In this period, the two rehabilitated buildings (Oroel 2–4th R, Oroel 2–3rd R) maintained a relatively constant temperature, while the non-rehabilitated house (Oroel 4–4th L) had greater temperature fluctuations during the day-night cycle. This greater oscillation is accompanied by higher heating consumption in nonrenovated homes. This shows the benefit of exterior insulation on the stability of the interior temperature.

The cooling or heating rate ($\Delta T/\Delta t$) of the apartments can be evaluated considering the variation in the ambient temperature (ΔT) of the same in a certain period of time (Δt) (Fig. 7).

In this case, the average nighttime cooling rate ($\Delta T/\Delta t$) of the building (from 1 to 7 am) is 0.23 °C/hour for the renovated dwelling, while for the nonrenovated dwelling, it is 0.51 °C/hour. Therefore, the renovated building cools 2.21 times faster than the renovated building for the same outdoor temperature.

During the day, when a lack of comfort is detected in the home, the heating system is switched on. The heating of the rehabilitated buildings is 70 % faster than that of the non-rehabilitated buildings, with a heating rate of 0.93 °C/hour for the former and 0.64 °C/hour for the latter.

In addition, there is a small increase in thermal losses on the fourth floor compared to the third, since at the beginning of the period without heating (00:00 h), the apartment located under cover (last floor) is at a higher temperature than that located between floors, and at the end of the period without heating (7:00 h), its temperature is lower, so it has a slightly higher cooling rate. The behaviour that has just been mentioned is associated with a specific day, but it has been verified that it is fulfilled during the entire period studied and is caused both by the influence of the thermal bridges of the roof and by the greater surface exposed to the outside-temperature conditions.

4.2. Behaviour of dwellings in the face of a sudden change in weather

An important aspect offered by the rehabilitation using EIFS is that the exterior enclosures of the building are incorporated into the internal mass of the building, offering a significant increase in the thermal inertia of the house.

Its influence is clearly seen in short periods of time change (for example, sudden drops in outdoor temperatures).

A sample of the effect of thermal inertia is the week of May 16 to 22, 2019 (Fig. 8). From May 16 to 17, the outdoor temperature dropped sharply (a difference of 18.5 °C between the daily maximums), and the low temperatures were maintained for three days, recovering later. In the three days, the interior temperature of the rehabilitated building barely fell 3 °C. The apartment did not need to

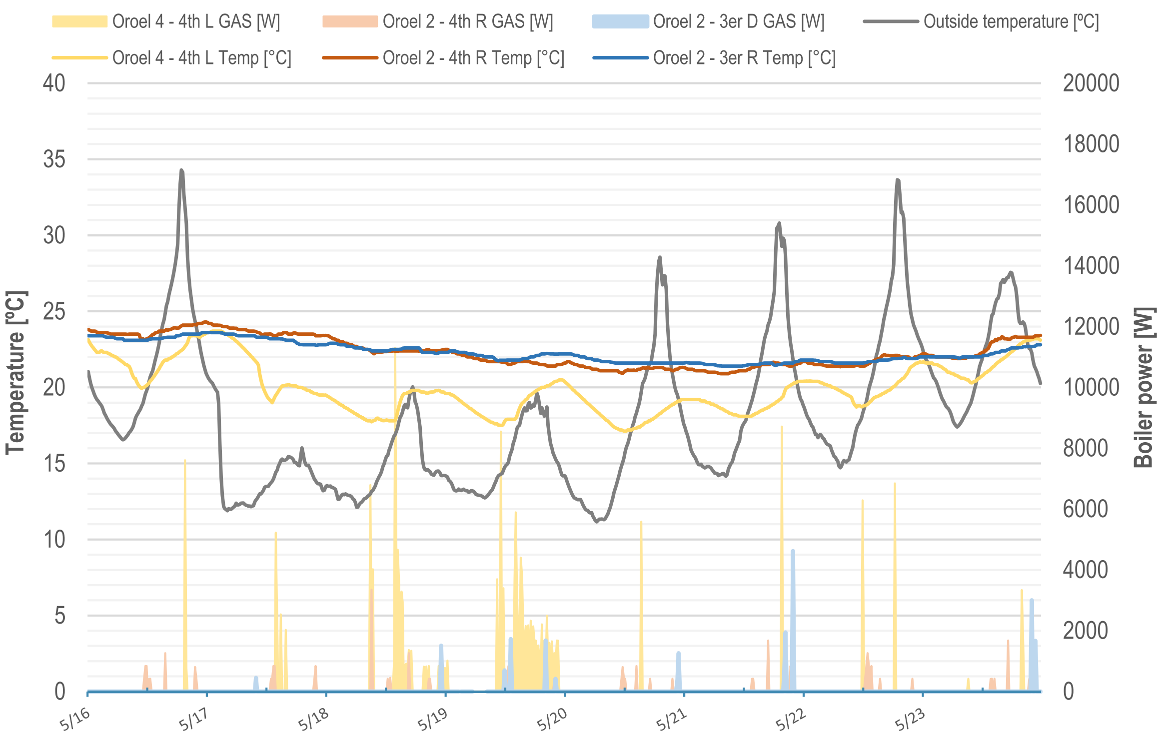


Fig. 8. Effect of thermal inertia (05/16 to 05/22).

connect the heating.

Table 4 shows the thermal stability of the apartments during this period.

Non-insulated apartment (for example, Oroel 4–4th L) are needed to connect the heating (see consumption in Table 4). These have a compartment of rapid temperature drop and slow recovery.

The thermal inertia of the building meant an energy savings in that week of 83.41 % compared to those that were not insulated from the outside.

4.3. *Behaviour of the dwellings in the change of season (summer ↔ winter)*

In periods of time in which the temperature variation is continuous, as is the case of the change of season towards winter, the effect of the exterior insulation is also important (thermal inertia), as shown in Fig. 9.

From November 4 to 11, 2019, the tendency of the outdoor temperature decreased due to the onset of winter, with an average drop of approximately 10 °C on those days. It is observed that the trend of the interior temperature of the renovated homes tends to decrease, but in a more buffered way (Fig. 9 red line), with a drop of only 4 °C, without having the need to connect the heating system.

The thermal oscillation of the noninsulated dwelling is higher. The heating system must be connected two days after the start of the temperature drop to maintain indoor comfort. Gas consumption grows significantly (375 %).

As with the change to winter season, in the change towards summer, the trend of the outdoor temperature changes to positive, increasing this over the days. As seen in Fig. 10 (red line), the trend of the interior temperature of the renovated building tends to rise with a lower slope than that of the houses without renovation. At the beginning of these days when the outside temperature is still low, the nonrenovated house maintains heating until the outside temperature is such that it allows the house to be maintained within the comfortable temperature range.

4.4. *Comfort conditions*

In a seasonal analysis, the average behaviour of the apartments can be studied, and the advantages and benefits of the proposed rehabilitation can be analysed.

During the winter, in the renovated building, an average temperature inside the home of approximately 21 °C and 42 % RH (Table 5), comfort temperature according to the RITE [63], with a standard deviation between 0.57 and 0.97, which indicates great thermal stability, when the average outdoor temperature was 12.93 °C (52.5 RH), with a deviation of 4.01. The gas consumption in that period was 686 kWh (Oroel 2–4th R) compared to the 1538 kWh needed in the non-renovated house (Oroel 4–4th L) to reach an average temperature of 18.93 °C.

Thermal stability in the interior of rehabilitated building is also a fundamental characteristic during the spring. The houses without having the heating system in permanent operation (setpoint of the thermostat of Oroel 2–3rd R at 21 °C) maintain an average temperature higher by approximately 4 °C than the outside, and the thermal oscillation is considerably lower (Table 5). with a standard deviation of the records lower than 1 and an oscillation for the outdoor temperature records of 4.75 (Table 5).

The rehabilitated homes do not have any active cooling system. The thermal stability in the interior of the house that is shown in summer is due to the thermal inertia produced by the exterior insulation. The building maintains an average temperature similar to the exterior temperature (28.30 °C), see Table 5, with a considerably lower thermal oscillation. The standard deviation of the records of the indoor temperature of the homes is less than 20 % (approximately 1.20 compared to 5.12) of the outdoor temperature.

In the months of September and October, the outdoor temperature has the typical decay that orients towards the winter season. The mild temperatures recorded are only altered at the end of October, which forces heating in the non-renovated apartment (Oroel 4–4th L), consuming 247 kWh in that period. In renovated homes, thermal stability means that gas consumption is not so high (approximately 60 kWh per home).

Air quality is also a very important aspect in the comfort and health of neighbours. The average values recorded in the apartments (Table 6) give IDA 2 values (indoor air [63]), with occasional peaks mainly due to family celebrations. It has been detected in the records that CO_2 pollution fell sharply when the neighbours opened the windows (the houses do not have automatic ventilation). The ventilation of the apartments has not been optimal.

4.5. *Gas consumption for heating*

The estimation of the average DHW (domestic hot water) consumption in the dwellings is made based on the records of natural gas consumption by the use of the boiler during the days that the heating service is not connected. The period considered is from May 30 to

Table 4
Temperatures and consumption from May 16 to 22.

	Low Temp. [C]	Average Temp. [C]	Top Temp. [C]	Standard deviation	Gas [Wh]
Oroel 2 – 3rd R	21.4	22.31	23.61	0.70	3675
Oroel 2 – 4th R	20.90	22.27	24.30	1.02	7770
Oroel 4 – 4th L	17.12	19.74	23.70	1.62	46830
Outside	11.60	17.57	34.29	4.87	–

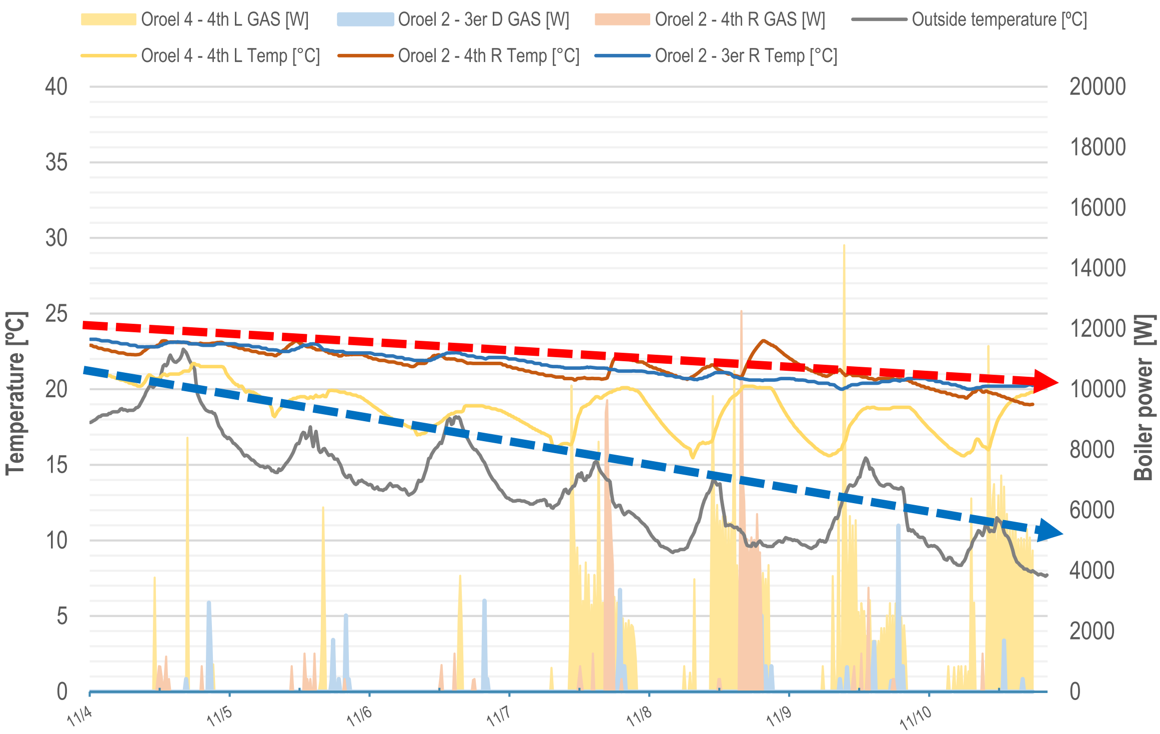


Fig. 9. Effect of thermal inertia change towards winter (11/4 to 11/11). The dashed red line shows the trend of indoor temperatures, the dashed blue line the trend of outdoor temperatures.

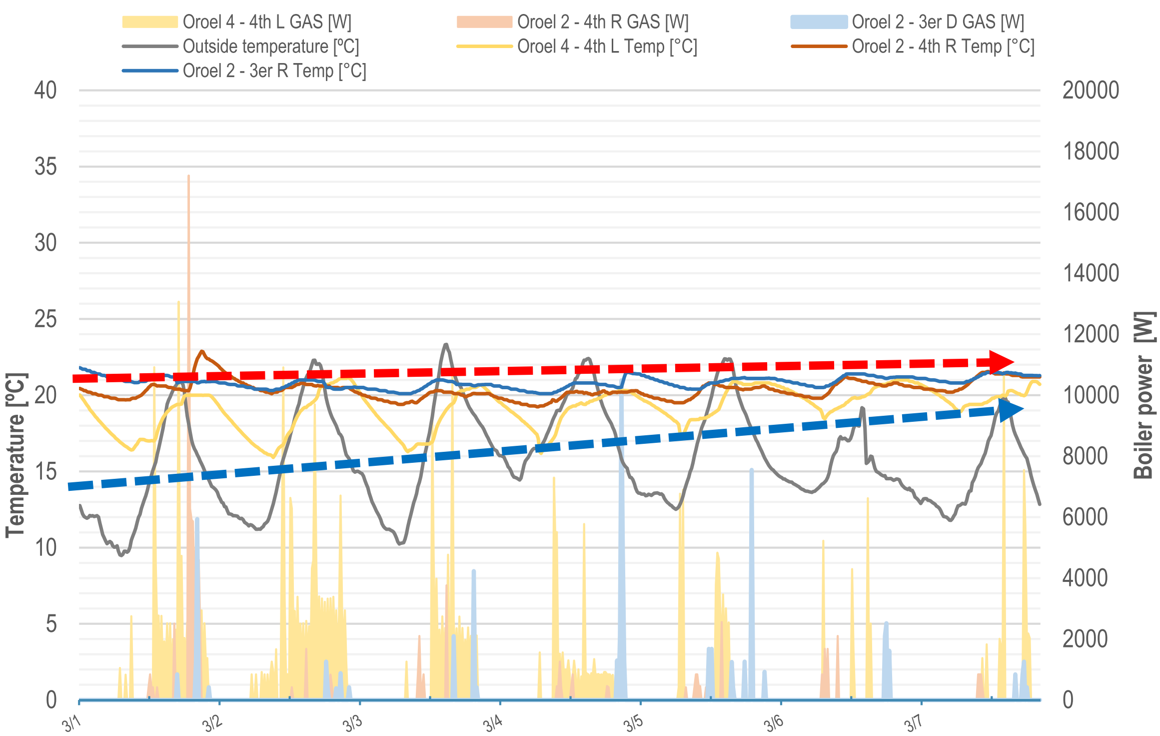


Fig. 10. Effect of thermal inertia change towards summer (3/1 to 3/7). The dashed red line shows the trend of indoor temperatures, the dashed blue line the trend of outdoor temperatures.

Table 5
Maximum, minimum and average values of temperature (Temp.) and relative humidity (RH) registered in the homes.

	Minimum Temp. [C]	Mean Temp. [C]	Maximum Temp. [C]	*σ (Temp.)*	Minimum RH [%]	Mean RH [%]	Maximum RH [%]	*σ (HR)*
Winter (January to March)								
Oroel 2 – 3rd R	19.60	21.05	22.60	*0.57*	32.7	42.9	49.1	*2.4*
Oroel 2 – 4th R	18.7	21.03	24.58	*0.97*	30.9	41.3	50.1	*3.0*
Oroel 4 – 4th L	14.50	18.93	22.00	*1.49*	34.6	48.5	60.7	*3.5*
Outside	3.80	12.93	26.32	*4.01*	15.6	52.2	78.4	*12.4*
Spring (May)								
Oroel 2 – 3rd R	22.58	22.19	23.61	*0.69*	40.6	48.0	52.3	*2.1*
Oroel 2 – 4th R	19.87	22.29	24.70	*0.94*	31.2	42.3	50.5	*3.5*
Oroel 4 – 4th L	16.15	20.35	24.80	*1.73*	29.3	48.4	64.9	*6.2*
Outside	9.72	18.85	37.2	*4.88*	14.1	47.3	94.0	*14.9*
Summer (July to August)								
Oroel 2 – 3rd R	26.7	28.74	31.40	*1.13*	33.1	44.3	51.5	*3.3*
Oroel 2 – 4th R	26.50	28.95	32.57	*1.30*	30.3	42.2	54.6	*4.2*
Oroel 4 – 4th L	21.32	26.83	33.20	*2.54*	32.0	45.6	62.9	*6.0*
Outside	18.20	28.30	44.30	*5.12*	16.0	42.7	77.6	*12.5*
Autumn (September-October)								
Oroel 2 – 3rd R	21.00	25.24	29.55	*1.87*	32.8	47.3	60.9	*4.6*
Oroel 2 – 4th R	20.30	25.16	30.40	*2.14*	31.3	44.5	59.5	*5.3*
Oroel 4 – 4th L	16.99	22.73	30.38	*2.24*	32.7	49.6	69.6	*7.5*
Outside	11.28	21.56	34.85	*5.12*	17.9	50.0	83.4	*13.0*

Table 6
Maximum, minimum and average values of CO_2 concentration [ppm] registered in the houses.

	Minimum CO_2. [ppm]	Mean CO_2. [ppm]	Maximum CO_2. [ppm]	*σ (CO_2)*	*Median (CO_2)*
Winter (January to March)					
Oroel 2 – 3rd R	382.9	800.3	1706.1	*186.3*	*788.0*
Oroel 2 – 4th R	466.5	946.6	3542.1	*301.1*	*894.8*
Oroel 4 – 4th L	426.9	939.6	2067.0	*284.0*	*932.8*
Outside	394.2	434.7	738.8	*21.3*	*435.0*
Spring (May)					
Oroel 2 – 3rd R	389.6	856.8	1349.2	*194.8*	*862.5*
Oroel 2 – 4th R	498.3	831.7	1903.0	*209.9*	*796.8*
Oroel 4 – 4th L	435.1	665.0	1334.2	*215.7*	*592.3*
Outside	400.3	435.2	493.4	*15.8*	*436.6*
Summer (July to August)					
Oroel 2 – 3rd R	386.9	595.6	1255.0	*158.9*	*568.7*
Oroel 2 – 4th R	465.0	637.2	2085.1	*199.8*	*576.8*
Oroel 4 – 4th L	415.8	515.4	1202.9	*145.1*	*458.7*
Outside	398.1	434.9	497.0	*15.2*	*434.2*
Autumn (September-October)					
Oroel 2 – 3rd R	380.9	738.5	1522.4	*244.4*	*801.5*
Oroel 2 – 4th R	477.3	757.9	2232.7	*248.1*	*758.0*
Oroel 4 – 4th L	405.9	575.0	1847.5	*268.2*	*462.8*
Outside	392.6	431.1	575.6	*18.7*	*428.2*
The entire monitoring period					
Oroel 2 – 3rd R	380.9	822.3	1706.1	*236.0*	*827.4*
Oroel 2 – 4th R	465.0	886.5	3542.1	*317.7*	*819.8*
Oroel 4 – 4th L	405.9	816.8	3169.7	*370.3*	*729.4*
Outside	381.0	430.5	738.8	*18.9*	*429.7*

October 14. The average consumption recorded was 0.56 kWh/day (203.65 kWh/year) for Oroel 2–3rd R, 1.02 kWh/day (372.34 kWh/year) for Oroel 2–4th R and 2.24 kWh for Oroel 4–4th L./day (816.29 kWh/year).

Once these values are known, the average daily consumption of natural gas necessary to provide heating service can be discriminated. For this, we take the cold periods from January 29 to March 3 and November 8 to December 12, which guarantee the joint use of DHW and heating. Table 7 shows the energy consumption and its percentage distribution to provide heating and DHW service in the homes.

With the consumption records, the positive effect of the rehabilitation of the building can be estimated. The building insulated from the exterior has had an energy savings of 58.42 % with respect to the original building in energy consumption for heating.

The difference in consumption between an intermediate flat and the apartment under cover in the renovated building is also important, detecting a decrease of 63.81 % in the needs of natural gas to cover the heating needs. This invites us to try to improve the constructive solutions of the roof insulation and the slab fronts of the eaves (see thermographic images, Fig. 5). Its influence is significant.

In Spain, the current construction regulations (Código Técnico de la Edificación - CTE (Technical Building Code)) [50] limit the consumption of nonrenewable primary energy ($C_{ep,nren}$) of buildings. Its value should not exceed the indicated limit ($C_{ep,nren,lim}$). Specifically, for the case of renovations in the city of Zaragoza, this is 70 kW h/useful m^2 year. Table 8 shows the consumption values obtained for the rehabilitated and non-rehabilitated apartments analysed.

5. Conclusions

One of the main objectives in social housing rehabilitation is energy saving. Unfortunately, in many occasions, it is not possible to measure the annual energy performance of the building before the reform. Therefore, the annual energy performance after the refurbishment cannot be compared with the initial conditions.

In this study, in order to ease the assessment of the reformed building performance, we have tried to obtain a definite reference, motorizing, for a year, two similar buildings, one rehabilitated and the other not. However, both under the same conditions namely, climate and location (Zaragoza, Spain), orientation and geometry and indoor conditions (as similar as possible). Although, for the rehabilitated and the original enclosures, different materials have been used.

The non-renovated building is used as a reference, to clearly indicate the energy advantages that the rehabilitation has brought. It allows to compare, in similar boundary conditions (indoor and outdoor), the consumption of the building in its original and renovated state.

The rehabilitation has consisted of changing the building envelope using 80 mm rock wool insulation on the exterior (EIFS), replacement of exterior carpentry and insulation of the roof with 120 mm rock wool.

A complete monitoring system installed in the two buildings (IAQ and energy consumption probes) and a social study of their neighbours has allowed a rigorous analysis of the energy consumption and comfort achieved in the dwellings. The monitoring was carried out for a full year.

The analysis of the measured data shows us that the average annual savings obtained with the rehabilitation of the building is 58.42 % of the heating energy, with respect to what the building consumed before the reform. Soutullo [64] in simulations with the Transys program estimates that the renovation of the external facades and the roof (8 cm facade insulation and 10 cm roof insulation) produces annual savings ranging between 34 % and 47 % compared to the initial situations. In our initial simulations we estimated a saving of 38.8 %, expectations were exceeded.

The savings can be compared to other NZEB listed buildings: Amtshaus Schlargasse in Austria (68 %), Hotel Campo dei Fiori in Germany (75 %), IÖR in Germany (85 %) and Näset 51:54 in Sweden (63 %) [65].

The study shows that the energy savings obtained with the rehabilitation have been implemented by achieving great thermal comfort in the homes, marked by stability in interior temperatures throughout the year. It has been possible to solve the usual problem of overheating that is common in NZEB facilities [66].

The improvement of the insulation of the façade and its arrangement, on the external part of the enclosure (EIFS), has meant an increase in the internal mass of the building and therefore its thermal inertia. Analysing the variation of the temperatures recorded over a period of time (ΔTemperature/Δtime, average cooling or heating speed) it has been detected that the non-renovated building cools down 2.21 times faster than the rehabilitated one, for the same outside temperature. While the heating of rehabilitated homes is 70 % faster than non-renovated ones. This effect is clearly seen in short periods of weather change (e.g. sharp drops in outdoor temperatures).

It is also important to point out that energy savings are not homogeneous in the rehabilitated building. There are important differences in energy needs depending on the position of the home (ground floor, first floor.). The consumption of an intermediate house is 63.81 % less than that of the apartment that is under cover. This result indicates that, in a comprehensive rehabilitation of homes, the particular characteristics of each floor such as insulation of the roof, of the floor slab fronts, etc., must be considered because their influence is significant.

Under the comprehensive energy reform, the building's recorded average annual consumption of non-renewable primary energy

Table 7
Annual consumption of Natural Gas for DHW and Heating.

	Annual consumption of Natural Gas [kWh / year]	Annual consumption of Natural Gas for DHW [kWh / year]	Percentage of annual consumption of Natural Gas destined for DHW	Annual consumption of Natural Gas for heating [kWh / year]	Percentage of annual consumption of Natural Gas for heating.
Oroel 2 – 3rd R	990.84	203.65	20.55 %	787.18	79.45 %
Oroel 2 – 4th R	2547.67	372.34	14.61 %	2175.33	85.39 %
Oroel 4 – 4th L	6048.59	816.29	13.50 %	5232.30	86.50 %

Table 8
Annual consumption of non-renewable primary energy.

	Annual consumption of Natural Gas [kWh / year	Annual consumption of non-renewable primary energy (Cep.nren) [kW h/ year]	Annual consumption of non-renewable primary energy per unit of useful area (Cep.nren) [kW h/ useful m^2 year]	Annual consumption of non-renewable primary energy per unit of built area (Cep.nren) [kW h/built m^2 year]	Limit value of the CTE regulation Cep.nren. lim [kW h/ useful m^2 year]
Oroel 2 – 3rd R	990.84	1179.09	20.68	18.28	70
Oroel 2 – 4th R	2547.67	3031.73	53.17	47.00	70
Oroel 4 – 4th L	6048.59	7197.82	126.23	111.59	70

has been achieved at 53.17 kWh/m^2. As a reference, note that this value is lower than the limit required by Spanish regulations of 70 kWh/m^2, for renovations carried out in the climatic zone corresponding to its location (Zaragoza - Spain). In the simulations with the CE3X program, the estimated consumption for the building after the renovation was 60 kWh/m^2. The initial forecast has been improved with the good execution of the reform.

Particularly for some dwellings of the building, specifically intermediate floors, this consumption is lower than the limit established by the Spanish regulations of 38 kWh/m^2 to consider the rehabilitation as a net-zero energy building (NZEB). If the roof insulation and certain specific thermal bridges (eaves, balconies, etc.) were improved, the entire building could achieve an NZEB rating.

CRediT authorship contribution statement

Monne Bailo Carlos: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Cabello Cristina:** Conceptualization, Funding acquisition, Investigation, Writing – original draft. **García-Ballano C. Javier:** Conceptualization, Investigation, Writing – original draft. **Ruiz-Varona Ana:** Conceptualization, Investigation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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