Energy & Buildings 256 (2022) 111737

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enb

Monitoring of housing blocks in Zaragoza (Spain) to validate the energy savings calculation method for the renovation of nZEB dwellings

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ARTICLE INFO

Article history:
Received 10 August 2021
Revised 21 November 2021
Accepted 24 November 2021
Available online 04 December 2021

Keywords:
Energy efficiency
Nearly zero energy buildings (nZEB)
Building envelope
Cadastral survey information
Geographic Information Systems (GIS)
Building renovation
Energy retrofit
Zaragoza

ABSTRACT

The European directives and objectives of the 2020 strategy and NextGen funds highlight the importance of rehabilitating urban environments. In this context, it is important to make available planning tools that evaluate the possible improvements in the energy efficiency of housing blocks, transforming them, in accordance with the established regulatory criteria, into nearly zero-energy buildings. Methods based on geographic information system (GIS) can be a great help in energy planning and constitutes a step forward from other proposals, due to its automation in the calculation process, and the possibility of replicating it for any city and the scale of analysis. Due to the potential of the method, the validation of GIS methods is very necessary. Our research empirically evaluates the reliability of one of these methods by monitoring a housing block built in Zaragoza (Spain). This was monitored for a year to evaluate the percentage of savings achieved after the energy renovation of the building according to nZEB parameters. The results indicate that the quality of the analyzed model is high. This research concludes that the method offers objective criteria when delimiting priority areas for energy improvement in the city and constitutes a planning tool of interest for different agents involved in renovation activities.

1. Introduction

Currently, the percentage of energy inefficient homes in Spain is high. 84.5% of existing residential buildings ranks very high in energy consumption, according to current environmental labeling (Gobierno [14]. The fundamental reason lies in the fact that this issue was not regulated until 1979, with the publication of NBE-CT 79 (Gobierno [12]. These percentages of houses constructed before 1979 (54.10%) reaches similar values (66.30%) than most of the European countries (European [7]. Fig. 0.

In cities such as Madrid or Barcelona this value reaches 69.36% and 83.18%, while, in other cities with more than 500,000 inhabitants, such as Valencia, Seville or Zaragoza, these values reach 74.95%, 64.45% and 59.58%, respectively [16].

This fact becomes an important conditioning factor when defining meaningful energy rehabilitation policies, especially considering that the cost savings potentially achieved provide necessary information about the feasibility of the action, not only at the building but also at the block or neighborhood level [10]. Over these last decades, rehabilitation has experienced a sustained growth[8]. Actually, the European Commission is promoting the Clean Energy for All actions to provide the decarbonisaton of the residential buildings before 2050[1]. Therefore, the most active and committed cities in establishing urban renovation policies are working on new mechanisms to evaluate the potential energy savings and the implementation of the adopted solution (Gobierno [13]. Indeed, in some cases (i.e., Barcelona), authors highlight the limited experience of the rehabilitation public programs in the city, because improving the energy efficiency of dwellings has reduced, at some point, the effectiveness of such programs and, as a consequence, it raises the need to develop methods capable of supporting stakeholders decision making [29].

Recent scientific literature provides several clues that allow effective progress to be made on this issue. For example, El-Darwish & Gomaa [6] focus on studying the thermal transmittance of enclosures as an urban strategy to define criteria for improving the energy performance of buildings. By establishing the composition of the initial thermal envelope, they analyze the improvement in the thermal transmittance of the enclosures and openings and can simulate the improvement in energy efficiency. From this perspective, Pérez-Bella et al. [23] contribute with a methodological improvement that corrects the standardized values of thermal

https://doi.org/10.1016/j.enbuild.2021.111737
0378-7788/

Nomenclature

CTE	HE: Technical Building Code – Energy Saving
DHW	Domestic Hot Water
EIFS	Exterior Insulated Finishing System
ETIS	External Thermal Insulation System
GIS	Geographic Information Systems.
NBE-CT	Basic Building Norm – Thermal Conditions.
nZEB	Nearly zero energy buildings
XPS	Extruded Polystyrene Foam

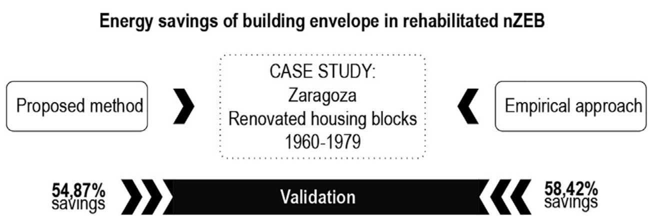


Fig. 0. Conceptual workflow followed in the research.

conductivity of the facade materials, applied to the south of Spain. Pallis et al. [22] evaluate the cost-effectiveness of these actions for the case of residential buildings in Greece. Corrado & Ballarini [5] address a real-scale building case study in detail and Martín-Consuegra et al. [20] for an urban complex. However, these methods do not solve how to calculate using large datasets nor at different scales of simultaneous intervention, from building to neighborhood or even city. In fact, no studies have yet been undertaken to determine, prior to their intervention, the ranges of improvement in the energy efficiency of these complexes with respect to the city as a whole, an essential issue from a strategic planning and public policy point of view.

2. Material and methods

García-Ballano et al. [9] propose an automated and replicable GIS-based method that takes as data source the cadastre to evaluate the energy savings generated from adapting the outer envelope of buildings to achieve nZEB. The proposed methodology is based on the difference between the initial thermal transmittance values, which are calculated considering the age of the buildings and their compliance with the regulations for each of the periods, compared to the final thermal transmittance values required to achieve nZEB performance. Preliminary studies have shown how structural solutions in housing vary as a function of different techniques or in response to regulatory restrictions on the maximum and indicative thermal transmittance values [17]. According to the regulatory limitations and the structural solutions applied, García-Ballano et al. [9] demonstrates that the relation between constructive techniques and thermal transmittance values enables the housing stock to be classified into 8 age groups (Table 1). This classification is comparable to those proposed by recent literature[26].

The solutions proposed for the improvement of the facade envelope, detailed for each of these age groups, are explained by incorporating an exterior insulated finishing system (EIFS) of variable thickness, as well as the replacement of windows and/or glass. In accordance with previous studies, extant research fives support to the fact that main strategies to reduce energy demand focus on increasing the insulation in exterior envelopes (façade and roof) and replacing windows and glass [15]. For the roof envelope, it is also proposed to incorporate a layer of insulation, of variable thickness according to the age group. The surface area of facades and roofs (flat and sloped) exposed to the outside is also obtained so that replacement costs and savings variation percentages can be estimated according to other variables, not only the age of the buildings but also the type of dwelling and morphology or percentage of openings in the facade. The authors apply the method to the specific case of the city of Zaragoza, Spain. The results show that the energy saving potential varies from 30.60% to 57.90% at the building level. The main interest of this method lies in being able to evaluate, prior to any refurbishment intervention, the energy improvement percentages of any city by using cadastral data.

However, the reliability of this adjustment has not yet been tested from a monitoring approach, i.e., by comparing the thermal transmittance values of a residential building before and after the energy renovation intervention to achieve nearly zero energy buildings (nZEB). By monitoring the consumption before and after a renovation action undertaken in a specific case study (dwelling from group 4), this study evaluates the adjustment of the method. As a result of this study, we can conclude the validation and correct adjustment of the proposed method, demonstrating its reliability as an operative tool for the evaluation of energy savings prior to any refurbishment intervention. This issue is important in the current context of promoting renovation activity and the need to establish objective criteria from which to set a clear planning strategy for intervention in the housing stock at the neighborhood or city scale. This study compares the energy performance of two residential buildings that have been monitored over a period of one year.

2.1. Study area

The authors apply this method to the specific case of the city of Zaragoza, Spain. It represents a paradigmatic case study for the research to be carried out, because the reality of residential construction activity reveals that the highest number of dwellings

Table 1
Age groups established by García-Ballano et al. [9].

Group	Age	Reason for the group classification	
1	<1900	Changes in construction systems	
2	1900 < 1940	Changes in construction systems	
3	1940 < 1960	Changes in construction systems	
4	1960 < 1979	Changes in construction systems	
5	1979 < 1990	Regulatory changesNBE CT-79	Changes in construction systems
6	1990 < 2006		Changes in construction systems
7	2006 < 2013	Regulatory changes CTE-2006	
8	z2013	Regulatory changes CTE-2013	

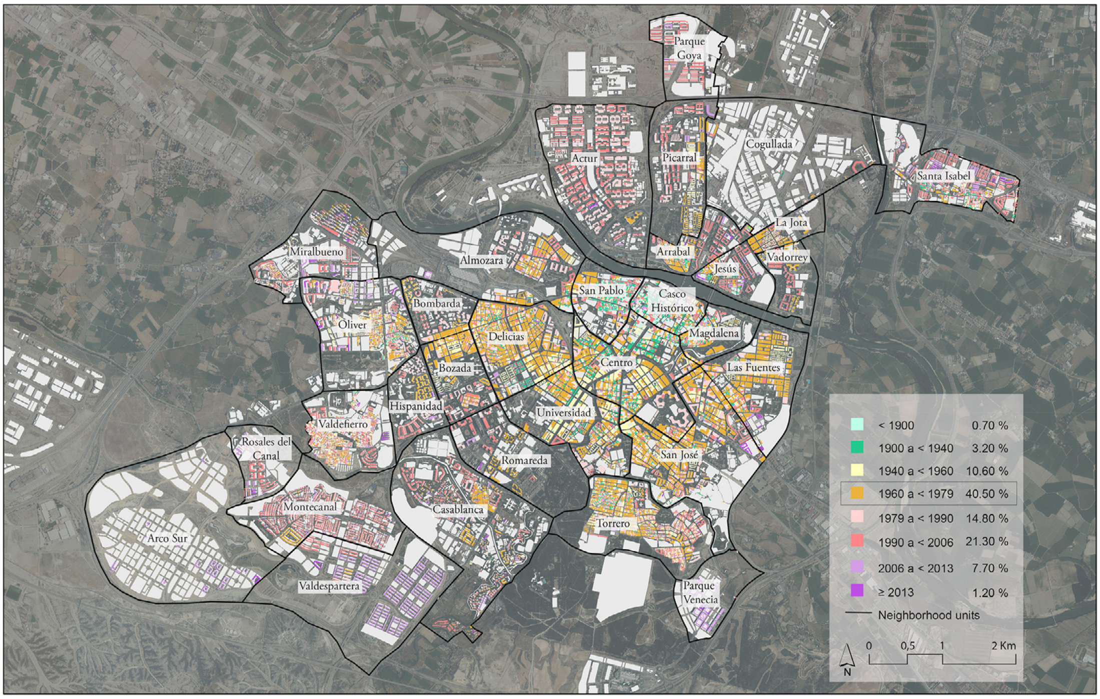


Fig. 1. Age ranges and geographic location for all housing in Zaragoza.

built per period (40.50% of total dwellings) corresponds to the fourth age group (1960–1979), a percentage that is practically double (1990–2006: 21.30%) the group that follows (Fig. 1). In Europe the percentage of houses built in the same period (from 1960 to 1979) is similar to Zaragoza, so analyzing this case is representative at the European level [31].

Moreover, it is important to note that the first Spanish energy efficiency regulation was approved in 1979, therefore, the age group that is being studied is among those that potentially will be subjected to the greatest number of energy rehabilitation improvements.

Specifically, the research focuses on the study of two housing blocks belonging to that age group, located in Balsas de Ebro Viejo area [24]. These housing blocks are within the Picarral neighborhood delimitation (Fig. 2).

These buildings were constructed in 1969 and belong to a group of 1,260 workers' housing units promoted by the *Obra Sindical del Hogar y de Arquitectura* [32]. Their morphological characteristics are defined by simple materials, brick as an exterior enclosure, and all openings to exterior facades. Each of the blocks has four floors, with stair access and two dwellings per floor, for a total of 8 dwellings. All floors, including the ground floor, are for residential use.

Moreover, these dwellings have been the object not only of special attention in the special planning of urban complexes of interest by the city council (along with other groups, such as Alférez Rojas or Las Fuentes), for singular urban landscape of the residential blocks reasons [19], but also of regeneration and accessibility improvement operations, many of them benefiting from European funds [28]. Furthermore, many of these buildings have been subjected to different studies regarding their historical interest or the analysis of the constructive types [25].

The two housing blocks studied has been also chosen considering their similar characteristics, regarding surface area, orientation, and use of the dwelling, as well as exterior exposure of the facade, so that identical thermal conditions are guaranteed for both (Table 2). For the two selected housing blocks, one of them has not undergone any type of rehabilitation or renovation (only maintenance operations) during the last five decades, while the other has undergone an integrated rehabilitation.

Fig. 2. Location of Balsas de Ebro Viejo and position of the block of buildings studied. Source: Compiled by the authors and Google maps.

Table 2
Common characteristics of the dwellings studied.

	Occupation [people]	Surface
Case 1. Initial state.		
Unrenovated dwelling(top floor)	4	85 m^2
Case 2. Renovated state.		
Renovated dwelling (intermediate floors)	1.50	85 m^2
Renovated dwelling(top floor)	2	85 m^2

The study focuses on the monitoring of several dwellings, located in both blocks. The choice of the dwellings was based on the same user profile, in addition to compliance with the above common characteristics, so that the results do not present biases derived from the different use that, in this case, the owners may make of the two dwellings (Figs. 2 and 3).

2.2. Methodology

The process requires the thermal transmittance values of both dwellings, before (case 1) and after (case 2) to the rehabilitation to know the reliability of the theoretical method proposed by García-Ballano et al. [9]. To do so, two steps approach has been defined.

First, the calculation of transmittances for each of the building's exterior envelopes is proposed, comparing the values obtained by this theoretical method regarding the technical specifications of the two selected housing blocks defined in the rehabilitation project (Gerencia [11]. Second, measurement probes are installed to calculate the temperatures inside and outside the dwellings. Moreover, gas and electricity consumption are monitored, so the potential energy savings are also evaluated regarding the renovated building versus the no renovated one. It is important to realize that the possibility of studying the behavior of two buildings similar in geometry and orientation allows monitoring to be carried out during the same meteorological year (2019). This issue is essential when comparing results, because likely temperature variations from one year to another are eluded.

2.2.1. Calculation of roof transmittances.

The theoretical method estimates thermal transmittance values for roofs belonging to the fourth group (housing built between 1960 and 1979, Table 1) of 1.69 W/m^{2}K.

The proposed type of construction solution consists of an air chamber, a 4-centimeter-thick ceramic coating and a one-way slab with concrete or ceramic beams and blocks (Table 3.A). This specification of the construction types does not differ from that of the buildings selected in Balsas de Ebro Viejo, consisting of a four-slope slab with partitions, ceramic slab and curved roof tile (Table 3.B), resulting a thermal transmittance of 1.59 W/m^{2}K. This solution has also been considered suitable for other authors [27].

However, when proposing an energy renovation solution for nearly zero energy buildings, the main difference between the theoretical method and the construction solution carried out in the renovation focuses on insulation. The first method proposes a solution of 14 cm of extruded polystyrene foam (XPS; 0.03 W/mK) with a layer of mortar on which to place the tiles, obtaining a final thermal transmittance value of 0.22 W/m^{2}K (Table 3.C). Nevertheless, in the renovation carried out, a 12-centimeter rock wool insulation (0.04 W/mK) was chosen in the space between the partitions, coated on one side with Kraft paper that acts as a vapor barrier, installed on the false slab of the last horizontal between the load bearing partitions (Table 3.D).

2.2.2. Calculation of transmittances in facades.

Similarly, there is practically no difference in the thermal transmittance values for the opaque envelope of the facade between the theoretical method and the selected buildings of Balsas de Ebro Viejo. On the one hand, the theoretical method defines a cavity enclosure, composed of a layer of cement mortar (1.50 cm), half a foot of solid brick (11.50 cm), an unventilated air chamber (5 cm), single brickwork (4 cm) and gypsum plaster (1.00 cm). The thermal transmittance value for this typical construction solution is 1.68 W/m^{2}K (Table 4.A.). On the other hand, the buildings studied are formed by half a foot of facing brick (12 cm), cement render (1.50 cm), unventilated air chamber (1 cm), single brick-

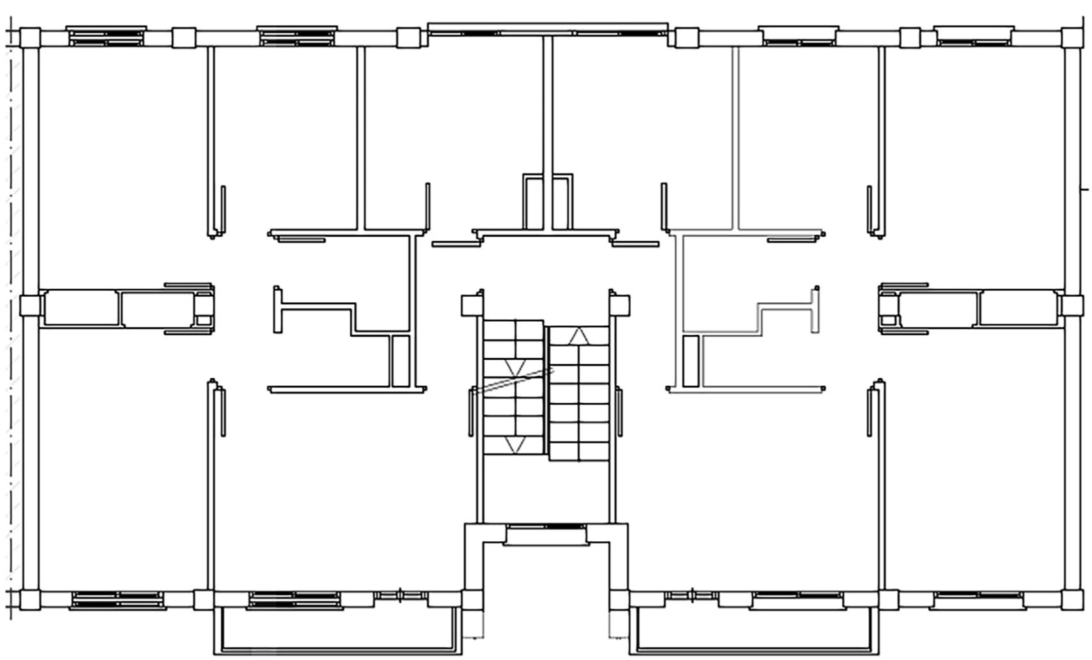


Fig. 3. Typical floor plan of the dwellings studied. Top side is North.

Table 3
Comparison of roof thermal transmittance values for both the initial and renovated state, including the theoretical method and the renovation project.

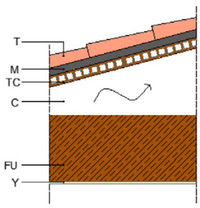
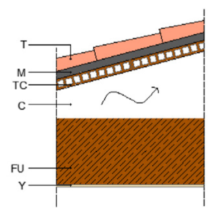
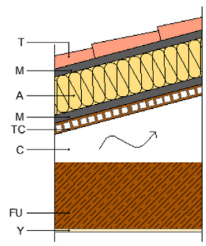
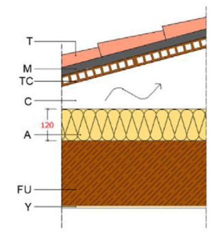
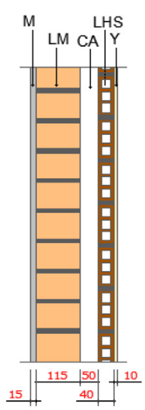
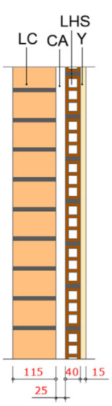
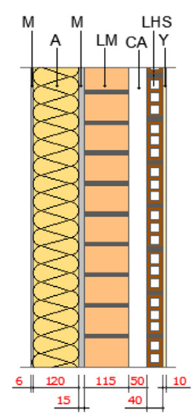
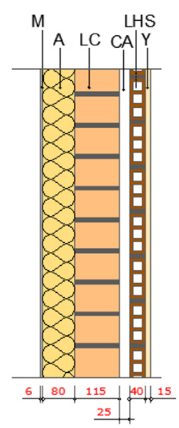
Initial state (Case 1) A	B	Renovated state (Case 2) C	D
García-Ballano et al. [9] U = 1.69 W/m²K	Balsas de Ebro Viejo U = 1.67 W/m²K	García-Ballano et al. [9] U = 0.22 W/m²K	Balsas de Ebro Viejo U = 0.28 W/m²K
			
(T) Ceramic tile(M) Cement mortar (3 cm)(TC) Ceramic Slab (4 cm)(CA) Air chamber (2.50 cm)(FU) One way slab(Y) Gypsum plaster (1 cm)	(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)	(T) Ceramic tile(M) Cement mortar (3 cm)(A) 140 mm. XPS with thermal conductivity 0.03 W/mK.(M) Cement mortar (3 cm)(TC) Ceramic Slab (4 cm)(CA) Air chamber (2.50 cm)(FU) One way slab (Y) Gypsum plaster (1 cm)	(T) Ceramic tile(M) Cement mortar (3 cm)(TC) Ceramic Slab (4 cm)(CA) Air chamber (2.50 cm)(A) 120 mm. rock wool (Ursa Glasswool) with thermal conductivity 0.04 W/mK.(FU) One way slab(Y) Gypsum plaster (1.50 cm)

Table 4
Comparison of thermal transmittance values of the opaque envelope for both the initial and renovated state, including the theoretical method and the renovation project.

Initial state (Case 1) A	B	Renovated state (Case 2) C	D
García-Ballano et al. [9] U = 1.68 W/m²K	Balsas de Ebro Viejo U = 1.67 W/m²K	García-Ballano et al. [9] U = 0.24 W/m²K	Balsas de Ebro Viejo U = 0.35 W/m²K
			
(M) Cement plaster (1.50 cm)(LM) 1/2-foot solid brick (11.5 cm)(CA) Unventilated air chamber (5 cm)(LHS) Hollow brick (4 cm)(Y) Gypsum plaster (1 cm)	(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)	(M + A) ETIS. The proposed insulation thickness is 120 mm of rock wool with a conductivity of (0.03 W/m K).	(M + A) (ETIS) using the REDArt system. RockSATE Duo insulation consists of 80 mm rock wool with a thermal conductivity of 0.04 W/mK.

work (4 cm) and gypsum plaster (1.50 cm), resulting in an average thermal transmittance value of 1.67 W/m^{2}K (Table 4.B; [18].

When defining the energy renovation solution for the opaque facade envelope, both approaches propose an external thermal insulation system (ETIS) solution, obtaining thermal transmittance values of 0.24 and 0.35 W/m^{2}K. The theoretical method proposes a 12 cm rock wool insulation, with a conductivity of 0.03 W/m^{2}K (Table 4.C). Meanwhile, the construction solution used in the Balsas de Ebro Viejo buildings proposes a solution of 8 cm of double density rock wool with a thermal conductivity of 0.04 W/m K, where the insulation is anchored to the outer leaf of the solid facing brick facade (Table 4.D). This adopted solution is similar to the one proposed in specific rehabilitation projects undertaken recently in Spanish cities [30]. It is important to note that the jambs, sills and lintels of the window openings that have been replaced have also been coated with 2 cm thick ETIS.

2.2.3. Calculation of transmittances in facade openings.

According to the considerations made by the theoretical method, the openings of the dwellings belonging to the 1960–1979 age group are characterized by metal work without thermal break and with single-pane glass with a thickness of 4 or 6 mm. The thermal transmittance of these openings is 5.70 W/m^2 K (Table 5.A). This value is comparable to that of the housing studied in Balsas de Ebro Viejo, defined in the project with wooden windows with single-pane glass of 4 or 6 mm thickness. The thermal transmittance of the openings of the dwellings in Balsas de Ebro Viejo is estimated at 5.00 W/m^2 K (Table 5.B).

Table 5
Comparison of thermal transmittance values of the envelope of facade openings for both the initial and renovated state, including the theoretical method and renovation project.

Initial state (Case 1) A	B	Renovated state (Case 2) C	D
García-Ballano et al. [9]	Balsas de Ebro Viejo	García-Ballano et al. [9]	Balsas de Ebro Viejo
U = 5.70 W/m^{2}K	U = 5.00 W/m^{2}K	U = 1.58 W/m^{2}K	U = 2.16 and 2.18 W/m^{2}K
Metal without thermal break. Single-pane glass(4 to 6 mm)	Wood.Single-pane glass(4 to 6 mm)	Aluminum with thermal break thicker than 12 mm.Double-pane low-emissivity glass and 16 mm chamber(4 + 16 + 6) with argon	Aluminum with thermal break thicker than 12 mm.Double-pane glass

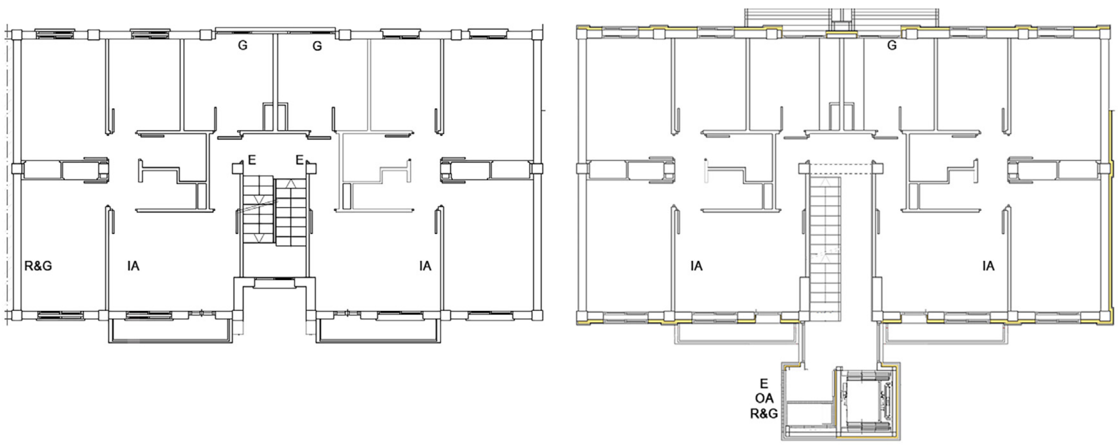


Fig. 4. Location of measurement equipment used, and type of variables monitored. G (gas), E (electricity), IA (indoor air), OA (outdoor air), R&G (router & gateway). Left side, non-renovated dwelling and right side, renovated dwelling.

Both the theoretical method and the project carried out in Balsas de Ebro Viejo addresses a common renovation proposal. It consists of replacing the original windows with double-pane glass and aluminum frames. On the one hand, the theoretical method defines an aluminum work with thermal break thicker than 12 mm and a double-pane, low-emissivity glass, with different diffusers in the two panes to improve the acoustic conditions of the opening (low emissivity and with argon), in addition to an air chamber of 16 mm, that is to say, a (4 + 16 + 6). The thermal transmittance value obtained is 1.58 W/m^2 K (Table 5.C). On the other hand, the renovation project proposes replacing the original window frames with extruded aluminum windows. The final transmittances of the openings of the renovated dwellings are 2.37 and 3.58 W/m^2 K (Table 5.D).

Based on the above, it can be considered that the thermal transmittance values calculated for each of the envelopes (roof, opaque facade and facade opening) are not very different, in comparative terms between the theoretical method and those defined in the project for the buildings of Balsas de Ebro Viejo. The only difference noted is explained because the renovation project was developed in a period (2018) in which the regulatory requirements in terms of energy savings (Boletin [3]were different from the current ones, which are the ones that the theoretical method has taken as a reference (Boletin [4]. Since these values are similar, then it is possible to compare the energy saving percentages of the dwellings, so that the proposed theoretical method can be validated thanks to the monitoring approach calculation.

2.3. Installation of measuring probes

It is important to guarantee the equivalent characteristics of the dwellings for the data obtained from the monitoring to be useful. So, the monitoring approach calculation verified that the following criteria were accomplished. First, a similar resident profile, for the energy pattern of demand and comfort; second, a similar location of the dwellings with regard to the building, considering floors and orientations; third, and last, a comparable air conditioning and heating system installed in each dwelling, so that energy consumption can be analyzed in more detail.

Considering the above criteria, four dwellings with common characteristics have been selected to be monitored, distributed two by two for each of the blocks, one of them corresponding to the last floor and one intermediate floors. The heating system for the selected dwellings is by individual gas boiler.

To evaluate the energy savings produced in the renovated building versus the non-renovated one, it is necessary to monitor gas and electricity consumption as well as temperature, relative air humidity and the presence of CO_2 in the indoor and outdoor environment of the dwellings.

The measuring equipment was selected to minimize interaction with the user, so that data collection, storage and transfer is done through a wireless connection recording on a server. Data are recorded every fifteen minutes for the whole year, so that a quantity of data per variable of 35,040 observations is obtained.

For recording electricity consumption, CERM1 electricity meters were used in all dwellings (model Powersense). For gas consumption, Kromschroeder BK-G4M sensors were installed in the gas meters (model Realsense Gas). Four Energomonitor Cliensol Energy probes were also used to record temperature, humidity and CO_2 (model Airsense) values indoors and one outdoors. The data monitored by the sensors is collected by a gateway (model Energobox) that transfers it to the cloud, enabling this data to be downloaded and processed. Data analysis has been undertaken with Microsoft's Power Bi software. Fig. 4 shows the placement of all the equipment used.

3. Results

Results are structured into two sections. A first one considers a monitoring approach and is dedicated to calculating the savings according to the monitoring carried out during the year 2019 (section 3.1.) of the buildings of Balsas de Ebro Viejo (case 1 and 2). A second section considers the theoretical approach (section 3.2.), and explains the results obtained by applying the method proposed by García-Ballano et al. [9] to the same building units.

3.1. Percentage of savings according to monitoring approach

To determine the energy savings obtained after the renovation from a monitoring approach, it is necessary to study the comfort and the uniformity of temperatures reached in the dwellings. This question is addressed not only for the winter but also for the spring and summer periods.

For the winter season, one of the most unfavorable periods of that season is selected, specifically, during the days from January 28 to March 21, 2019, with a mean outdoor temperature of 12.9 °C. For the renovated dwellings, the mean indoor temperature recorded was 21.0 °C (Table 6), with a standard deviation between 0.57 and 0.97, indicating great thermal stability and reaching the comfort values established by the regulations (Boletin [2]. Meanwhile, for the unrenovated dwellings, the mean temperature values did not exceed 18.9 °C.

Thermal stability inside the renovated dwellings is also the fundamental characteristic during spring, a period when the heating system not continuously running. During this period, the dwellings maintain an average temperature approximately 4 °C higher than the outside temperature, fluctuating less than during the winter period, with a standard deviation of<1 for the indoor temperature and 4.75 for the outdoor temperature.

During the summer, the exterior insulation of the renovated dwellings provides thermal stability inside the dwellings. It should be noted that these renovated dwellings do not have any active cooling system for summer. The building maintains an average temperature similar to the outside temperature (28.30 °C), but with a considerably lower temperature fluctuation. This is mainly due to the increase in thermal inertia provided to the building by having the mass inside and the insulation outside. The standard deviation of the indoor temperature for the dwellings is 20% lower than the outdoor temperature records, at approximately 1.20 versus 5.12.

It is also necessary to consider the consumption of the heating system of the residential units (renovated and non-renovated) for the energy consumption evaluation. All the building units analyzed in this study includes a natural gas-based heating system of individual wall-hung boilers, which supply domestic hot water and heating. Improvements in the active systems have not been considered because the heating system has not been modified with respect to the initial installation.

3.1.1. Average domestic hot water consumption

By estimating the average consumption of domestic hot water in the dwellings, the partial consumption of gas that has been dedicated to the heating system can, by subtraction, be discriminated. The amount of water consumed is estimated from records of natural gas consumption based on boiler use during the days when the heating service is not connected. Specifically, the summer period from June 4 to July 27, 2019 (period 1) is studied. During these dates, in addition, it is verified that the residents have not left on vacation and that they occupy the dwelling on a regular basis. Table 7 shows the recorded domestic hot water (DHW) consumption. In a complementary manner, the energy needs for DHW production have been calculated, according to the current normative regulation (Boletin [4]and using the CHEQ4 tool [21], developed

Table 6
Temperatures recorded during winter periods (January 28 to March 21, 2019).

Winter		Minimum Temperature [°C]	Mean Temperature [°C]	Maximum Temperature [°C]	Standard deviation of data
Outdoor		3.80	12.93	26.32	4.01
Indoor	Case 1. Initial state.				
	Unrenovated dwelling(top floor)	14.50	18.93	22.00	1.49
	Case 2. Renovated state.				
	Renovated dwelling (intermediate floors)	19.60	21.05	22.60	0.57
	Renovated dwelling(top floor)	18.70	21.03	24.58	0.97

Table 7
Consumption recorded during periods 1 and 2.

	Gas [Wh]	DHW consumption [kW h/day]	DHW consumption [kW h/year]	CTE (HE 4) [kW h/day]	CTE (HE 4) [kW h/year]
Period 1: June 04, 2019 to July 27, 2019					
Case 1. Initial state.					
Unrenovated dwelling(top floor)	121,800	2.25	823.27	6.07	2,218
Case 2. Renovated state.					
Renovated dwelling (intermediate floors)	25,935	0.48	175.30	2.27	832
Renovated dwelling(top floor)	60,060	1.11	405.96	3.03	1,109
Period 2: May 30, 2019 to October 14, 2019					
Case 1. Initial state.					
Unrenovated dwelling(top floor)	306,390	2.24	816.29	6.08	2,218
Case 2. Renovated state.					
Renovated dwelling (intermediate floors)	76,440	0.56	203.65	2.28	832
Renovated dwelling(top floor)	139,755	1.02	372.34	3.04	1,109

Table 8
Contribution of domestic hot water in percentage to the non-renewable primary energy limit values.

	Annual consumption of Natural Gas for DHW[kW h/year]	Annual consumption of non-renewable primary energy (Cep.nren) for DHW[kW h/year]	CTE (HE 0)Limit valueCep.nren.lim [kW h/m^2 usable year]	CTE (HE 0)Limit valueCep.nren. lim[kW h/year]	Contribution of DHW in % to non-renewable primary energy limit values.
Case 1. Initial state.					
Unrenovated dwelling(top floor)	816.29	971.39	70	3,991.58	24.34%
Case 2. Renovated state.					
Renovated dwelling (intermediate floors)	203.65	242.35	70	3,991.58	6.07%
Renovated dwelling (top floor)	372.34	443.08	70	3,991.58	11.10%

Table 9
Consumption recorded during periods 3 and 4.

	Gas [Wh]	DHW Consumption [kW h/day]	Heating Consumption [kW h/day]
Period 3: January 29, 2019 to March 03, 2019			
Case 1. Initial state.			
Unrenovated dwelling(top floor)	1,208,970	2.24	33.32
Case 2. Renovated state.			
Renovated dwelling (intermediate floors)	219,135	0.56	5.89
Renovated dwelling(top floor)	576,450	1.02	15.93
Period 4: November 08, 2019 to December 12, 2019			
Case 1. Initial state.			
Unrenovated dwelling(top floor)	1,494,360	2.24	40.46
Case 2. Renovated state.			
Renovated dwelling (intermediate floors)	184,905	0.56	4.73
Renovated dwelling(top floor)	649,320	1.02	17.53

by the *Instituto para la Diversificación y Ahorro de la Energía* and the *Asociación Solar de la Industria Térmica*. These values are compared with the results obtained during a longer period of record (period 2), from May 30 to October 14, 2019. Since domestic hot water consumption is similar, these values obtained during period 2 are inferred as average consumptions.Table 8.Table 9.

The results obtained show that, on average, the energy consumption for DHW in the renovated dwellings is 32.89% of what was established by the regulations.

Finally, it is possible to calculate the contribution of domestic how water to non-renewable primary energy consumption ($C_{EP.NREN}$) in dwellings. According to established standards, for the case of renovated residential buildings located in climate zone D (Zaragoza), the contributions in renovated dwellings range from 6.07% to 11.10%.

3.1.2. Average domestic hot water consumption

Once the value of the average gas consumption to provide domestic hot water service to the dwellings has been calculated, it is possible to discriminate the average daily consumption of natural gas necessary to provide heating service. To do this, the cold periods are studied, which guarantee the joint use of domestic hot water and heating, specifically two: from January 29 to March 3, 2019 (period 3) and November 8 to December 12, 2019 (period 4).

The heating consumption records made during these two periods allow estimating the average energy consumption to provide heating service in the days when the heating is on, being 36 kW h/-day for the case of non-renovated dwellings (top floor) and 5.30 and 16.74 kW h/day for the case of renovated dwellings, intermediate floors and top floor, respectively.

3.1.3. Effect of building renovation on energy consumptions

Table 10 shows the percentage distribution of energy consumption for heating and domestic hot water in the dwellings studied. From the results obtained, it is possible to estimate the positive effect that the renovation of the building has had. The case 2 studied, which corresponds to a building insulated on the outside, achieved an energy saving of 58.42% compared to case 1, corresponding to the initial state of the unrenovated original building. In addition, these results allow us to evaluate an important difference between the performance of a between-floors dwelling and that of the top floor, since a decrease of up to 63.81% has been detected in the former compared to the latter in the need for natural gas to cover heating needs.

3.2. Percentage of savings according to the theoretical method

The method which is applied in this study to calculate the necessary improvements proposed to the facades and roofs in addition to the corresponding current and indicative transmittance values considers several variables: age, building type, percentage of facade openings and exterior envelope surface. Indeed, it defines an algorithm for calculating transmittances and energy savings values generated by adapting the exterior envelope of buildings to achieve nZEB conditions. This algorithm is explained in terms of energy losses. Because thermal transmittance determines energy losses, according to the proposed solutions for improving the building envelope, it also determines the percentage of energy savings obtained from adapting buildings to nZEBs. Once the transmittance values were defined, according to the indicative values established by the regulatory framework, an adequate structural solution for the envelope was developed to transform the buildings into nZEBs. The method is based on the analysis of existing cadastral data as main database and is applied to the specific case of Zaragoza, Spain. A more detailed explanation is referred in[9].

For the specific case of the residential buildings located in the Picarral neighborhood, the actions foreseen by this methodology involve modifying the initial thermal transmittance values of the roof, opaque facade and openings to values of 0.22, 0.24 and 1.58 W/m^{2}K, respectively. The proposed method allows to know, prior to the intervention, the savings obtained for these dwellings,

Table 10
Percentage of annual natural gas consumption for domestic hot water and heating.

	Annual Natural Gas Consumption [kW h/year]	Annual Natural Gas Consumption for DHW[kW h/year]	Percentage of Annual Natural Gas Consumption for DHW	Annual Natural Gas Consumption for Heating[kW h/year]	Percentage of Annual Natural Gas Consumption for Heating.
Case 1. Initial state.					
Unrenovated dwelling(top floor)	6048.59	816.29	13.50%	5232.30	86.50%
Case 2. Renovated state.					
Renovated dwelling (intermediate floors)	990.84	203.65	20.55%	787.18	79.45%
Renovated dwelling (top floor)	2547.67	372.34	14.61%	2175.33	85.39%

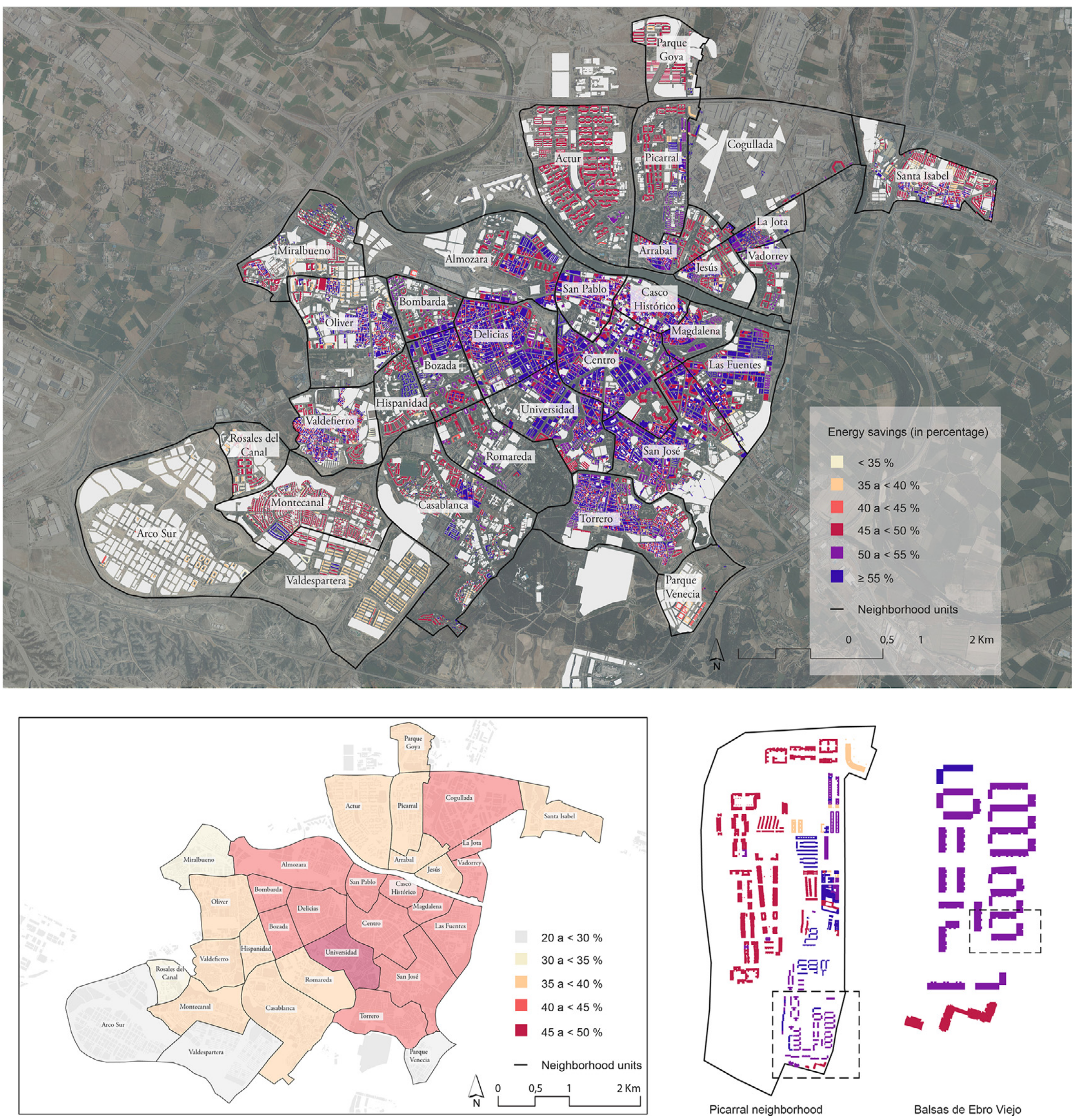


Fig. 5. Percentages of energy savings at the neighborhood and housing block level. Specific study of the Picarral neighborhood.

as a result of improving their energy efficiency after having intervened on the exterior envelope. Specifically, the percentage of savings reaches 54.48% for these dwellings. Although the housing block studied reaches one of the highest values in terms of percentage of energy savings, these values drop to 40–45% if analyzed at the neighborhood level (Fig. 5).

4. Conclusions

This study has taken as a case study some residential buildings built in the 1960–1979 age range, i.e., those that are more than 40 years old and were built before the first regulations governing their energy efficiency. In addition, they constitute the largest housing block (40.50% of the total number of dwellings), making them a priority group in regard to receiving a greater number of energy renovation improvements. These residential buildings have been monitored over a period of one year. Both buildings are in the same age group with similar surface, typology and morphology. The only difference is that one of them has been renovated while the other has not. Since the initial and final transmittances of the buildings before and after renovation correspond to the values established by the theoretical method[9], it is possible to calculate, for these buildings, the percentage improvement in energy efficiency. Moreover, the possibility of having monitored these buildings over a long period of time has provided sufficient data to verify that these savings percentages are actually obtained in reality, since the value obtained by the theoretical method (savings obtained: 54.87%) is only 3.50% lower than the values obtained monitoring (savings obtained: 58.42%). Moreover, the obtained value is very close to the 53,32% obtained from the wearisome calculation process undertaken in the renewal project (Gerencia [11]. It demonstrates that the adjustment of the obtained energy saving values by the proposed model is highly precise (only 1.55% higher that the obtained in the renewal project).The obtained value was calculated by the architect in charge using the current tools supported by the administration in the general building's energy certification procedure. This approach is more expensive in terms of time -because it is not automatized- and is only considered at the building scale level than our methodology that is validated in this study. This means that the innovative proposed method guarantees a quicker and applied to an urban scale analysis. It is also shown that this method constitutes a planning tool of great interest, not only for planners but also for different agents involved in renovation activity: from owners to different professional associations such as property managers or architects. One of the reasons for this interest lies in the possibility of evaluating these improvement rates for any city using cadastral data and the automation of the calculation process, prior to any intervention. This means evaluating energy efficiency improvement scenarios at different scales, not only for buildings but also for blocks, neighborhoods or even cities. In addition, it also provides objective criteria when defining priority areas for energy improvement in the city, within the framework of the requirements established in the European directives and objectives of the 2020 strategy and NextGen funds.

CRediT authorship contribution statement

Ana Ruiz-Varona: Conceptualization, Methodology, Writing – original draft, Visualization, Writing – review & editing, Project administration. **Claudio Javier García-Ballano:** Conceptualization, Methodology, Writing – original draft, Data curation, Visualization, Investigation. **Carlos Monné Bailo:** Conceptualization, Methodology, Resources, Data curation, Writing – original draft, Visualization, Funding acquisition. **Cristina Cabello Matud:** Resources.

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.

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