Chapter 10
Analysing the Effectiveness of the Energy Conservation Measures to Reduce Energy Poverty Cases in the Southern Regions of Spain

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Abstract Reducing energy poverty is among the main current concerns. Deficient energy performance could contribute to energy poverty cases, so energy rehabilitation in buildings is essential to take action from a technical perspective. However, the limitations related to the use of energy conservation measures in warm climates could prevent from reducing energy poverty cases. This study analyses the effectiveness of applying energy conservation measures in buildings located in warm climates. A case study in Seville was selected, and 20 combinations of energy conservation measures were analysed. The results showed the suitability of using approaches combining the envelope and systems to obtain favourable results and reduce energy poverty.

Introduction

Energy poverty is among the main challenges that the governments of each region should face. This problem could affect approximately over 124 million people in the European Union [1]. Building energy performance is one of the main factors contributing to energy poverty [2, 3] because of the age of the building stock. In this regard, 70% of the building stock of the countries in southern Europe was built before the implementation of the regulations on energy efficiency [4].

The energy improvement of the existing building stock is therefore a challenge that should be addressed by the building sector to reduce energy poverty cases. Moreover, this improvement would in turn imply improving other aspects, such as the environmental ones. Energy rehabilitation could contribute by 2050 to achieve the low-carbon goals established by the European Union [5].

Thus, energy conservation measures (ECMs) should be adopted in existing buildings. ECMs are understood as any type of modification that improves the energy

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performance of an existing building [6]. These measures include the adoption of solutions focused on improving various building elements, such as envelope elements or HVAC systems [7–10].

Although the advantages of applying ECMs have been analysed in detail [11–14], most studies have been focused on cold climates. In these climates, measures to improve envelopes usually obtain favourable results. However, results could be different in warm climates [15]. Studies focused on this type of climate have shown both the limitations to improve envelopes and the fact that payback periods could be long [16]. Nonetheless, the social element of energy poverty and the potential of these improvements have not been considered to reduce the number of energy poverty cases. This study analyses the potential of applying ECMs to reduce energy poverty cases. For this purpose, a case study representing the Spanish building stock was selected, and various ECMs were analysed. The case study is located in Seville, a zone characterised by hot summers and mild winters.

Methodology

Case Study

A case study located in Seville was used to analyse the influence of improving both building energy performance and the energy poverty of families. Seville was chosen because its summer climate conditions highly affect both building energy consumption and the limitations related to the implementation of ECMs in buildings. In this regard, the climate zone of Seville is B4 according to the Spanish Building Technical Code [17]. This climate zone is characterised by mild winters and hot summers.

The case study is an isolated building located in a residential neighbourhood (Fig. 10.1). The building was built before the implementation of the first standard on building energy efficiency in Spain (the basic standard of 1979 (NBE-CT 79) [18]), so it is characterised by having low energy performance. Moreover, it represents a high percentage of the Spanish building stock [19]. The building has five floors, its geometry is rectangular, with orthogonal salients in the façade corresponding to rooms including living rooms and kitchens. There are 116 dwellings in the building.

Characteristics of the Case Study

The characteristics of the building are common in buildings erected in that building period. Regarding the envelope, Table 10.1 summarises the constructive characteristics of the façade and the roof. These data were obtained by analysing similar buildings previously. However, given the uncertainty of the representation of data, a

Fig. 10.1 Case study analysed in the research

room was monitored following the criterion included in ISO 9869-1 [20] to determine the thermal transmittance value. A data logger ALMEMO 2590-4AS with thermocouples of type K and a heat flow meter plate were used. The test was conducted from 10 February 2019 to 13 February 2019, thus lasting the minimum duration established by ISO 9869-1, i.e., 72 h. The result was 1.23 W/(m2·K). This result is a percentage deviation lower than 20%, so the initial hypothesis of the composition of the wall meets the validation criterion of the standard.

The original windows of the building were of monolithic glass with metallic framework without thermal bridge break (a total thermal transmittance of 5.7 W/m^{2}K is estimated in these windows). However, some users have replaced these windows by modern designs. The new most-used window is of a metallic framework with thermal bridge break and insulating glass units (4+6+4). Nonetheless, given the difficulty of

Table 10.1 Thermophysical properties of the envelope

Type	Layer	Description	Thermal conductivity (W/(m·K))	Thickness (cm)
Façade	1	Cladding	0.550	2.00
	2	Perforated brick	0.680	11.50
	3	Filling	0.550	1.50
	5	Air gap	0.278	5.00
	6	Hollow brick	0.469	7.00
	7	Plaster	0.180	1.00
Roof	1	Ceramic tile	1.000	2.00
	2	Mortar	0.550	2.00
	3	Separating layer	0.500	0.20
	5	Felt underlayer	0.500	0.10
	6	Concrete with light aggregates	1.150	5.00
	7	Slab	0.893	25.00
	8	Plaster	0.180	1.00

knowing accurately the number of users who have partially or fully modified the windows of their dwellings, the hypothesis is that the building still has the original design in 100% of its windows.

Regarding thermal bridges, thermographs of the building envelope were taken (Fig. 10.2). Thermographs were taken on 15 October 2019 by using a FLIR camera (E60bx model). Intakes were taken between 7 am and 7:15 am. Finding an acceptable angle to take thermographs appropriately from various points of the envelope was something of a challenge, so only the south-west corner of the building was evaluated. There were significant thermal bridges in the slab front of the building. Likewise, various typologies of corners in the building (salient and entrants) generated various effects on the thermal bridge, thus resulting in negative or positive values of the linear thermal transmittance.

The building is characterised by having only electrical installation. The domestic hot water service is provided by this energy source as all dwellings have an electric water heater. Likewise, all dwellings have a compact heat pump system for cooling as they are not reversible, thus hugely affecting users' thermal comfort in cold months, particularly if the surveys of the constructive characteristics of the envelope and the results obtained in the tests conducted in the envelope (thermal transmittance and thermograph) are considered. Nonetheless, most users have a support system based on portable heaters. These systems could be useful as a measure to achieve certain thermal comfort, although having an effective thermal conditioning system for indoor spaces in winter would be the most adequate measure.

In general terms, the contracted power of dwellings oscillates between 4.3 and 4.6 kW. The most usual rate is 2.0 DHA (many companies provide service to dwellings, with ENDESA and EDP being the main ones), and just some users have

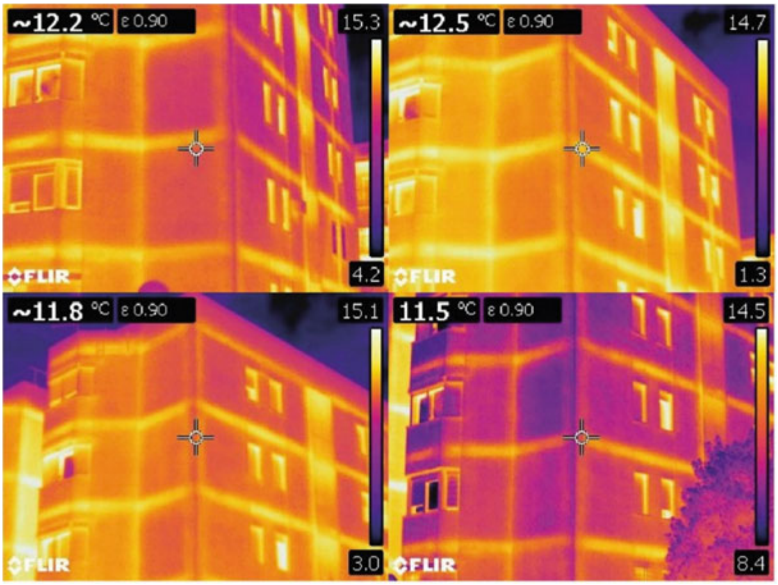

Fig. 10.2 Thermographs taken in the building envelope

the voluntary price for the small consumer (PVPC in Spanish). After analysing previously the invoices of the dwellings from the last years, an annual mean consumption of 3600 kWh was estimated. Table 10.2 includes some examples of these invoices.

Table 10.2 Example of electricity consumption in the last months in three dwellings of the case study

Invoicing period	Energy consumption (kWh)		
	Dwelling 1	Dwelling 2	Dwelling 3
January 2019	271	300	387
February 2019	260	280	281
March 2019	229	160	265
April 2019	280	200	120
May 2019	314	220	325
June 2019	357	420	350
July 2019	400	456	450
August 2019	460	441	425
September 2019	360	280	350
October 2019	300	220	285
November 2019	280	225	286
December 2019	220	230	350
TOTAL ANNUAL	3731	3432	3874

The peak of monthly consumption in dwellings was in summer. These results are expected because of the great similarity of dwellings in terms of equipment and surface. Nonetheless, the operational pattern of each dwelling generates the variations detected in energy consumption.

Energy Conservation Measures

Given the characteristics of the case study, the possibility of implementing various ECMs was analysed. In particular, three measures of the envelope (façade, roof, and gaps) were analysed, as well as one measure related to the improvement of systems and another to the implementation of renewable energies. The description of each measure is included below:

- ECM 1. Energy rehabilitation of façade through thermal insulation from the exterior, with a SATE system, of rigid panel of expanded polystyrene of 60 mm of thickness (thermal conductivity of 0.038 W/(mK)).
- ECM 2. Energy rehabilitation of passable flat roof, rigid panel of extruded polystyrene Ursa XPS F N-III L "URSA IBÉRICA AISLANTES" (thermal conductivity of 0.033 W/(mK)).
- ECM 3. Replacement of windows with double glazing LOW.S "CONTROL GLASS ACÚSTICO Y SOLAR", LOW.S 4/6/6 Templa.lite Azur.lite blue colour (thermal transmittance of 2.5 W/(m^2K) and solar factor (coefficient g) of 41%) and metallic carpentry with thermal bridge break (thermal transmittance of 2.8 W/(m^2K)).
- ECM 4. Replacement of HVAC systems from external units VRV-IV+ (Variable Cooling Volume), heat pump, RYYQ18U "DAIKIN" model, and low silhouette indoor unit, FXDQ15A3 model.

  Replacing the existing HVAC system by a centralised system made up of external units for the VRV-IV+ system (Variable Cooling Volume), RYYQ18U "DAIKIN" model, for R-410A gas, with variable cooling temperature was considered to improve the seasonal effectiveness and the continuous heating by phase change heat accumulator (400 V/50 Hz), nominal cooling capacity of 50 kW, nominal heat output of 56 kW, SEER of 6, and SCOP of 4,2. Dwellings have an indoor conditioning unit, for VRV system (Variable Cooling Volume), of roof with rectangular pipe distribution, of low silhouette, FXDQ15A3 "DAIKIN" model.
- ECM 5. Incorporation of a photovoltaic solar installation to meet 100% of the energy demand of the case study. The installation takes place in the roof of the building.

These measures were analysed through the combination matrix indicated in Table 10.3.

Table 10.3 Combination of measures analysed

Combination	ECM 1	ECM 2	ECM 3	ECM 4	ECM 5
Combination 01	X				
Combination 02		X			
Combination 03			X		
Combination 04				X	
Combination 05					X
Combination 06	X	X		X	
Combination 07	X		X	X	
Combination 08	X		X	X	X
Combination 09	X			X	
Combination 10	X			X	X
Combination 11	X	X		X	X
Combination 12		X	X	X	
Combination 13		X	X	X	X
Combination 14		X		X	X
Combination 15	X	X	X	X	
Combination 16	X	X	X	X	X
Combination 17				X	X
Combination 18	X				X
Combination 19		X			X
Combination 20			X		X

Energy Simulation and Energy Poverty Analysis

The case study was modelled and simulated in CYPETHERM EPlus (Fig. 10.3). The simulation was performed with both the initial configuration of the case study and the various combinations indicated in section "Energy Conservation Measures".

The load profile determined by the Spanish Building Technical Code for a residential use was used (see Table 10.4). This profile is characterised by the variation of the occupancy according to the day: from Monday to Friday, the occupancy load varies between 0.54 and 2.15 W/m^2 (sensible load) and between 0.34 and 1.36 W/m^2 (latent load), whereas at weekends the occupancy load is 2.15 W/m^2. The load of both lighting devices and equipment has the same use profile, which varies between 0.44 and 4.40 W/m^2 according to the hour of the day. Setpoint temperatures (Table 10.5) are based on a static thermal comfort model in which users' thermal expectations do not depend on the outdoor conditions [58]. A period of using heating systems between October and May is established (with setpoint temperatures of 17 and 20 °C), as well as a period of using air conditioning systems between June and September (with setpoint temperatures of 25 and 27 °C). These periods of using HVAC systems are coincident with the periods established for the winter and summer months used in the

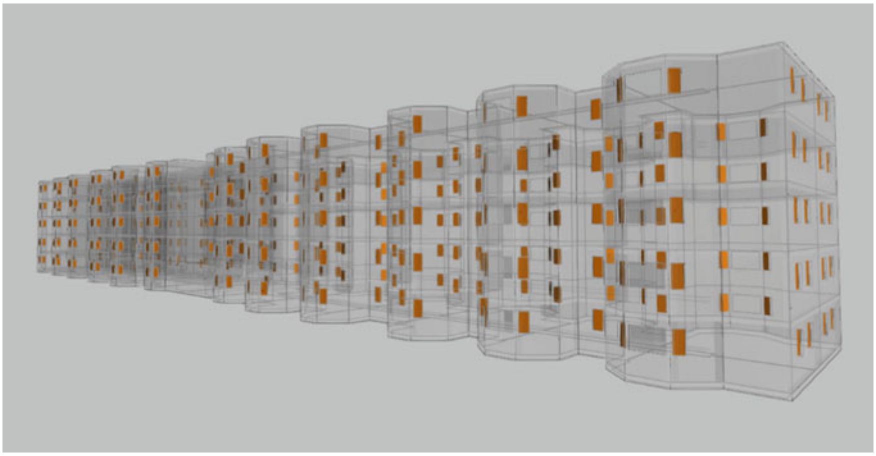

Fig. 10.3 Case study in CYPETHERM EPlus

climate zones of the CTE. The value of the setpoint temperature varies according to the hour of the day. Climate data of Seville were obtained through METEONORM.

Energy poverty was analysed with the high share of energy expenditure in income (2 M) used by the Energy Poverty Observatory (EPOV). The 2 M indicator is adjusted to the needs as it could be applied for users who try to keep thermal comfort conditions inside their dwelling. Thus, 2 M considers that families are in energy poverty when the percentage relation between the energy cost (EC) and the household income (HI) is greater than the national median. For this study, the percentage relation is shown in Eq. (1). Regarding the value of the national median expenditure, a recent study by Sánchez-Guevara Sánchez et al. [21] determined that the threshold value for this indicator in Spain is 10%, coincident with the value established by Boardman [22]. This threshold value was therefore used in this study. The analysis was performed in the 116 dwellings of the building.

$$\text{Energy poverty ratio } = \frac{\text{household energy consumption expenditure}}{\text{household income}} \cdot 100\,[\%] \tag{1}$$

$$\text{Case in energy poverty if Energy poverty ratio} \geq 2M(10\%)$$

Regarding the level of families' incomes, the data given by the Spanish Institute of Statistics were used (Fig. 10.4). For this purpose, the most unfavourable income decile was determined, as well as the representative centroid value of that decile. This value was used as a reference for the resident families' incomes.

Table 10.4 Hourly distribution of the loads in the case study

Loads		Time period					
		0:00–6:59	07:00–14:59	15:00–17:59	18:00–18:59	19:00–22:59	23:00–23:59
Sensible load (W/m^2)	Weekdays	2.15	0.54	1.08	1.08	1.08	2.15
	Weekend	2.15	2.15	2.15	2.15	2.15	2.15
Latent load (W/m^2)	Weekdays	1.36	0.34	0.68	0.68	0.68	1.36
	Weekend	1.36	1.36	1.36	1.36	1.36	1.36
Lighting devices (W/m^2)	Weekdays and weekend	0.44	1.32	1.32	2.20	4.40	2.20
Equipment (W/m^2)	Weekdays and weekend	0.44	1.32	1.32	2.20	4.40	2.20

Table 10.5 Setpoint temperatures used in the case studies

Setpoint temperature	Months	Time period			
		0:00–6:59	07:00–14:59	15:00–22:59	23:00–23:59
Heating setpoint temperature (°C)	October–May	17	20	20	17
Cooling setpoint temperature (°C)	June–September	27	–	25	27

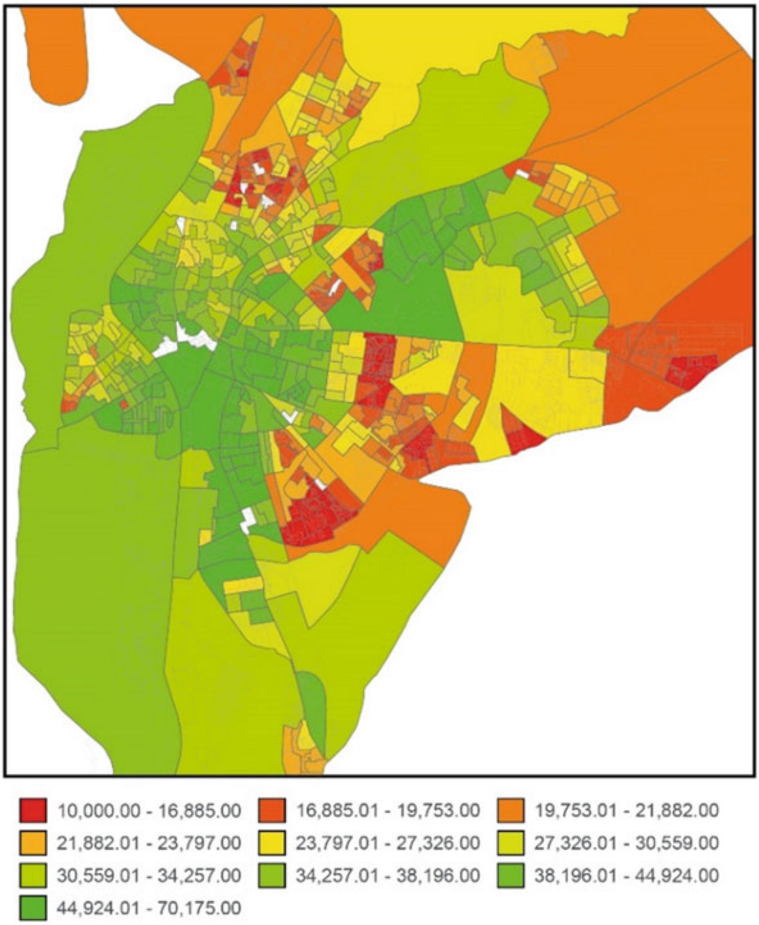

Fig. 10.4 Spatial representation of the incomes related to the census units in Seville. Data correspond to 2016

Limitations of the Study

This type of study is limited by the methodology established. First, the energy poverty analysis was related only to the 2 M indicator, and other indicators used by EPOV were not considered. This aspect could imply that the results vary by using other indicators. Nonetheless, the authors have considered that thermal comfort is guaranteed throughout the whole simulation period. Second, the operational profile could not be representative of the use of dwellings. In this regard, teleworking [23] or adaptive patterns [24] could vary the operational profile considered by the Spanish Building Technical Code.

Results and Discussion

The percentage of energy poverty cases obtained in the current scenario and with the various combinations is included in Fig. 10.5. The current situation was characterised by 100% of cases in energy poverty due to the high building energy consumption. Thus, the design of the envelope, together with the use of heat pumps with inappropriate performance, generated an unfavourable situation for families. The situation of families could be improved by using various energy improvement combinations, although systems and envelope improvements should be combined. In this regard, the improvement of the façade or the roof did not vary the percentage of energy poverty cases, whereas the incorporation of windows with better thermal properties reduced the percentage of cases due to the reduction of cooling energy demand. Nonetheless, the percentage obtained by Combination 3 (51.72%) is not an appropriate measure to guarantee appropriate conditions for families. Likewise, the use of heat pumps with better performance obtained percentages of energy poverty similar to those obtained by replacing the windows. Thus, the use of one measure or another could imply similar reductions of energy poverty cases, although the performance costs of each measure are different and could vary the amortisation periods.

However, the measure which could be greatly applied is the use of photovoltaic systems to meet the energy requirements of the building as it removed energy poverty cases in the case study. This is a clear aspect as the electric energy is just the energy consumed in the building, following a usual way of consumption in the region. Nonetheless, Combination 5 could present limitations due to both the availability of space to install the number of modules required to cover the consumption of the building and the variability that could be presented by the energy production throughout the year. For this reason, combining measures focused on reducing energy demand or consumption could be interesting. Only Combinations 6, 7, 9, 12, and 15 obtained energy poverty cases. The common factor in all these combinations is that photovoltaic systems were not included. In the remaining combinations, the use of photovoltaic systems with some improvements in the envelope or systems obtained reductions in all energy poverty cases, together with the reduction of the size of the photovoltaic installation.

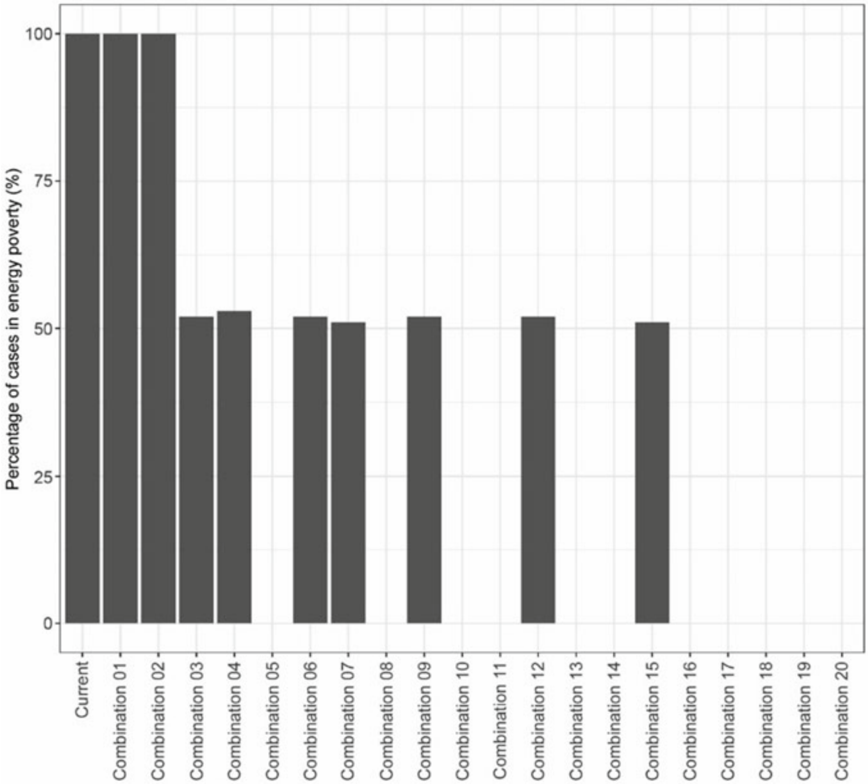

Fig. 10.5 Percentage of dwellings with families in energy poverty

Conclusions

This study analysed the viability of adopting energy conservation measures (ECMs) in existing buildings located in warm climates to reduce energy poverty cases. A case study representing the built environment in the south of Spain was selected, and 20 combinations of three types of ECMs were analysed: envelope, replacement of HVAC systems, and photovoltaic systems.

The results showed the feasibility of using ECMs focused on self-consumption, instead of other measures usually used, such as envelope improvement or replacement of existing systems. Only the limitations related to the implementation of a photovoltaic system with appropriate dimensions regarding users' energy requirements could force to combine other measures, such as window replacement. Likewise, the existing systems should be previously analysed because there could be difficulties to acclimatise all the rooms inhabitable inside dwellings if HVAC systems are not well designed.

Nonetheless, the context changing by climate change that the built environment should face should be considered. The progressive increase of the outdoor temperature could imply a more extreme situation in these latitudes and reduce the effectiveness of the ECMs analysed in this study. For this reason, future works should address the effectiveness of ECMs to reduce energy poverty cases in warm climate zones from a climate change perspective.

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