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Article

Retrofitting of Energy Habitability in Social Housing: A Case Study in a Mediterranean Climate

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Abstract: Much of the residential sector in Spain is obsolete, with inadequate conditions of comfort and high energy consumption. For this reason most of the potential for improving energy efficiency lies in the existing residential sector, which requires upgrading to meet the quantitative and qualitative changes required at present. This study of specific cases aimed at establishing general criteria for action has been prompted by the difficulty in proposing general intervention strategies. This paper presents a case study for the energy retrofit of 68 social housing units in Cordoba (Spain) evaluating their energy consumption, with a view to improving the building's energy balance and indoor thermal comfort, on which user comfort depends.

Keywords: energy efficiency; retrofitting of social housing; thermal comfort; improvement of habitability

1. Introduction and objectives

The renovation of residential buildings provides an excellent opportunity for the improvement of energy consumption and indoor climate. Upgrading the thermal envelope insulation and the use of passive measures such as the use of solar control in the summertime lead to energy savings and an improvement in indoor and user comfort.

The studies carried out by Ramesh *et al.* [1], Sartori and Hestnes [2] and Hernández and Kenny [3] show that when analyzing the lifecycle of residential buildings the use phase accounts for between 80–90% of the total energy consumption. Therefore, the reduction of energy demand during the use phase, particularly making use of passive solar design strategies, is the most important factor to consider when designing the building.

The latest Energy Performance of Buildings Directive, EPBD [4] established clear instructions for large refurbishments, aimed at increasing insulation requirements to make the most of the great potential for energy saving in buildings.

There are a significant number of energy retrofit activities in Northern and Central Europe, characterized mainly by a high level of thermal insulation. However, in regions with a Mediterranean climate fewer interventions are carried out, and these are usually linked to International [5-8] or National Projects [9-12] including best practice case studies in Spain, Portugal, Italy, and Greece. Thermal insulation levels in Mediterranean climates do not need to be as high as in other parts of Europe. However, given the greater degree of solar radiation this strategy should be combined with other measures such as thermal inertia, solar control, night ventilation, or reduced internal gains. Most case studies have evaluated energy consumption and savings, but few examples of retrofit actions executed have been assessed in terms of indoor thermal comfort conditions [7,13] In these Mediterranean case studies, the values of indoor temperature in summer often exceed the indoor comfort band as a result of solar radiation.

The unique nature of each retrofit project and a wide range of climate zones make it difficult to establish guidelines for action. There is therefore a need to define the most efficient cost and performance solution for each case. This has prompted the proposal of specific case studies to establish general criteria for action.

The building under study consists of 68 social housing units for rent, with commercial premises and a garage, built in 1994 by the municipal construction company Viviendas Municipales de Córdoba (Vimcorsa) and financed by the State Fund for Employment and Local Sustainability [14]. Construction work was recently completed on the retrofit project initiated in early 2010 by the architect Rafael Suárez.

Generally, proposals for energy rehabilitation are based on the promotion of energy saving and efficiency, concentrating on the reduction of CO_2 emissions and users' energy consumption. The main aim of this study is to incorporate improved thermal habitability conditions in the building into the design phase.

2. Residential Building: Case Study

In terms of typology, the building is a symmetrical U-shaped block five stories high, with housing units, an interior courtyard, a southeast-facing main façade, a ground floor devoted to commercial premises, and an underground car park (Figure 1).

Figure 1. Floor plan.

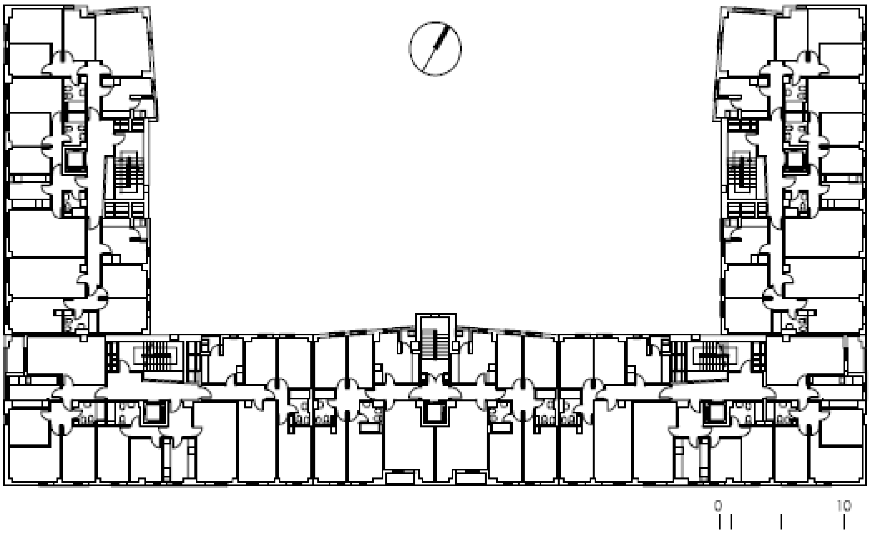


Table 1. Characterization of the thermal envelope in its original condition and after retrofitting.

	Building element	**U (W/m² K)**		**Retrofit improvement**
		Original	Retrofitting	
Façades	24 cm porous ceramic brick with exterior rendering and interior plastering	0.94	0.33	Ventilated façade with 6 cm MW
	Staircase: single layer, perforated brick wall, 5 cm MW insulation, air chamber exceeding 5 cm, plastered hollow brick wall.	0.52	0.52	
Openings	Anodized aluminum frames with 5 mm single glazing.	5.70	3.8	4 + 6 + 6 glass
			3.3	Low emission 4 + 6 + 6 glass
Roofs	Ceramic tiles, key mortar, brick board bedded on sand, asphalt sheet, leveling mortar, slopes formed with 10 cm cellular concrete and 5 cm XPS on framework.	0.47	0.47	
Floors	Unidirectional framework 25 + 5 semi-resistant joists finished with terrazzo flooring and plaster.	2.25	0.54	5 cm XPS insulation, air chamber and metal false ceiling.

Table 1 shows low levels of thermal insulation in the thermal envelope, particularly on façades and external frameworks, and in the aluminum doors and windows with single glazing. Thermographic analysis shows thermal deficiency, revealing considerable energy dissipation in the building envelope through thermally weaker elements, with thermal bridges in framework edges, pillars, and window frames.

The north- and east-facing façades of the building are barely in contact with the sun in the winter, but the southeast and southwest façades are exposed to it, a problem which is resolved in summer with awning systems at some points.

The main strategies in the retrofit proposal for winter and summer are:

- Encouragement of airflow, mainly through natural ventilation at night during the summer depending on exterior conditions.
- Energy conservation, improving insulation, and the accumulation of energy through thermal inertia. To guarantee complete efficiency in the summer time the thermal mass must be in contact with the night airflow to ensure passive cooling, while in winter the wall must receive solar radiation.
- Solar Radiation and Solar Control, capturing solar radiation in winter and ensuring suitable protection from radiation in summer (solar protection of the openings with the most solar exposure, depending on orientation, using sliding, folding, or fixed slat systems. East and west windows are protected by external movable shading devices which are activated during the cooling period).
- Thermal envelope insulation (Table 1) using a ventilated façade system, with a ceramic or metal finish. This system reduces thermal bridges in beams and pillars and along the joints between bricks and load-bearing structure.
- Thermal transmittance of windows, incorporating double glazing and improving insulation on external framework (Figure 2).

Figure 2. Building in original condition (left) and following retrofit (right).

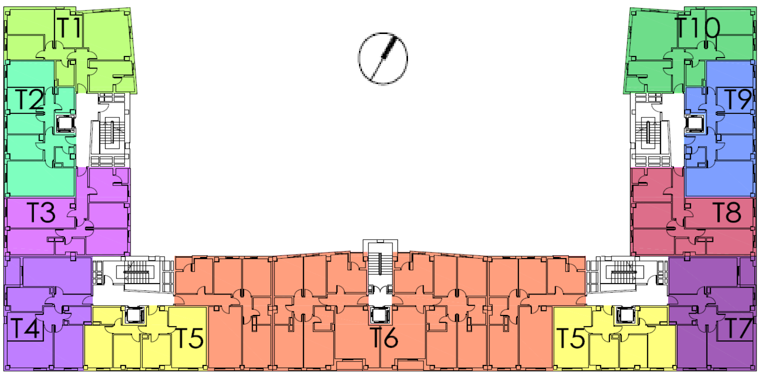
3. Analysis Methodology

The energy assessment of the building, both for its original condition and for the retrofit project, defined the intervention strategy. The computer program used was Design Builder version 2.2.5.004, whose simulation engine, Energy Plus, enabled the authors to obtain precise data on annual, monthly, and hourly demands for each model, as well as indoor temperature values in housing units considered to be free running. A comparative analysis was established to measure the predicted improvement following the action.

Table 2. Operating conditions of the housing units.

Period (h)		1-7	8-15	16	17-18	19	20-23	24
Summer temperature setting (°C)		27	25	25	25	25	25	27
Winter temperature setting (°C)		17	20	20	20	20	20	17
Sensitive heat due to occupants (W/m2)	Weekday	2.15	0.54	1,08	1.08	1.08	1.08	2.15
	Weekend	2.15	2.15	2,15	2.15	2.15	2.15	2.15
Latent heat due to occupants (W/m2)	Weekday	1.36	0.34	0,68	0.68	0.68	0.68	1.36
	Weekend	1.36	1.36	1,36	1.36	1.36	1.36	1.36
Lighting load (W/m2)		0.44	1.32	1,32	1.32	2.2	4.4	2.2
Appliance load (W/m2)		0.44	1.32	1,32	1.32	2.2	4.4	2.2

Figure 3. Details of building.



Initially, conditions for occupancy operations, lighting and appliance loads, and temperature settings (Table 2) were established. The occupancy schedule considered varies depending on whether the day in question is a weekday or weekend. Summer ventilation at night was established at four air changes per hour. Infiltrations were measured onsite, using the Blower Door fan pressurization method, with M2 protocol [15]. The grills or openings through which air was extracted, mainly in kitchens and bathrooms, were sealed. This was considered the most suitable protocol for evaluating the relationship between the airtightness of housing units and their energy demand, calculating 0.55 air changes per hour in original condition. Following retrofit, and after insulating the recesses and lintels of the openings and improving the airtightness of the window frame joints, this decreased to 0.46 air changes per hour.

Summer regime was defined as the period between the months of April and September, and the rest of the year was considered winter. Given the importance of the orientation and position of the building, each of the 10 different housing unit types, which took their respective orientations into account, was analyzed (Figure 3). In addition an analysis of the average of all the top-story housing units was considered.

4. Energy Performance of the Building

The initial diagnosis detected deficient indoor comfort conditions affecting users. A series of calculations were carried out to establish the levels of thermal comfort inside the housing units to provide an in-depth analysis of thermal habitability upgrades in the proposal for energy retrofit. These calculations followed the free running hypothesis and evaluated the environmental indicators of temperature and thermal oscillation by studying local climate, thermal evolution, and energy characterization.

4.1. Location and Climate

The building is located in the city of Cordoba in the south of Spain (altitude: 90 m, latitude: 37° 50' 39" N–longitude: 4° 50' 46" O).

The climate is sub-continental Mediterranean with warm summers, very high temperatures (maximum average temperatures of 36 °C) and an average of over 300 hours of sun per month from June to September. The winters are mild and last from November to March, with short springs and autumns. Winter is the season with the most rainy days, although the annual rainfall level is low.

Typical days were calculated for the two main annual periods as part of the climate analysis of the location, winter (October 1–March 31) and summer (April 1–September 30). January 15 and August 19 were set as representative days in terms of the outdoor temperature values for winter and for summer.

Table 3. Climate values in Cordoba. Period: 1971–2000.

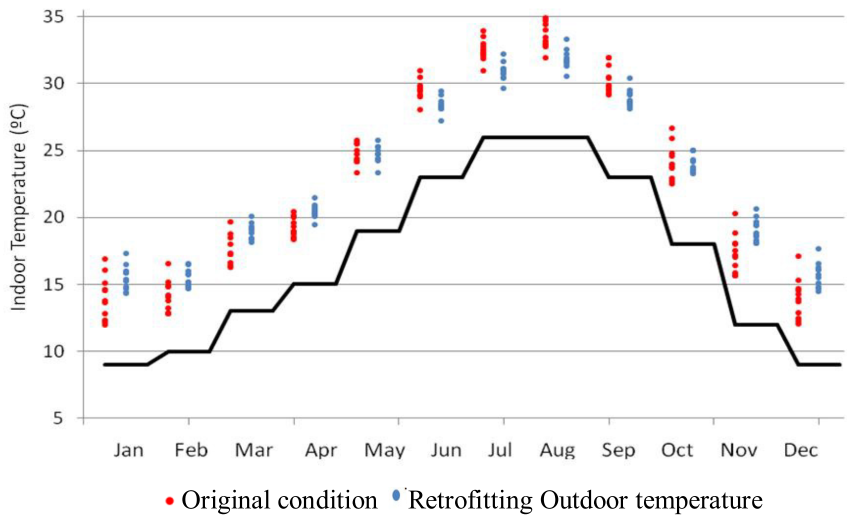
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average monthly/annual temperature (°C)	9.2	10.9	13.5	15.4	19	23.5	27.2	27.2	24.0	18.5	13.2	10.2	17.6
Average monthly/annual maximum day temperature (°C)	14.7	16.9	20.5	22.1	26.2	31.6	36.2	35.9	31.7	25.0	18.9	15.3	24.6
Average monthly/annual minimum day temperature (°C)	3.7	4.9	6.4	8.6	11.8	15.5	18.1	18.5	16.2	12.1	7.6	5.2	10.7
Average monthly/annual rainfall (mm)	64	53	40	61	34	17	3	3	24	62	85	89	536
Average relative humidity (%)	77	73	64	62	58	52	44	46	53	65	75	80	62
Average monthly/annual number of days with rainfall ≥1 mm	7	6	5	8	5	2	1	1	2	6	6	8	56
Average monthly/annual hours of sunshine	168	172	212	212	272	312	352	328	241	208	176	148	2800

4.2. Thermal Evolution

For the study of the thermal evolution of the housing units the authors used the procedure followed by Heras *et al.* [16], which monitored several buildings calculating indoor temperatures in winter and summer, and also analyzed the level of thermal comfort reached in each period, completing the study with the analysis of typical days.

The average indoor temperatures were compared with the average external temperatures, both monthly and on the typical days, in order to establish the thermal behavior of the housing units and their level of comfort. In the proposal for retrofitting, the monthly assessment (Figure 4) shows an increase of about 2 to 2.5 °C of the lower temperatures within housing units in winter, while in the summer there is a reduction of approximately 1.5 to 2.5 °C of the higher temperatures. The differences in temperature of the different types and orientations of housing units for both periods become homogenized.

Figure 4. Average indoor temperature *vs*. average outdoor temperature. Original condition and following retrofit.



The thermal evolution of the different types of housing unit throughout the 24 hours of the day was analyzed to establish at what points peak temperatures occur. The typical days for each season were analyzed, and cooling with a thermal oscillation ranging between 12.5 and 21.5 °C was observed between 15:00 and 20:00 hours in some of the housing units in their original condition. After retrofitting all the housing units retained a higher heat in relation to the outdoor temperature, thus raising the lower range of temperatures from 12.5 to 15.5 °C, with relatively stable behavior during the day, lower thermal oscillation between housing units, and very homogeneous temperatures (Figure 5).

In summer, cooling occurs between 15:00 and 21:00 hours and is more pronounced in the retrofit project, along with a drop in oscillation from 30–35 °C to 28–33.5 °C. These values are high, due mainly to the high outdoor temperature values (Figure 6).

The study of thermal inertia through an energy balance between indoor and outdoor temperatures throughout the 24 hours of the day allows us to establish whether or not overheating occurs and if so, when this takes place.

Figure 5. Evolution of average indoor temperature on a typical winter day. Original condition (left) and following retrofit (right).

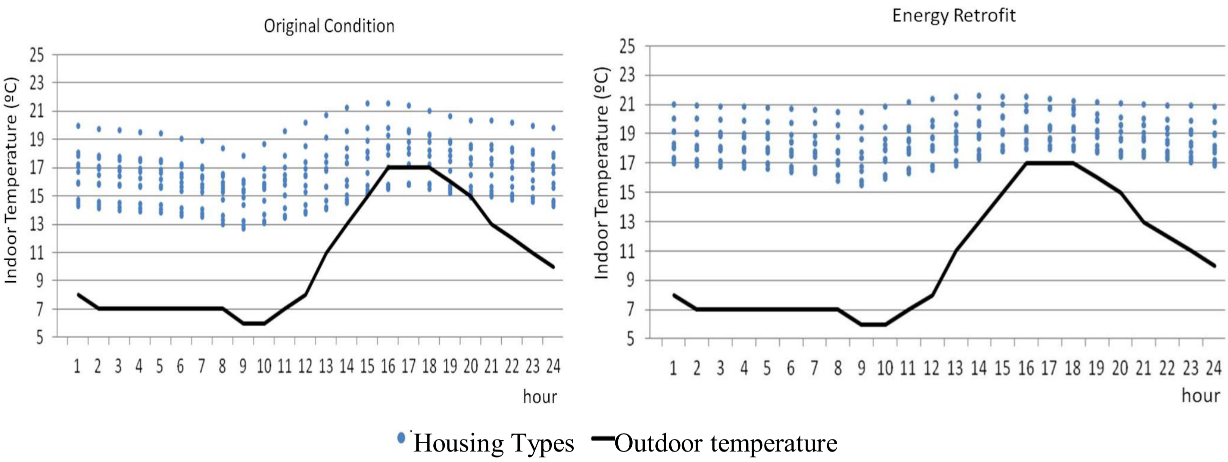
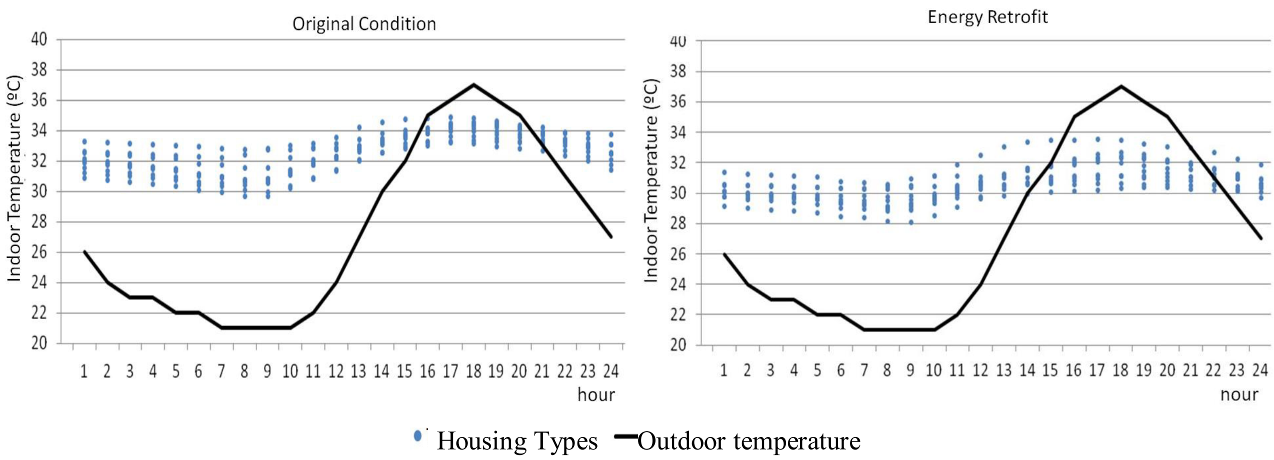


Figure 6. Evolution of average indoor temperature on a typical summer day. Original condition (left) and following retrofit (right).



In winter, in the retrofit proposal the inside of the housing units maintains a higher temperature thanks to natural heating. Early in the morning, when the sun begins to heat the building, the difference between outdoor and indoor temperatures decreases, peaking noticeably during early afternoon. This difference is caused by the increase in outdoor temperature, so there is no detriment to the indoor comfort conditions of the housing units (Figure 7).

In summer the performance of all the housing units follows the same pattern (Figure 8), but improves after retrofitting, with an increase in thermal oscillation compared to winter and a thermal wave with two distinct periods:

- A period of lower indoor temperature in which the outdoor temperatures are more than 5 °C higher than indoor ones. This phenomenon occurs between 15:00 and 22:00 hours, and is desirable in a summer with high solar radiation, since it avoids overheating and improves thermal comfort.
- A period of higher indoor temperature in which the difference between indoor and outdoor temperatures can reach 10 °C in the early stages of the day when the outdoor temperature is not too high and the housing units are still making use of the heat accumulated the previous day.

Figure 7. Study of thermal inertia in the winter. Original condition and following retrofit.

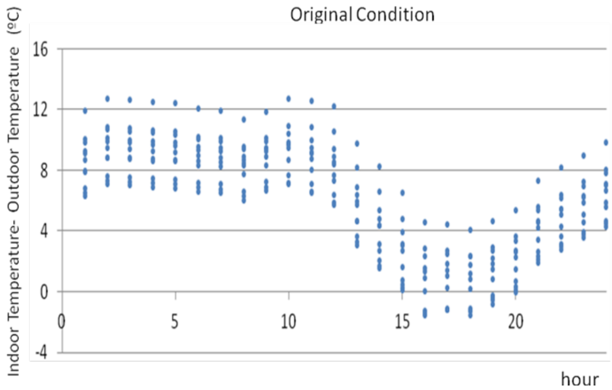
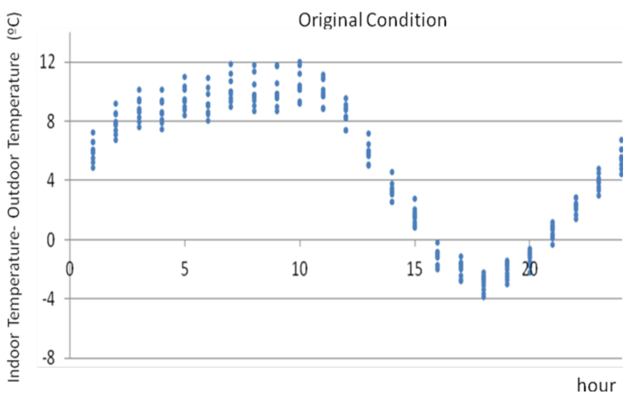
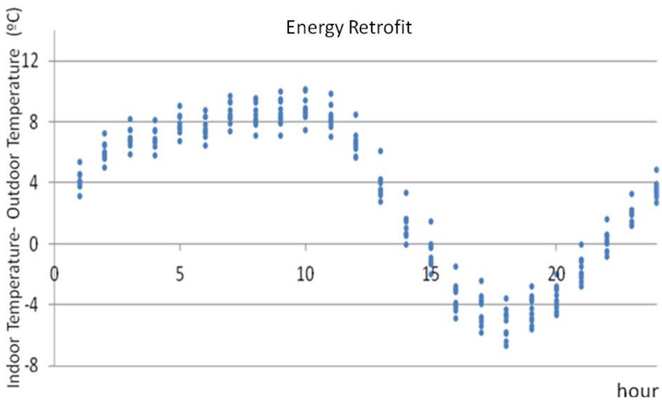


Figure 8. Study of thermal inertia in the summer. Original condition (left) and following retrofit (right).





4.3. Energy Characterization

To establish the thermal process occurring in buildings, comparisons are presented between indoor and outdoor temperatures, that is to say, effective heating or cooling, rather than room temperature. A rapid assessment of the level of thermal comfort can be obtained by comparing this with an indoor comfort band.

Establishing indoor comfort bands is simply a guide to thermal comfort. The concept of thermal comfort is rather subjective and difficult to evaluate. A comfort temperature interval of between 20–22 °C in winter and 22–27 °C in summer was established. This followed the theoretical studies by Fanger [17], incorporated into norm UNE EN ISO 7730:2006; the adaptive models of Auliciems and Szokolay [18], which include external climate conditions; and Givoni's climograph [19], which is particularly suited to warm dry climates.

Figure 9. Heating and cooling in winter. Original condition (left) and following retrofit (right).

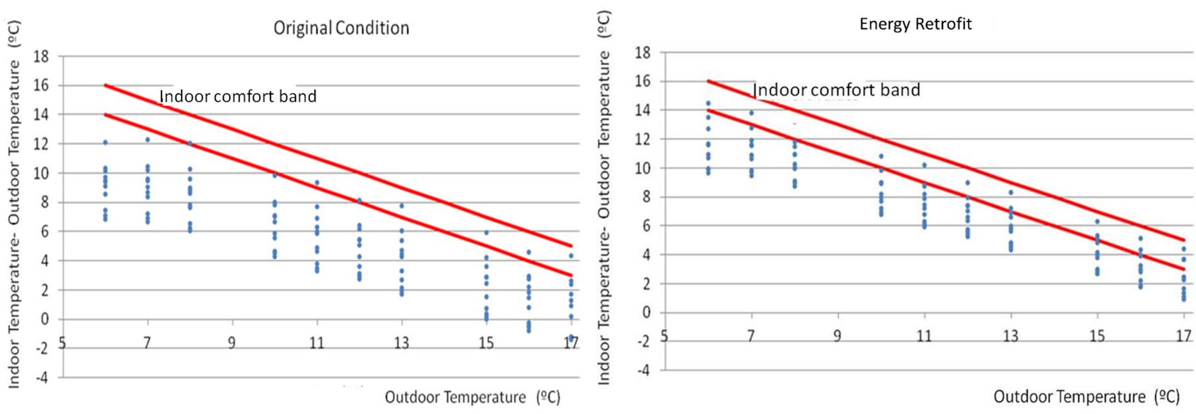
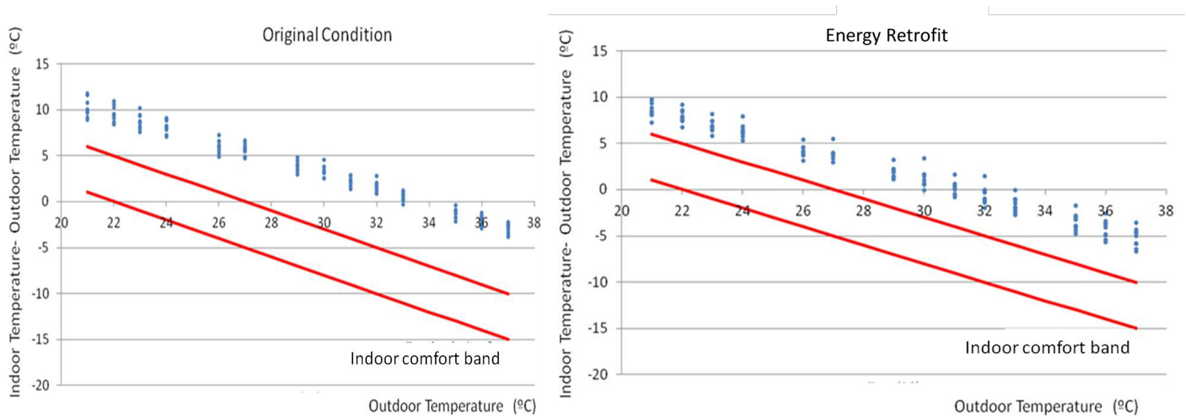


Figure 10. Heating and cooling in summer. Original condition (left) and following retrofit (right).



While during the winter the conditions of the housing units in their original state were inferior to those established in the comfort level, after retrofitting natural heating achieves values within or close to comfort level (Figure 9) in all the housing units, regardless of orientation.

In contrast, in summer the values observed were higher than the established comfort levels, but after retrofitting the values are somewhat closer to comfort values (Figure 10). Despite the openings being protected from excessive sun in the summer, the thermal mass of the building heats up as a result of high outdoor temperatures, even in the absence of solar radiation.

Natural cross ventilation makes it possible to reduce the heat loads accumulated during the day, but the severe summer climate makes it harder to reduce loads given the minimal difference between indoor temperatures (ranging from 28 to 33 °C) and outdoor ones (ranging from 21 to 37 °C).

5. Conclusions

The retrofit proposal entails a significant reduction of the overall energy demand, calculated at 38.16%, and shows a more significant reduction of the demand for heating (45%) as opposed to the demand for cooling (30.2%).

There is an increase in the energy features of housing units through thermal stability and reductions of temperature oscillations. This is due to an increase in thermal mass, thanks to the incorporation of thermal insulation on the exterior, and the reduction of thermal exchanges through transmission due to the improvement of walls and windows. After retrofitting there is an increase in benefit from solar radiation in the winter. The effects of solar radiation are reduced in the summer, as a result of protection from the sun. All these factors contribute to comfort conditions. The thermal behavior of housing units can in actual fact be found in conditions of comfort during the winter period thanks to the natural heating of the building. In summer the temperature values in the different housing units are homogeneous, with differences of 2 to 3 °C, and a wave fluctuating between 28 and 33 °C. This varies by several degrees above the comfort values as a result of solar radiation and the high values of outdoor temperature in the area, which has the hottest summers in Spain. The energy analysis calculated in the retrofit project will be monitored following the recent completion of the building work.

The improvement of thermal habitability and the energy performance of housing units confirms energy retrofitting as the best solution for countering the aging of existing residential buildings and achieving financial savings stemming from the improved energy efficiency, thus transforming it into a powerful tool for fighting climate change.

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