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Building characterisation and assessment methodology of social housing stock in the warmer Mediterranean climate: the case of southern Spain.

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Abstract. The increase in the average temperature of the planet due to global warming has serious repercussions on buildings, affecting indoor environmental quality and thermal comfort. Currently, one of the building stocks most at risk is that of the residential sector in southern Spain, given the high sensitivity of the Mediterranean climate to the effects of climate change and the massive volume of this built environment with obsolete energy conditions. However, it is crucial to carry out an in-depth assessment of the necessary retrofitting strategies for implementation in this existing stock, with an overall analysis of building characterisation and current state of the building stock. This research takes these aspects into consideration, using statistical descriptive techniques to evaluate the building characterisation of public social housing in southern Spain. This public sector is managed by the Regional Government of Andalusia and is made up of 39.486 social housing units. Results reported in this research make it possible to establish which buildings require short-term and priority retrofitting actions, thus creating a useful tool for decision-making within the political context.

Introduction

According to a recent study by NASA, in 2016 the average temperature of the planet had increased by almost 1 ºC compared to 1970-1975 [1]. If the current rate of greenhouse gas emissions is maintained, the average temperature forecast for 2081-2100 may be 4,8 ºC higher than that of 1986-2005 [2]. Climate change is therefore a potential threat to natural ecosystems and life [3], worsened in cities by the heat island effect [4] and longer and more frequent heat waves [5]. Moreover, in summer the average annual temperatures are expected to increase significantly in southern European countries [6].

In the building sector in warmer climates, such as the Mediterranean, increased temperatures may seriously impact indoor quality and reduce comfort conditions [7], leading to issues of overheating [8] and increased cooling energy consumption [9]. However, the thermal response of the existing building stock in southern Europe is conditioned by its current energy deficiencies, and is especially poor in the residential sector. In fact, over 60% of the residential building stock in southern Europe was built prior to the introduction of the first energy efficiency regulations [10], and their poor performance renders them obsolete.

Energy retrofitting of these buildings must be promoted considering both present demands and future scenarios to ensure preventive adaptation to climate change. In recent decades a large number of standards and regulations on energy efficiency have been developed. In Europe, several directives regarding the reduction of primary energy consumption and CO_2 emissions have been passed, including

Directive 2010/31/CE [11], Directive 2012/27/EU [12], "2030 Climate and Energy Framework" [13] and "2050 Low-carbon Economy" [14].
In general, energy retrofitting strategies on the built environment are implemented on two main scales: micro and macro. The former is based on the occasional individual retrofitting of buildings, whereas the latter is applied at urban and city level through an approximation to the building stock and is mostly managed by public stakeholders. However, extensive prior assessment of the building stock is required in order to propose guidelines and retrofitting strategies on a macro scale.
This research assesses the public housing building stock in southern Spain (Mediterranean climate), presenting a study focusing on the recognition and analysis of its current condition. This analysis was conducted with the institutional collaboration of the Andalusian Agency for Housing and Retrofitting (AVRA in Spanish) [15], a public organisation which owns and manages the public social housing in Andalusia. In total, this paper analyses 39.486 social public dwellings included in the database provided by AVRA, the content of which has been expanded with additional information. The main aim of this research is to determine how the climatic zone (as related to geographical location), year of construction, building typology and morphological conditions influence the average energy demand values of this housing stock.

Methodology
The methodology used in the building characterisation and assessment of the public housing stock in southern Spain is graphically represented in Figure 1. The following tasks were conducted:

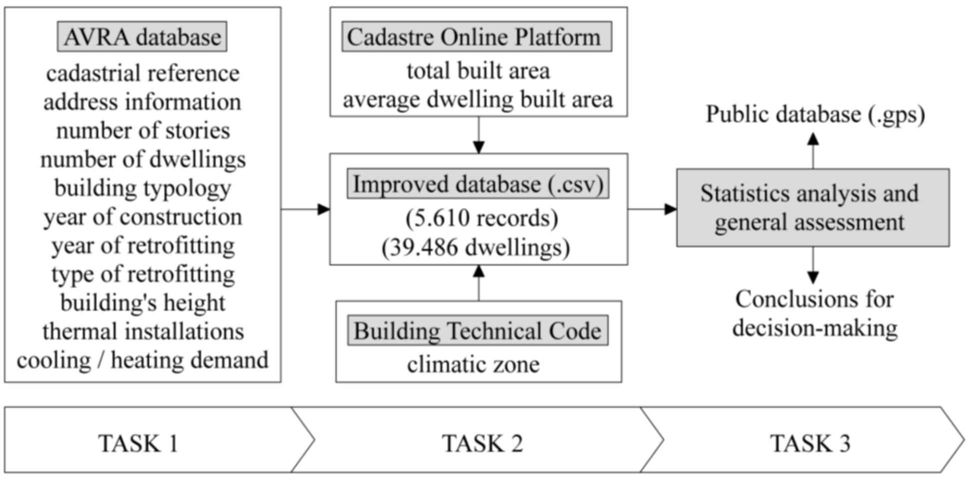

Figure 1. Methodology followed for the building characterisation and assessment of the public housing stock in southern Spain.

- Task 1. Compiling and rearranging general, typological, morphological and energy data related to public housing stock.
- Task 2. Improving the original database through the incorporation of new variables.
- Task 3. Statistics and general assessment of the public housing stock. Discussion of results focused on two analysis levels: 3.1) Whole database; 3.2) Multi-family dwellings.

The database provided by AVRA includes information on the public social housing in Andalusia and a series of variables. These include cadastral reference; address information; number of stories; number of dwellings; building typology (single-family, multi-family or others – a mix of the first two); year of construction; year of retrofitting; type of retrofitting intervention; building height; thermal installations; and annual energy cooling and heating demand of the dwellings. The building characterisation data were compiled from the "Execution Projects", while energy characterisation was obtained from the "Building Evaluation Report" (detailing the conservation status, the adaptation of accessibility and the grade of energy efficiency of a dwelling).

In Task 1, data included in 5.838 AVRA files were consolidated into a single .csv file, deleting duplicate information and incomplete housing developments (228 files). Thus, the total number of files analysed is 5.610, covering 39.486 dwellings.
In Task 2, the previous database was completed using public and open access tools with other variables relevant to this analysis. Firstly, the Spanish Electronic Cadastral Platform [17] made it possible to include the average floor area per dwelling and the total built surface for each housing development. Moreover, the classification of dwellings by climatic zones was made possible thanks to the climatic data included in the Spanish Building Technical Code [18]. In this standard, Climatic Severity in Winter (SCI) is represented by a letter, with "A" corresponding to milder winters and "D" referring to colder winters. Climatic Severity in Summer (SCV) is indicated by a number, so that areas with milder summers correspond to "1" while warmer ones are represented by "4" (Table 1). Climatic zones are determined through the combination of a letter and a number, obtained from the degree-day and solar radiation levels shown in Table 2.

Table 1. Climatic Zones according to the Spanish Building Technical Code [18]. The existing climatic zones in southern Spain are highlighted in bold.

Climatic Severity	Parameter	Range	Climatic Zones
SCI	A	SCI≤0,3	**A3**, **A4**, **B3**, **B4**, C1, C2, **C3**, **C4**, D1, **D2**, **D3**, E1
	B	0,3<SCI≤0,6	
	C	0,6<SCI≤0,95	
	D	0,95<SCI≤1,3	
	E	SCI>1,3	
SCV	1	SCV≤0,6	
	2	0,6<SCV≤0,9	
	3	0,9<SCV≤1,25	
	4	SCV>1,25	

Table 2. Determination of the Winter Climatic Severity (SCI) and Summer Climatic Severity (SCV) according to the Spanish Building Technical Code [18].

Climatic Severity	A	b	c	D	e	f
$SCI=a \cdot R_i+b \cdot G_i+c \cdot R_i \cdot G_i+d \cdot R_i^2+e \cdot G_i^2+f$	$-8{,}35 \cdot 10^{-3}$	$3{,}72 \cdot 10^{-3}$	$-8{,}62 \cdot 10^{-6}$	$4{,}88 \cdot 10^{-5}$	$7{,}15 \cdot 10^{-7}$	$-6{,}81 \cdot 10^{-2}$
$SCV=a \cdot R_v+b \cdot G_v+c \cdot R_v \cdot G_v+d \cdot R_v^2+e \cdot G_v^2+f$	$3{,}73 \cdot 10^{-3}$	$1{,}41 \cdot 10^{-2}$	$-1{,}87 \cdot 10^{-5}$	$-2{,}05 \cdot 10^{-6}$	$-1{,}39 \cdot 10^{-5}$	$-5{,}43 \cdot 10^{-1}$

R_i: cumulative average global solar radiation in January, February and December [kWh/m^2]
G_i: average of the degree-day in winter in base 20 for January, February and December. It is determined in on an hourly basis for each month and divided by 24.
R_v: cumulative average global solar radiation in June, July, August and September [kWh/m^2]
G_v: average of the degree-day in summer in base 20 for June, July, August and September. It is determined on an hourly basis for each month and divided by 24.

In view of the above, all climatic zones in Andalusia (in bold in Table 2) are covered by the dwellings included in the database, identified as A3, A4, B3, B4, C3, C4, D2 and D3.
In Task 3, for the building characterisation and assessment of the dwellings, the final database has been analysed through statistical descriptive techniques, using Microsoft Excel® [19].

Analysis and Discussion

Figure 2 shows the typological distribution of the Andalusian public social housing stock in southern Spain, considering the climatic zones, identified with different colours. Regarding the building typologies, single-family housing is represented in light colours, multi-family housing in medium colours and, finally, other typologies in dark colours. A high percentage of the dwellings analysed (77,5%), 30.592 housing units in total, corresponds to multi-family housing. A large portion of the dwellings in the database are found in decreasing order in climatic zones B4, A3, B3, C4, C3 and A4. In all the cases, the percentage of multi-family housing is predominant, for instance, 29,7% out of 35,3% in the case of climatic zone B4 or 19,6% out of 21,9% in A3. The Others typology percentage is quite small and is always the lowest of the three typologies for all climatic zones. D2 and D3 barely account for 1,5% of the total sample. For the sake of clarity in the figure, these last two climatic zones have been grouped together in Others.

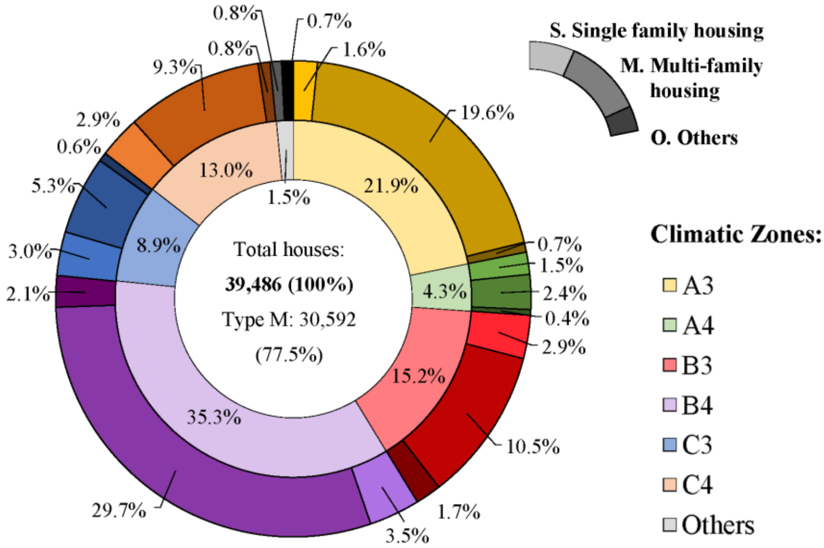

Figure 2. Typological distribution of public social housing in southern Spain by climatic zone.

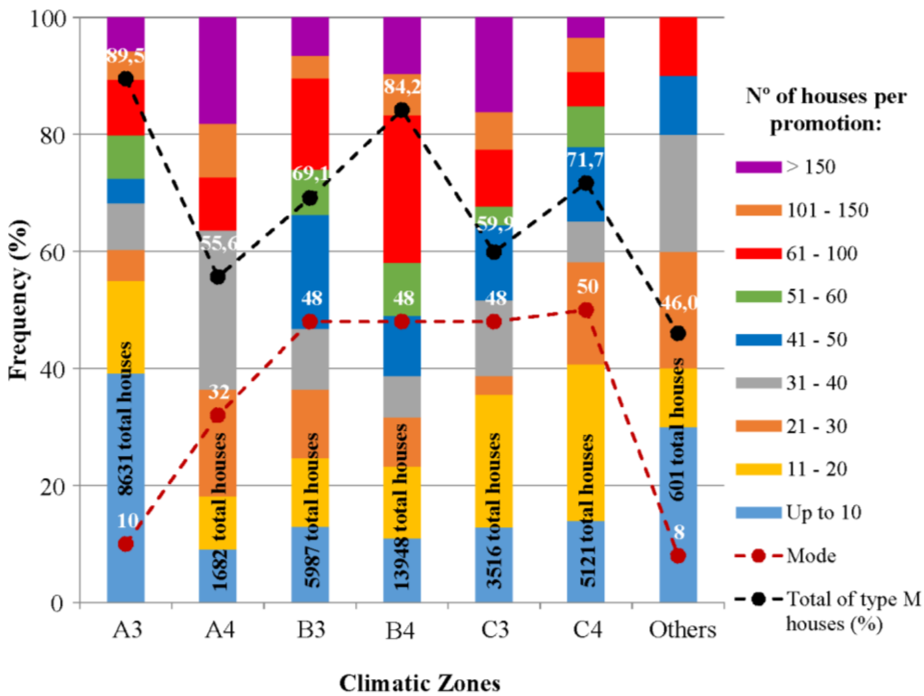

Figure 3. Number of housing units per development in southern Spain by climatic zone.

The bar chart (Figure 3) shows the number of dwellings built per housing development (absolute value in black), according to the climatic zone. The red dotted line represents the mode of each sample, while the black one indicates the percentage of multi-family dwellings out of the total for each climatic zone. In climatic zone B4, where most of the public dwellings are (35,3% according to Figure 2), specifically 13.948 dwellings, housing developments with 48 housing units are quite representative. The same is true of the B3 and C4 climatic zones, also with a high number of built dwellings. Nevertheless, in A3, with a total of 8,631 dwellings, the construction of housing developments with fewer housing units (10 dwellings) is more frequent.
Based on the above results and given the predominance of multi-family housing, both in terms of numbers and in the decision-making of public authorities (AVRA), the decision was made to extract single-family housing (16,1% of the total) and the Other typology (6,4% of the total) from this analysis.
Figure 4 shows the construction period of the multi-family housing, indicating the total number of dwellings analysed per climatic zone. The black line represents the average age of the dwellings. As can be observed, 94,6% of the multi-family dwellings were built before 2006, when the Spanish Technical Building Code [18], a standard incorporating energy criteria for the reduction of energy demand, was passed. 35,8% of these dwellings were built between 1991 and 2005, while almost 48,0% were built in the period from 1981 to 1990. The average age of these dwellings is around 31 years, with the oldest dwellings found in the B3, B4 and C3 climatic zones.

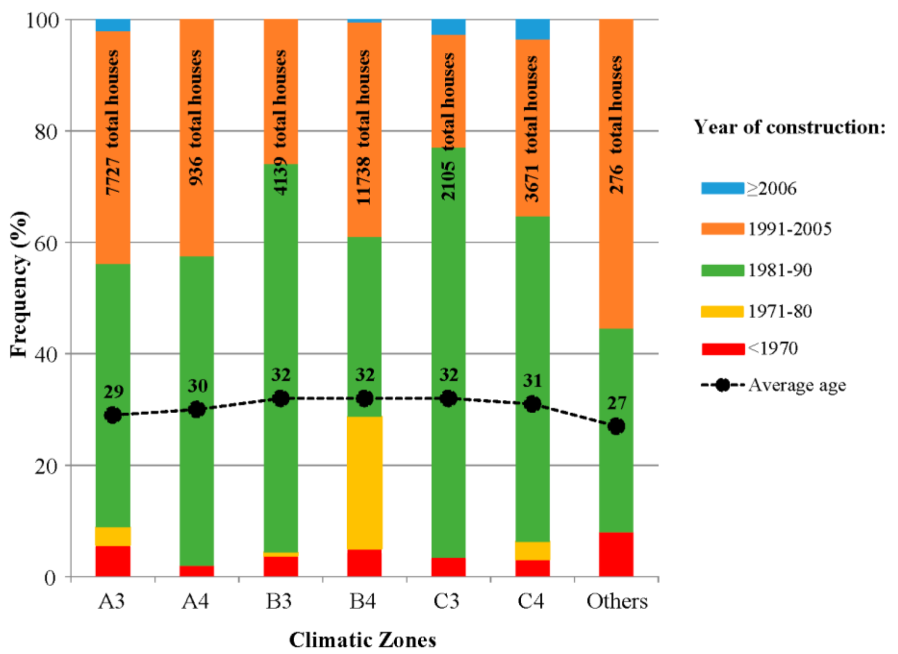

Figure 4. Construction period of the multi-family dwellings in southern Spain by climatic zone.

The percentage of retrofitted dwellings is represented below for each climatic zone (Figure 5), identifying and classifying the retrofitting actions into the following groups:

- Constructive interventions (in orange): Basic work for maintenance, accessibility adaptation, general repair and remediation (BW); Integral works for constructive repairs, replacement of equipment or systems and large urbanization works (IW); and Integral rehabilitation of structural elements, changes in use, and emergency works (IR).
- Energy retrofitting solutions (in blue): Thermal insulation in roof (TI_r); Thermal insulation in façade (TI_f); and Window replacement (WR).

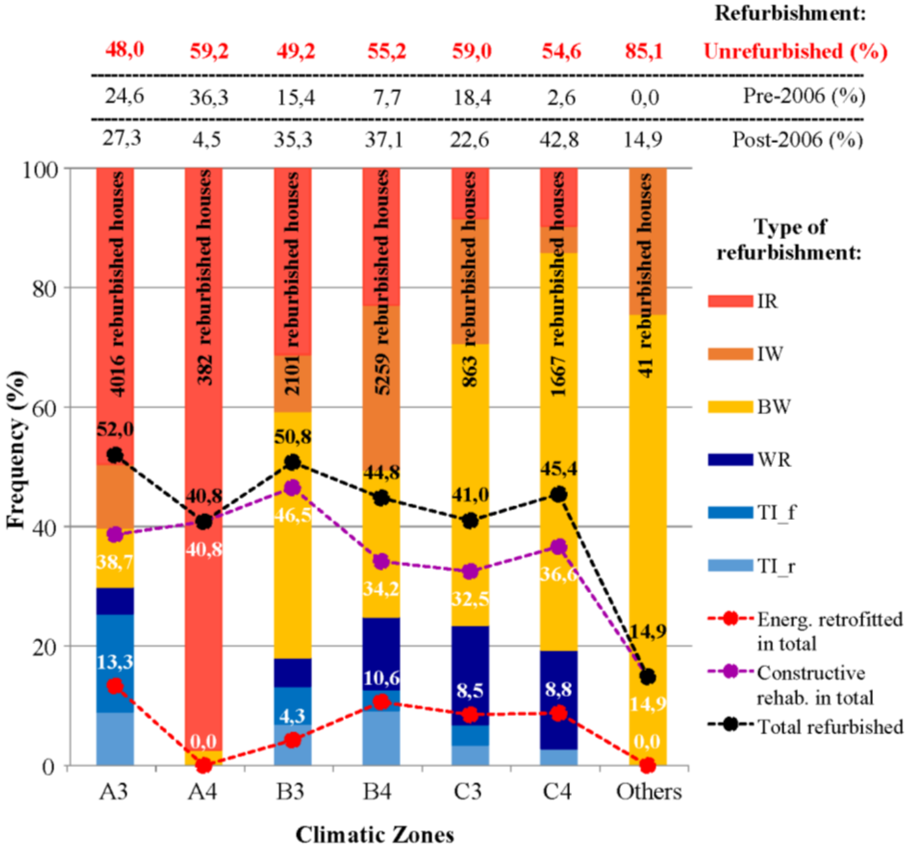

Figure 5. Percentage of multi-family retrofitted dwellings in southern Spain by climatic zone. The type of intervention is identified based on the definition provided in the study.

Only 9,7% of the multi-family housing units have been energy retrofitted, while a higher percentage of dwellings have undergone constructive rehabilitation works (37,1%). Moreover, energy efficiency solutions in keeping with current legislation were implemented in 32,9% of the total retrofitted dwellings [18]. In other words, more than half the sample has not undergone retrofitting strategies of any sort. In climatic zones with a higher number of dwellings, the percentage of housing units with constructive interventions increases from 32% to 46%. Constructive interventions focus mainly on basic maintenance and repair or accessibility adaptations, and are especially numerous in the Others climatic zone (D2 and D3). In contrast, structural rehabilitation and emergency works have been undertaken more frequently in the A4 climatic zone, where dwellings are more than 30 years old on average.

The percentage of energy-retrofitted dwellings for all climatic zones is under 15%, with no cases in A4 and Others (D2 and D3). In C3 and C4, it was decided to implement strategies on a larger scale including window replacements with improved energy features, rather than adding thermal insulation in the facades, most commonly used in A3. By comparison, in climatic zones B3 and B4 rehabilitations usually aim to strike a balance between adding thermal insulation to roofs and replacing windows.

An additional classification was conducted for the thermal active systems of the multi-family dwellings, differentiating central and individual systems for both heating and cooling (Figure 6). In the case of heating systems, information relating to the type of foil used is represented in a bar chart for all climatic zones. However, as there is no information available on the cooling systems used in the dwellings, only those centralised from individual systems could be identified (blue lines). Equally, percentages of non-heated and non-cooled dwellings are shown for each climatic zone.

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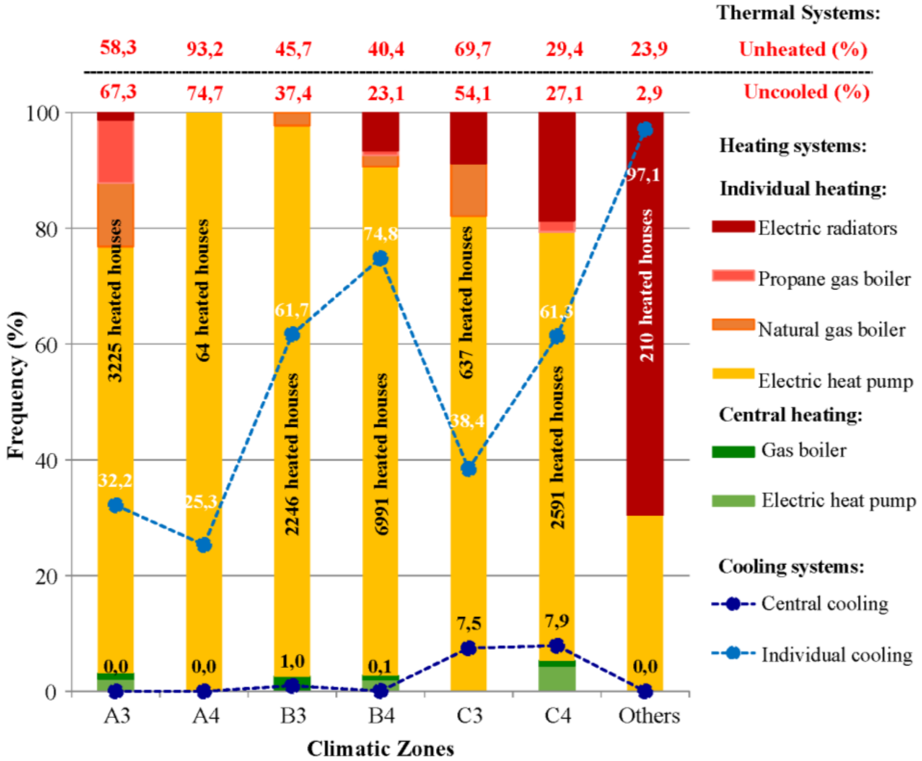

Figure 6. Thermal installations in multi-family dwellings in southern Spain by climatic zone.

Results show that the percentage of housing with cooling systems is higher than that of dwellings with heating systems, for all climatic zones, except A3. The percentage of non-cooled dwellings is especially high in A3 (67,3%) and C3 (54,1%) climatic zones, where most of the housing units analysed are located (7.727 and 2.105 housing units, respectively). The same occurs with heating systems in these climatic zones (58,3% and 69,7%, respectively).

A large part of the heated dwellings have individual systems, consisting of electric heat pumps (generally above 73,0%, with a value of 100% in the A4 climatic zone), with the exception of the Others zone (D2 and D3), where the use of individual systems based on electric radiators is more common (around 70,0%). The percentage of dwellings heated by natural gas boilers is lower (9,1-11,0%), and found both in climatic zones with mild winters (A3) and severe ones (B3, B4 and C3). The use of central heating systems is very low (under 4%), with some notable cases in C4, B4, A3 and B3, based mostly on electric heat pumps. In the case of cooling systems, dwellings with central systems and values under 8% in climatic zones C3 and C4 are barely relevant. In contrast, there is a high percentage of dwellings with individual cooling systems in all climatic zones. The areas with more severe climates (A4, B4 and C4) present percentages above 60%, except A4, with values around 25%. The remaining zones, with milder summers (A3, B3, C3 and Others) also present high percentages, varying from 32% to 97%, which represents the Others climatic zone (D2 and D3).

Finally, cooling and heating demand of the multi-family dwellings built prior to 2006 (when the Spanish Building Technical Code was approved) [18], and of those energy-retrofitted before 2006, were assessed. The results obtained are shown in Figure 7 through a boxplot diagram for each climatic zone. In this plot, dispersion and symmetry of the samples are easily visualised. Minimum and maximum values for all samples are indicated by the external segments (whiskers), which represent 25% of the inferior and superior part of the data, respectively. The rectangular box indicates the interquartile range or 50% of the intermediate data (distance between the first and third quartile). The second quartile is the median of the sample (interior line dividing the box). The average is marked as “X” in the boxplot.

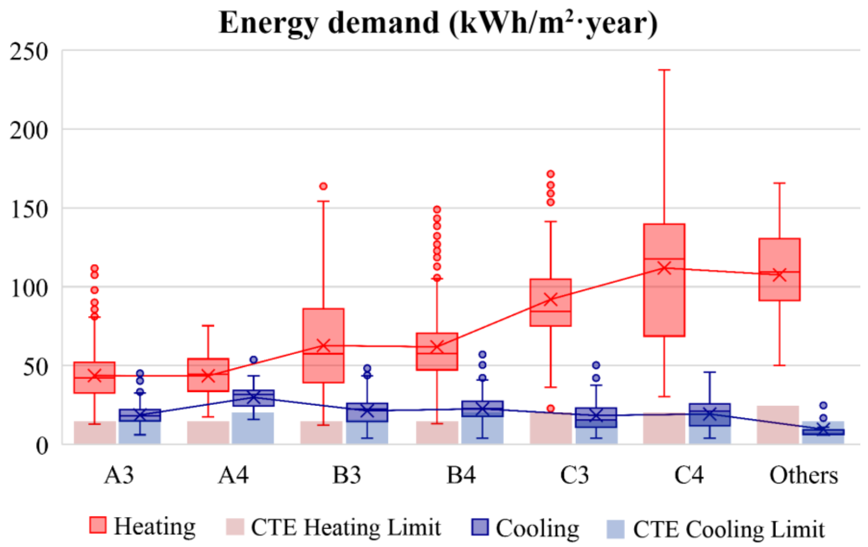

Figure 7. Heating and cooling energy demand of the pre-2006 multi-family dwellings in southern Spain by climatic zone.

It can be observed that cooling demand is significantly lower than heating demand. In general, dwellings located in areas with harsher winters present a higher variation range of the heating demand. This is especially significant in the cases of C4 and B3. The average value of the heating demand increases proportionally to the climatic severity in winter. Given the similar climatic severity in summer for all the climatic zones analysed, there are no major differences between cooling demand values. In general, it can also be seen that the energy demand values of these dwellings, especially heating demand, are much higher than the reference values of the Building Technical Code [18], also shown in the same figure.

Conclusions

The methodological model for analysing the social housing stock in the Mediterranean climate presented in this research successfully characterises and assesses the existing dwellings in Andalusia (Spain). Specifically, this methodology has made it possible to:

- Compile and reorganise general, typological, morphological, constructive and energy data for public social housing in southern Spain.
- Improve the original database, incorporating new variables into the study.
- Create a statistical database to facilitate the general assessment of this public social housing stock.

This in turn has made it possible to:

- Classify the dwellings by climatic zone (according to the Spanish Building Technical Code);
- Establish that the average age of the dwellings is over 30 years old;
- Establish the predominant and noticeable percentage of multi-family housing (77,5%), which justifies the intervention of public stakeholders in the retrofitting process.
- Obtain the percentage of multi-family dwellings which have been energy-retrofitted, less than 15% for all climatic zones.
- Inform public stakeholders that most of these dwellings are heated by individual systems based on electric heat pumps and radiators, while the percentage of dwellings with central heating systems is slightly lower.

- Determine an almost complete absence of multi-family dwellings with centralised cooling systems, whereas the use of individual systems is the most common. However, as cooling systems are not mandatory in this type of building there is no technical information on these systems and no data can be found in their Executive Projects.
- Establish that in multi-family dwellings predating 2006, cooling energy demand is significantly lower than heating demand. The average value of heating demand grows proportionally depending on the climatic severity in winter. Meanwhile, analysed dwellings do not present major differences in cooling energy demand, since climatic severity in summer is quite similar in all cases. In general, demand values for both heating and cooling are much higher than the reference values of the Spanish Building Technical Code for all climatic zones.

As future lines of research, it should be emphasised that the authors are currently working on expanding the content of the database, introducing further variables for analysis. Information is currently being collected on building orientation, urban and architectural typology (i.e. linear block, H, tower… grouped as collective closed blocks, terraced, isolated…) and constructive descriptions of the envelope.
The final aim of this research is to create an open-access public platform for the interoperability of the different import software used. This platform will be a planimetric tool for the visualisation and regionalisation of spatial data. It is expected to become a useful source of information for public stakeholders in decision-making, both short- and long-term. It will provide an overall panorama to prioritise energy retrofitting strategies, focusing on the more obsolete buildings.

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