Energy and Typological Building Characterization of the Social Housing Stock in Southern Spain.

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Abstract

Retrofitting buildings is key for meeting 2030 and 2050 energy efficiency targets, especially for existing residential buildings, which are expected to become a large proportion of the future stock. Prior to promoting energy saving measures, an extensive analysis of the current performance of the stock should be tackled. Thus, building characterization though a statistical approach is a necessary step in order to assess this stock under real variability conditions, instead of considering average fixed values, which has commonly been the approach taken so far. This research statistically analyses the most predominant variability ranges of the residential building stock of southern Spain (Andalusian region), focusing on the H-block, for its building characterization. Results are collected from an extensive database containing information on almost 39,500 dwellings. Conclusions reported may be later implemented into bottom-up building stock modelling approaches for creating real case archetypes to analyze the performance of the stock and provide useful information for policy makers.

Keywords: social housing stock; Mediterranean climate; large database; building characterization; statistical analysis.

I. INTRODUCTION

In the European Union (EU), final energy consumption has been exponentially increasing since the 90s, amounted to almost 940 Mtoe in 2019 [1]. According to the 2020 Global Status Report for Buildings and Construction [2], buildings (35%), industry (32%) and transport (28%) were the three dominant energy consumers in 2019 in EU, among which residential buildings represented 22% of the final energy consumed. The mentioned report also highlighted that the building sector was responsible for 38% of the total global energy-related anthropogenic carbon dioxide emissions, 17% of which were caused by residential buildings.

Cooling energy consumption is expected to noticeably increase in southern Europe due to climate change [3]. A recent study from NASA confirms that nineteen of the warmest years have occurred since 2000, with 1998 as the only exception, and establishes a temperature increase of 1.18 ºC in 2020, compared to 1880 [4]. Thus, global warming may result in a 5 to 10 increased probability in the occurrence of more frequent and severe heatwaves [5], leading to indoor overheating issues in buildings. This is particularly important in the Mediterranean region of southern Europe [6], affecting user's health and the quality of indoor environments.

In this context, energy efficiency has been promoted by regulations and international standards as a key objective for mitigating the effects of climate change in buildings, focusing on a rational use of energy and, subsequently, promoting building decarbonisation [7].

A major challenge of southern Europe in terms of sustainable development is that the aging residential building stock was mainly built prior to the implementation of energy performance regulations [8]. Along with a significantly low building renovation rate [9], current residential buildings are expected to become a large extension of the future stock [10]. For all these reasons, energy retrofitting the residential stock becomes a clear objective for meeting the 2030 and 2050 energy targets.

Assessing the current thermal and energy performance of the building stock is a necessary step prior to any retrofit measure [11]. Besides, in the building retrofit process towards climate change, not only geographical and weather data are relevant, but also building typologies [12] and constructive characteristics [13]. Generally, energy performance of buildings has been assessed at two different scales: macro, which considers the building stock, and micro, which individually assesses buildings. Since applying micro techniques to assess the whole building stock is highly time consuming, building stock modelling has been commonly used to assess large-scale building performance. Since this requires the extensive collection of data (constructive, geometrical, physical and operational variables), a viable stock solution is the development of a bottom-up approach through the definition of building archetypes, grouping buildings with similar parameters [14]. Even though building archetypes are generally used in energy modelling at the urban scale [15], they are developed from national survey databases which provide an overview of the whole national building stock. Thus, they may become invalid at the regional and urban levels [16], since several assumptions have to be made.

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Although building stock characterization has been extensively addressed in the literature [17], the case of Spain still requires more extensive research. Monzón-Chavarrías et al. [18] consider a linear block as real case study to analyse multi-family dwellings built in Spain from 1961 to 1980, both prior and after renovation strategies. Nonetheless, to do so these authors consider fixed geometrical, physical and construction characteristics, based on typical solutions of residential buildings. Given that the methodology used is case specific, there is a significant lack of scalability for analysing the stock level. Escandón et al. [19] predict thermal comfort of the housing stock built from 1940 to 1980, through building energy models. In contrast to the previous research, these authors consider a variability range of the main building simulation parameters, generating several building cases representative of the stock. Nonetheless, the analysis is only focused on the linear block typology. Blázquez et al. [20] applied a GIS framework to analyse the residential stock built from 1951 to 1980, at the urban level. Nevertheless, the performance of buildings is individually assessed through an external Energy Certification tool, later transferring the results into the GIS platform, so no building modelling is conducted.

Providing statistical data on the building stock at the regional and urban levels is the basis for developing accurate bottom-up building models for estimating energy performance through building stock modelling. Differently from other works, this research provides a thorough building characterization of the residential building typologies of southern Spain (Andalusia region), analysing a database with exhaustive data (year of construction, building height, number of storeys, average floor area, percentage of glazing surface, etc.) collected of an extensive example of around 39,500 dwellings. Given the typological research gap identified in the literature, efforts are put into analysing one of the most predominant social housing building typologies of southern Spain, the H-block (Figure 1). The objective of this paper is to statistically identify the most representative ranges of building parameters, so future research on this sector may be properly addressed by implementing this information into building performance analysis for building stock modelling, instead of assuming fixed average values. These results would allow generating bottom-up building stock models which will provide useful information to city planners, energy policymakers and key actors in the improvement of sustainable decision-making.

Figure 1. H-typology residential buildings in southern Spain

II. METHODOLOGY

For assessing and characterizing the public social housing stock of southern Spain, the tasks included in Figure 2 were carried out. In task 1, general, typological and morphological data on the social housing stock contained in the public database provided by the Andalusian Agency of House and Retrofitting (AVRA, in Spanish) [21] is compiled and rearranged. The mentioned database includes information on several variables regarding the social housing stock of Andalusia (southern Spain). Specifically, data on cadastral reference, address information, number of dwellings, number of building floors, building height, building typology (single family, multi-family and other), year of construction; year and type of retrofit plan; percentage of glazing surface; type of window frame and glass; cooling and heating annual demand and thermal building systems. This information is obtained from both Execution Projects and Building Evaluation Reports (detailed reports on conservation status, accessibility adaptation and energy efficiency of dwellings). Currently, this database includes information of 39,486 public social dwellings built between 1970-2005.

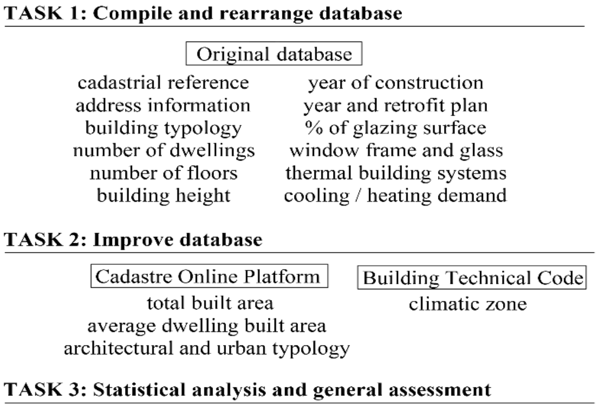


Figure 2. Scheme of the methodology and tasks followed.

In task 2, the original content of AVRA database is expanded through the incorporation of new variables, using public and open access tools. Average floor area per dwelling and building total built surface are collected from the Spanish Electronic Cadastral Platform [22] and included into the database. Likewise, building orientation, architectural typology (linear block, H block, tower block or other) and urban typology (buildings grouped as collective closed blocks, terraced, isolated or irregular) are also collected from the public cadastral online platform and introduced into the database. Finally, the classification of dwellings according to the climatic zone of Andalusia, southern Spain, established by the Spanish Building Technical Code [23] is also incorporated into the analysis. This code classifies the Andalusian territory of southern Spain into several climatic zones by taking into account two indexes (Equations 1 and 2): Climatic Severity in Winter (SCI) and Climatic Severity in Summer (SCV), which depend on the degree-day and solar radiation levels. The SCI is represented by a letter, from A to E, so that “A” defines milder winters and “E” refers to colder winters. SCV is defined by a number, from 1 to 4, so areas identified as “1” have milder summers, while “4” corresponds to warmer summers. In southern Spain, the combination of SCI and SCV defines A3, A4, B3, B4, C3, C4, D2 and D3 climatic zones (Table 1).

$$SCI=a\cdot Ri+b\cdot Gi+c\cdot Ri\cdot Gi+d\cdot Ri^2+e\cdot Gi^2+f \qquad (1)$$

$$SCV=a\cdot Rv+b\cdot Gv+c\cdot Rv\cdot Gv+d\cdot Rv^2+e\cdot Gv^2+f \qquad (2)$$

Where:

Ri: cumulative average global solar radiation in January, February and December [kWh/m^2]
Gi: average of the degree-day in winter in base 20 for January, February and December. Determined on an hourly basis for each month and divided by 24.
Rv: cumulative average global solar radiation in June, July, August and September [kWh/m^2]
Gv: average of the degree-day in summer in base 20 for June, July, August and September. Determined on an hourly basis for each month and divided by 24.
a to f: specific coefficients included in the Code’s appendix.

Table 1. Climatic severity according to the Spanish Technical Building Code.

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	

In task 3, the improved database is statistically analyzed through descriptive techniques, with Microsoft Excel and Matlab, in order to obtain the building parameters' ranges which adequately described the main characteristics of the social housing stock of southern Spain. Even though this study focuses on the characterization of the H-typology, previous results of this stock are available on [24], where data on year of construction, dwellings per block, retrofit year and plan, building systems and energy demand is provided.

III. ANALYSIS AND DISCUSSION

Figure 3 shows the percentage of social dwellings contained in the database, represented per each climatic zone in southern Spain (A3, A4, B3, B4, C3, C4 and others, which represents D2 and D3 zones), classified according to the building typology (single family, multi-family or other, which combines the previous ones). Red dots indicate the percentage of total dwellings per each climatic zone (all three building typologies), which relates to the total number of buildings included on the top of the figure.

It can be seen that 77.5% of the total 39,486 dwellings of the sample correspond to multi-family housing buildings (30,592 dwellings) and are located mainly in B4, A3, B3, C4 and C3 climatic zones. When analyzing single family dwellings, which only represents 16.1% of the total dwellings of the sample, they are located mostly in B4 C3, B3 and C4 zones. Only 6.4% of the sample buildings are categorized as other, which means those buildings include single and multi-family housing dwellings in the same development.

Since multi-family dwellings are predominant in all climatic zones, this building typology has been selected for further analysis. The classification of architectural typologies (H block, linear block, tower block or irregular) is indicated for A3, A4, B4 and C3 climatic zones in Figure 4, where the number of buildings of each architectural typology is also included inside the bars.

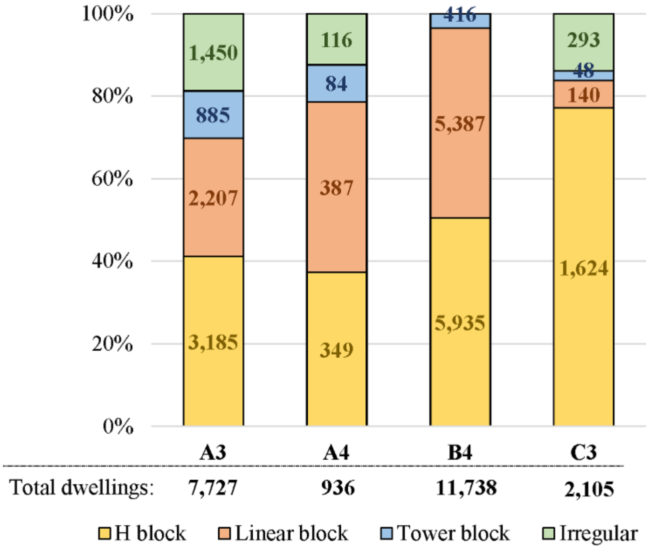


Figure 4. Classification of multi-family dwellings in southern Spain A3, A4, B4 and C3 climatic zones according to the architectural typology. The number of dwellings is also shown.

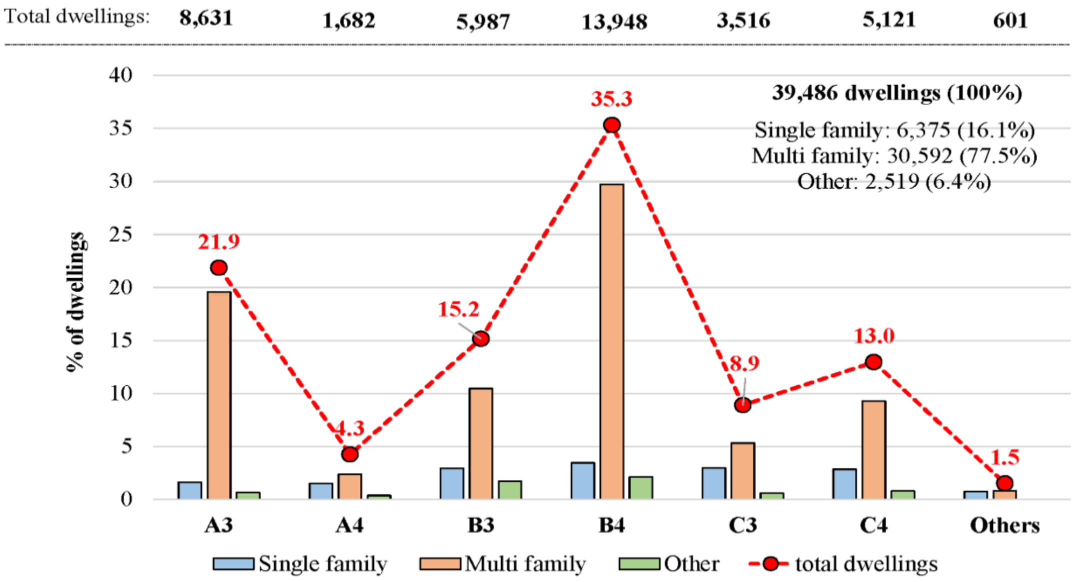


Figure 3. Percentage of single family, multi-family and other dwellings per southern Spain climatic zones. Red values represent the total percentage of dwellings in each climatic zone. Total number of dwellings in shown on the top of the figure.

It can be seen that in almost all four climatic zones, most of the buildings are identified as H block, specifically, 41.2% in A3, 37.3% in A4, 50.6% in B4 and 77.2% in C3. The second rank of typologies correspond to the linear block in A3 and B4 zones (28.6% and 45.9%, respectively). In A4 climatic zone, 41.3% of the total multi-family dwellings are linear blocks, which is only 4.0% higher than the number of H blocks. In C3, the second rank is held by buildings with irregular typologies, corresponding to 14.0% of the total sample. The lowest percentage refers to tower blocks in all zones.

Given the importance of H-blocks in the analyzed social housing stock, as shown in previous figures, and that, as stated in the introduction, most research conducted so far have focused on the linear block, an extensive analysis has been carried out regarding the H-typology. The urban classification of the H-typology multi-family dwellings in A3, A4, B4 and C3 climatic zones has been analyzed, considering the following categories: isolated (single building), terraced (buildings combined with each other leaving an inner courtyard), terraced combined in U-form or as collective closed blocks, terraced (oblique), where buildings are combined forming an oblique line, so there are no inner courtyards, and, finally, irregular typologies, which combine previous ones (Figure 5).

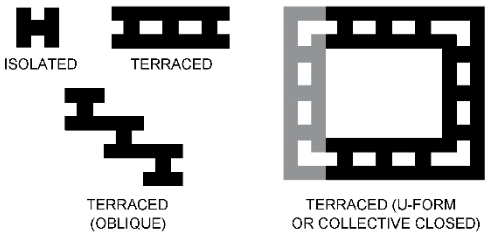


Figure 5. Urban classification considered

Results of these classifications are shown in Figure 6, indicating the total number of dwellings per climatic zone at the bottom of the graphic. All 349 H-blocks in A4 are isolated. In A3 and C3 climatic zones, 85% and 81% of the H blocks are terraced, which represent 2,654 and 1,317 dwellings, respectively. In B4, H blocks are combined in a more diverse way: 44% as terraced oblique (2,606 dwellings), 23% in U-form and collective closed blocks (1,364 dwellings) and 20% as terraced (1,193 dwellings).

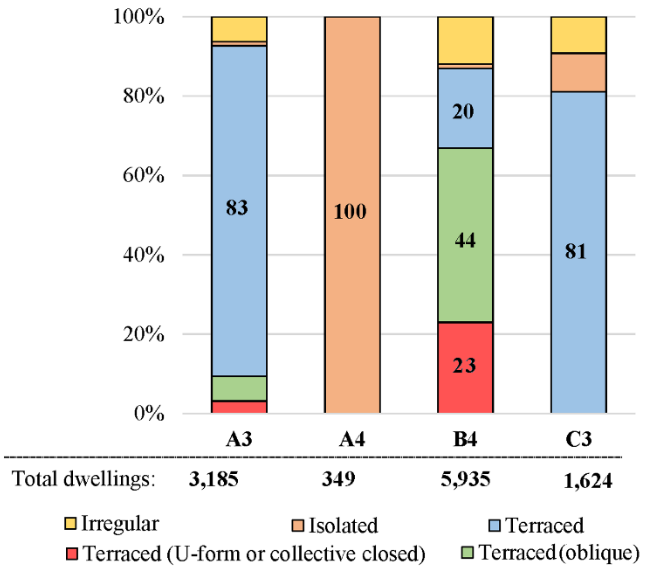
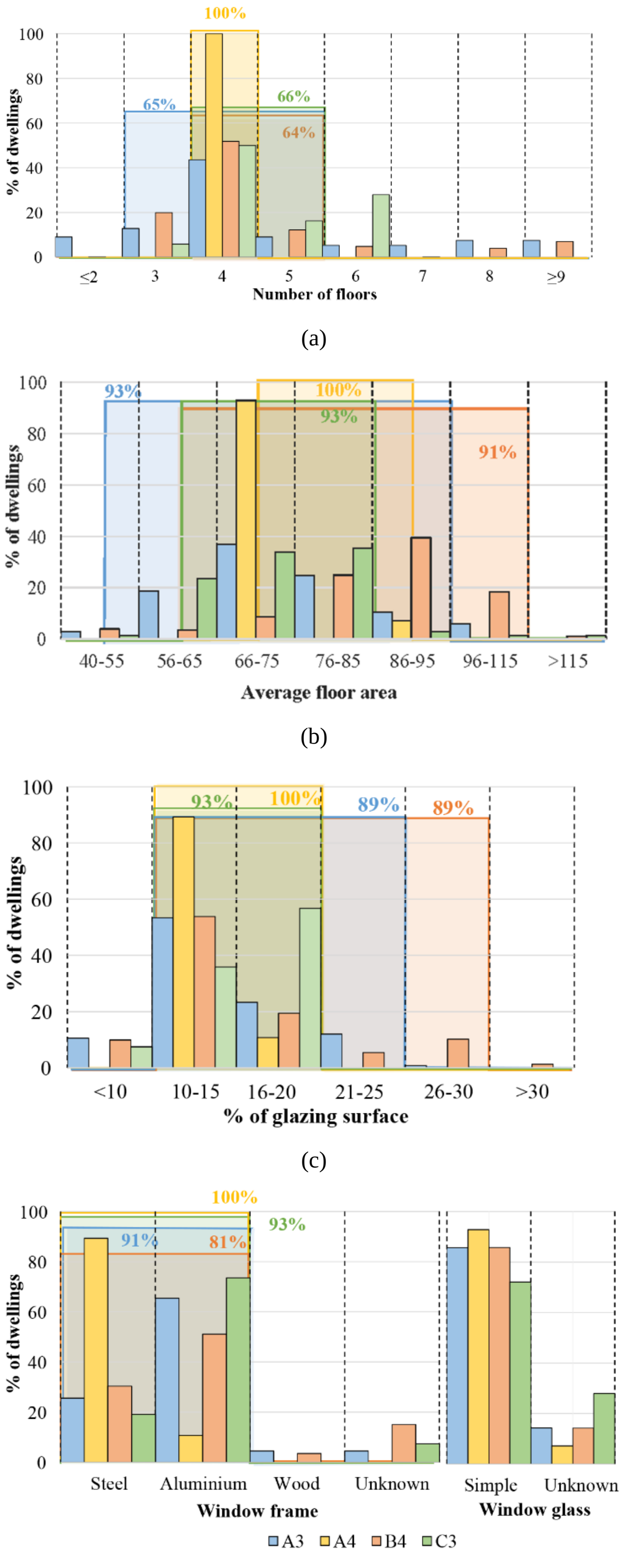


Figure 6. Urban classification of multi-family H-typology dwellings in southern Spain A3, A4, B4 and C3 climatic zones. The number of dwellings is also shown.



(a)

(b)

(c)

(d)

Figure 7. Percentage of H-typology multi-family dwellings classified according to the number of floors of the building, average dwelling floor area, % of glazing surface, window frame and window glass, per each southern Spain A3, A4, B4 and C3 climatic zone. Bold colored numbers indicate the percentage of dwellings represented in the colored ranges.

Building characterization of the H-typology social dwellings of southern Spain is shown in Figure 7, representing several constructive variables per each climatic zone: A3 (blue), A4 (yellow), B4 (orange) and C3 (green).

Firstly, dwellings have been classified according to the number of building floors in Figure 7a, showing the results as percentages of dwellings. In A3, H-blocks have mainly 3 to 5 floors, which refers to 65% of the sampling for this climatic zone. All blocks in A4 climatic zone have 4 floors. Blocks in B4 are mainly 4-storey buildings, but the number of buildings with 3 and 5 floors is also representative. When considered 3 to 5-storey blocks in B4, the percentage of samples analyzed is around 64%. Buildings in C3 are normally 4-storey blocks, but there is also a noticeable percentage of H-typology dwellings with 5 and 6 floors. 66% of the total number of buildings in C3 would be included when 4 to 5-storey blocks are considered. If buildings with 6 floors were also included, it would represent 94% of the dwellings.

The average floor area per dwelling can be seen in Figure 7b. In this case, 93% of the dwellings in A3 climatic zone are between 50 and 95m^2. In A4, 100% of the dwellings are between 70-90m^2. If dwellings between 60-115m^2 were considered, in B4 zone, 91% of the total H-buildings would be represented. Likewise, dwellings with average floor area around 60-85m^2, would represent 93% of the total dwellings in C3 climatic zone. Considering dwellings with floor area equal or less than 55m^2 and over 115m^2 is not representative of the stock since it would only be taken into account 3% of the buildings in A3 climatic zone, 5% in B4 and 2% in C3.

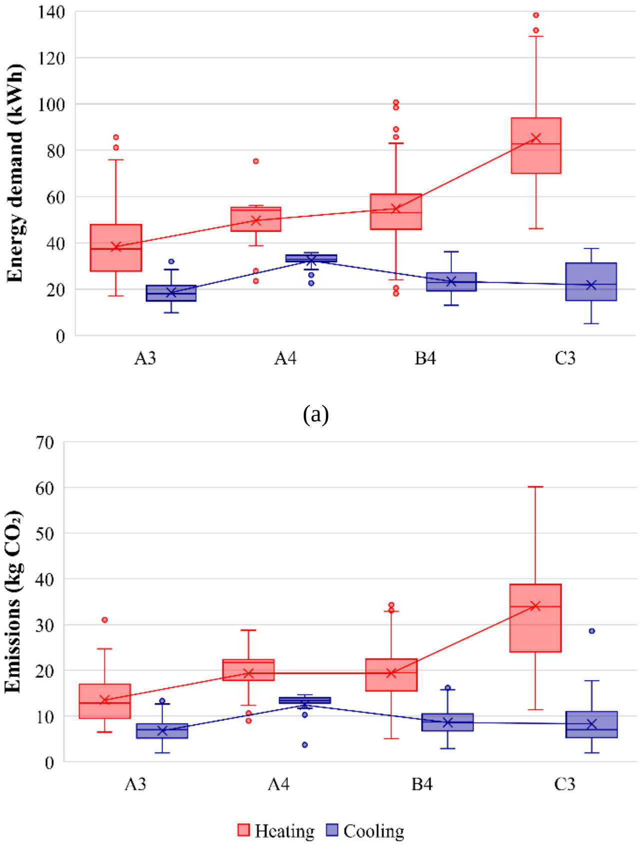
Figure 7c classifies the percentage of H-blocks according to the percentage of glazing surface, per each climatic zone. In A3, A4 and B4, most of the dwellings have a window to wall ratio approximately between 10-15%. While in C3, the percentage of dwellings with a glazing surface between 16-20% is higher. Nonetheless, if a percentage of glazing surface between 10-20% was considered, 93% and 100% of the dwellings would be represented for C3 and A4 climatic zones, respectively. In A3, 89% of the dwellings have a window to wall ratio around 10-25%. The same percentage of dwellings would be analyzed in B4 climatic zone if a glazing surface between 10-30% was considered. If a percentage of glazing surface between 5-10% was considered, that would increase the sampling representativeness by 11% in A3 climatic zone, 9% in B4 and 7% in C3. Considering a window to wall ratio above 20%, would only affect B4 climatic zone, adding 1% of buildings to the sample.

Window frame and glass types are assessed in Figure 7d. In the database, window frame has been divided into four groups: steel, aluminum, wood or unknown. It can be seen that the use of wood frames in the H-typology is quite low when compared to steel and aluminum. In fact, 91% of the dwellings in A3 have frames made of steel and aluminum. Likewise, these materials are represented in 100% of the total dwellings in A4, 81% in B4 and 93% in C3. Thus, considering windows with wood frames would not be representative of the analyzed stock. In parallel, information on the window glass type was classified in the database as simple (single glazing) or unknown, since no double or triple glazing was identified in the stock. Thus, 86% of the buildings in A3 have single glazing surfaces. This occurs in 93% of the cases in A4, 86% of the dwellings in B4 and 72% of the sampling in C3 climatic zone. The percentage of unknown glazing surfaces is higher in C3 climatic zone, when compared to the other zones.

Finally, energy demand and CO_2 emissions of the social H-blocks have been assessed per southern Spain climatic zones (Figure 8). Heating results are indicated in red color, while cooling data is represented in blue. In Figure 8a, it can be seen that in all climatic zones, cooling energy demand is lower than heating demand, which is particularly significant in A4 and C3 zones, where the whiskers of the cooling boxplots are below the ones of the heating boxplots.

Heating energy demand of the H-blocks in A3 and B4 climatic zones ranges between approximately 20-80 kWh, 40-60 kWh in A4 and 45-130 kWh in C3. Heating demand of C3 climatic zone is the highest, which is consistent with the winter climatic severity differences between zones. Cooling energy demand of H-typology dwellings in all climatic zones is generally between 5-40 kWh.

CO_2 emissions in the H-blocks (Figure 8b) follow a similar tendency to the energy demands results. The highest carbon dioxide emissions are related to heating systems, which normally consist of electric heat pumps, and are particularly high in C3 climatic zone. In contrast, lowest CO_2 emissions come from H-blocks in A4 climatic zone, where cooling systems are mainly also electric heat pumps.



(a)

(b)

Figure 8. Heating and cooling energy demand and CO_2 emissions of the multi-family H-typology dwellings in southern Spain A3, A4, B4 and C3 climatic zones.

IV. CONCLUSIONS

Prior to any retrofit intervention, it is necessary to assess the energy and thermal performance state of the existing building stock. In this sense, building characterization at the stock level is key to provide large-scale retrofit measures in order to meet future energy targets. This is especially significant in the social residential sector, since a large proportion of these buildings would become the future stock.

In this paper, the social housing stock of southern Spain (Mediterranean area) has been statistically characterized, analyzing morphological, geometrical and constructive aspects of the stock. A large database containing information of up to 39,486 dwellings have been analyzed. Efforts have been put on obtaining the main building parameter ranges which adequately represent the building stock, focusing on the H-typology buildings, since these dwellings have not been normally included in building characterization studies in the Mediterranean area. The final objective of this research is to provide useful and accurate data on building characterization ranges to be used for future performance analysis through bottom-up stock building modelling, instead of the commonly fixed values approach.

This research has confirmed that 77.5% of the social residential buildings in southern Spain are multi-family buildings, which represent 30,592 dwellings. Among them, the top two building typologies are the H-block (36.3%), with 11,093 dwellings, and the linear block (26.5%), which represents up to 8,121 dwellings. Even though results have been provided for each climatic zone in southern Spain, according to the Spanish Technical Building Code, some general conclusions may be reported. When considering the urban typology of the H-blocks, most of the buildings are isolated and terraced, with a significant number of terraced buildings which are combined forming an oblique line. A high percentage of the H blocks are 3 to 5-storey buildings, with an average floor area between 55-95 m^2. The percentage of the glazing surface of these buildings is normally between 10 and 20%. And a significant number of them have window frames made of steel and aluminum with single glazing windows. Energy heating and cooling demand is around 20-130 kWh and 5-40 kWh, respectively, with higher differences of heating demand according to the climatic severity. Despite of this overall conclusions, as previously stated, this research has also provided parameter ranges of several building variables per each climatic zone for the H-typology dwellings. The percentage of building samples which may be represented in each case according to the variable ranges selected has been also included. This information may be quite useful for the energy performance assessment of the existing stock in the Mediterranean area of southern Spain, providing more accurate results to be used by public stakeholders and energy policy makers in their involvement in decision-making processes.

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