On the assessment of the energy performance and environmental behaviour of social housing stock for the adjustment between simulated and measured data: The case of mild winters in the Mediterranean climate of southern Europe

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A B S T R A C T

Current European energy policies stress the potential of housing stock retrofitting to reduce global energy consumption. In order to implement efficient measures, it is essential to know its real in-use energy behaviour. In southern Europe, social housing represents an important percentage of the residential stock built before the implementation of the first energy regulations. However, there are few studies specifically analysing their energy behaviour. Standardized use and occupancy patterns are not usually suited to Mediterranean social housing, and this mostly results in estimated consumption exceeding real consumption.

This research aims to quantify the thermal comfort and energy consumption of the social housing stock during the characteristically mild winters in a Mediterranean climate, based on the monitoring of representative case studies from southern Spain. The results show that the dwellings analysed are far from conforming to adaptive comfort standard EN-15251 and yet, their limited local heating systems are rarely turned on, reducing the expected energy consumption. In addition, real use and occupancy patterns are defined for the case studies, allowing the development of energy simulation models that are better suited to the real behaviour of this social housing stock.

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1. Introduction

Over the last few decades, European building regulations have been establishing a common framework for the encouragement of energy efficiency [1,2], promoting the retrofitting of housing stock. In the case of southern Europe, residential stock built prior to the first regulations which globally limit the energy demand of buildings (1976–1979) represents between 63 and 76% of the total housing stock [3–5]. Most of these residential buildings do not incorporate any specific measures for thermal insulation in their envelopes, and are therefore obsolete from an energetic point of view.

Social housing represents an important percentage of the residential stock in southern Europe, with specific socioeconomic characteristics that entail particular needs and a use pattern different from the standardized one. Field research on social housing in southern Europe [6–9] shows that these buildings have much lower energy consumption than that estimated by the national energy assessment procedures derived from Directive 2002/91/EEC and its updates [10], based on general premises of intensity and habits of use of buildings and energy, not applicable in the case of social housing. An example of this is that the estimated average heating consumption of Spanish multi-family dwellings (with an average area of 88.7 m²) in the Mediterranean climate is 3673 kWh per year per dwelling [11], while for low income households (declared annual household income below 15,000 €) in southern Europe it is around 1386 kWh per year [6].

There is extensive research analysing the divergence between real consumption and consumption estimated through simulation, either by software recognized by the scientific community or the official software of the different countries [12–15]. This ‘performance gap’ has generally been attributed to user behaviour and, to a lesser extent, to a poor identification of the constructive characteristics of buildings [16,17]. In order to reduce the error rate due to
the poor identification of the constructive characteristics, it would suffice to carry out the relevant tests in the building, such as air permeability and infra-red thermography tests or U-measurements [12,18]. However, the error associated to user pattern definition is much more difficult to identify and reduce.

Many of the studies about occupant behaviour focus on retrofitted dwellings (low-energy) in central and northern Europe (climates with severe winters), where real consumption is frequently much higher than estimated consumption due to the Rebound effect [19,20]. However, in many other cases, the opposite occurs: real consumption is much lower than that estimated, because users spend far less time in the dwellings than the time established by the standardized use patterns of the different countries, known as the Prebound effect [13,20].

In the case of social housing, the divergence between real and estimated consumption is even greater due to an additional variable: when users occupy their dwellings, do they do so in conditions of thermal comfort? The standardized use patterns assume that users live in thermal comfort conditions, but in social housing in southern Europe, although it belongs to a mild winter climate zone, it is usual to forgo comfort and live in fuel poverty conditions [6,7]. In addition, in the specific case of southern Spain, only 5% of multi-family dwellings built before 1979 have a centralized heating system, and 13% have a local heating system [3]. These data demonstrate that this housing stock does not have thermal conditioning means to ensure the maintenance of thermal comfort conditions.

Due to the fuel poverty found in this social housing stock, investments in energy retrofitting (usually focused on improving the insulation of its envelope) [21–23] are often ineffective from an energy saving point of view with excessive payback periods. Although it is very difficult to reduce energy consumption when it is so low, this does not mean that retrofitting is not beneficial, but simply means that instead the final aim ought to be the improvement of thermal comfort conditions in the dwellings, where the profit margin is very high [24].

The main objective of this research is to quantify the real conditions of thermal comfort in the specific context of social housing in southern Europe (mild winter climate), based on the adaptive model established by standard EN-15251 [25] and energy consumption. To this end, a specific methodology based on in-use monitoring has been developed and applied to three case studies representative of the typology, constructive system and climate of southern Spain. Through this monitoring, real use and occupancy patterns are defined in order to develop energy simulation models adjusted to the real behaviour of this housing stock, significantly reducing the ‘performance gap’ between real and estimated consumption. The conclusions obtained are expected to be the potential starting point for a future change in the standardized use and occupation patterns, and the energy retrofitting policies of social housing stock in the Mediterranean climate.

2. Methodology

In this work the methodology used has been developed based on previous research in order to further examine the characterization of the current energy conditions of social housing stock in southern Europe [26]. To do so, a detailed energy and environmental assessment of the dwellings was carried out through monitoring and subsequent energy simulation.

2.1. Monitoring

Different monitoring methodologies have been validated by the scientific community. Two methodologies are distinguished focusing on the measurement of environmental parameters [27]: spot measurements taken only once or long-term measurements taken at specific intervals, from minutes to hours. The type of measurement depends on the type of data required for the investigation.

In general, spot measurements are used when the aim is the evaluation of thermal comfort through surveys and it is necessary to link these with the internal and external environmental conditions of that point in time, or when it is not possible to carry out long-term measurements due to economic or intrusion constraints. Long-term measurements are fundamental when the purpose of the monitoring is to determine the behaviour of the building over a given period of time such as a season or a full year. In addition, these types of measures are necessary to evaluate thermal comfort following an adaptive model, one of the main aims of this research. Thus, this monitoring methodology includes long-term measurements (temperature, relative humidity, CO₂ level, and energy consumption) which are complemented with spot tests (air permeability and infra-red thermography).

2.1.1. Air permeability test and infra-red thermography

Depressurisation tests were carried out in each case study in order to verify the airtightness of the envelope of the dwellings, according to norm UNE-EN-13829 [28]. The Blower Door equipment used in this test was installed in the entrance door of the dwellings and controlled from inside the residential unit.

This information was complemented with the capture of images of dwelling envelopes using a thermographic camera, following norm UNE-EN-13187 [29]. The aim of this test is to search for thermal behaviour patterns of the envelopes in the buildings under study.

2.1.2. In situ ambient measurements

The in situ data collection of environmental variables is essential for the evaluation of the environmental behaviour of the case studies. For this reason, this research has monitored air temperature, relative humidity, and CO₂ levels inside the dwellings. Two WOHLER CDL 210 indoor data-loggers were placed in each dwelling (one in the living room and the other in the main bedroom) to measure the variables every 30 min for a full year.

Data provided by three meteorological stations belonging to the Spanish State Meteorological Agency [30] were used to analyse external environmental variables. The variables of temperature, relative humidity, solar radiation, wind speed and direction, and precipitation were measured every 30 minutes over a year.

In addition to the analysis of environmental variables in winter this research also studies the level of thermal comfort in the dwellings according to the adaptive model established by EN-15251 [25]. This model of adaptive thermal comfort analysis focuses on the interaction between people and buildings (through indoor temperature) and on their expectations (based on outdoor temperature) [31]. In order to obtain the outdoor reference temperature (T Elk), the daily weighted average was calculated according to equation 1. For the calculation of the optimum operating temperature (T.op), equation 2, established in EN-15251, was used. Case studies belong to category III, associated with existing buildings, which means an acceptable band of °C in relation to the calculated T.op.

\[ T_{Elk} = (1 - \alpha) \times T_{ed-1} + \alpha \times T_{Ek-1} \]  

(1)

where:

- \( T_{Elk} \): running mean temperature for today
- \( T_{ed-1} \): daily mean external temperature for previous day;
- \( T_{Ek-1} \): running mean temperature for the previous day;
- \( \alpha \): is a constant between 0 and 1. Recommended to use 0.8.

\[ T_{op} = 0.33 \times T_{Elk} + 18.8 \]  

(2)
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