

SEVILLA



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EMPIRICAL METHOD APPLIED IN RESEARCH ON RESIDENTIAL ENERGY RETROFITTING

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Abstract: European policies currently focus on energy efficiency as one of the main targets to address, regarding energy retrofitting of the existent housing stock as a priority to reduce energy demand in the building sector. In Europe, an important part of the housing stock built after the Second World War and before the first energy regulations, presents a deficient energy performance and a great energy saving potential through its retrofitting with passive solutions.

Several PhD works share the aim to assess the environmental and energy performance of the social housing stock to foresee the most suitable retrofit strategies to carry. Energy simulation tools become essential to predict the energy behaviour of retrofit buildings. However, energy simulation results are not trustworthy without validating the adjustment of energy models to the reality. According to this, monitoring environmental and energy conditions, together with empirical in situ tests in real case study samples, become basic.

The aim of this work is to expose the empirical methodology shared by three on-going PhD thesis about environmental and energy assessment of the social housing stock, concerning climate conditions from the South of Spain. This methodology can be adopted in different scales of approach: from an urban level, to residential ensembles or single dwellings.

Keywords: residential stock, energy assessment, energy retrofitting, monitoring, energy simulation.

1. Introduction

Current European energy policies have established a common frame on energy saving and energy certification (European Parliament 2012), regulating basic conditions to promote and guarantee a sustainable and efficient retrofitting of the building stock. Europe counts on an important residential stock built between 1950 and 1980, previous to the first codes that regulated energy demand in buildings, reaching the 76% of the existing housing units (Di Pilla et al. 2016).

In particular, in southern Europe, an important percentage of the housing stock built during the aforementioned period, mainly social dwellings, present low energy performance, due to the lack of thermal insulation in their envelopes. For this reason, these dwellings present a high potential for their energy performance improvement if suitable retrofit strategies are employed in them. Previous to decision making, a first assessment on environmental and energy performance of the housing stock has to be developed, together with a forecast on the energy performance of retrofitting measures.

Many studies are based on the use of energy simulation tools. However, simulation results are often far to the real energy behaviour of buildings (Sunikka-Blank and Galvin, 2012). This gap amongst results is generally attributed to the user behaviour and, to a lesser extent, to the uncertainty regarding the constructive definition of the building (Guerra-Santin et al. 2013). This is the reason why it is not feasible to consider simulation results as trustworthy without a previous validation of the energy models. This task requires the monitoring of environmental and energy parameters, as well as the fulfilment of punctual tests in the case study dwellings (Cipriano et al. 2015).

The main aim of this work is to describe the empirical methodology shared by three on-going PhD thesis focused on the environmental and energy assessment of the existent housing stock from the south of Spain. The procedure allows for the development of an energy analysis from three different scope levels: urban, residential ensemble and dwelling scale. Furthermore, this work exposes partial results obtained from the application of the methodology in each of the three levels of approach to show its potential for energy analysis.

From the analysis of the original projects, the chosen buildings are morphologically characterized and analysed, overall regarding the main aspects related to the building typology: number of stores, compactness, number of bedrooms, dwelling's usable surface, free height... Moreover, an identification and characterization of the existent constructive systems is developed, analysing the main aspects related to the buildings' thermal envelopes. All this information is incorporated to the previously developed GIS at urban scale, incorporating the building level details and increasing the data for statistical analysis.

Lastly, an energy assessment of the case study buildings is developed by means of energy models generated with the Spanish official tool CE³X. This software, acknowledged by the scientific community, follows a simplified procedure for energy grading of existing buildings and allows to get heating, cooling and global demand. Besides, the obtained information is incorporated once again to the previous GIS database. This leads us to get a global image of the current energy performance of the urban area considered as case study sample.

2.3. Dwelling level

Once again, case study samples will be taken from a characterization and analysis of the residential stock at building level. It will give the key parameters to select the most interesting case study buildings to undergo an analysis at dwelling level. According to this, case study dwellings will be selected amongst those with the most representative morphological and constructive typologies.

Monitoring environmental conditions (air temperature, relative humidity and CO₂ concentrations indoors; air temperature and relative humidity outdoors) and energy parameters (detailed energy consumption) is the first step to carry out the environmental and energy analysis under real use and operational conditions. The scientific community has stated and validated different monitoring methodologies (Guerra-Santin and Tweed 2015), amongst which long-term measures stand out when the final aim is to assess thermal comfort according to an adaptive model.

The designed protocol proposes the use of two indoor data loggers (WOHLER CDL 210 or similar) (Fig. 2), located in the living room and the main bedroom of the flat. Each of them will record environmental data in 30-minute intervals for a year-period. To analyse outdoor environmental parameters, data from the Spanish Meteorological State Agency weather stations is used (temperature, relative humidity, solar radiation, wind speed and direction and rain), once it has been properly validated by punctual local measures.

For the monitoring of energy consumption, a general meter is placed in the electric panel, and several individual meters hang in the different sockets where the domestic appliances are plugged (mainly heating and cooling local equipment) (Fig. 2). Data is registered in kWh in 15-minute intervals, during a year. Besides, historical data from electric bills is collected to complete and contrast the recorded consumption.



Fig. 2 Environmental and energy monitoring equipment

Punctual infrared thermography and air-tightness tests are performed to complement the long-term measures. The depressurization test is carried out with a Blower Door equipment, according to UNE EN 13829 (2013). The test checks the level of air-tightness of the thermal envelope of the case study

dwellings. Moreover, thermographic images are taken with a thermographic camera according to UNE EN 13187 (2013), aiming to analyse the thermal behaviour of the façades.

Once the monitoring campaign is finished, the results are analysed in an hourly basis for the winter, summer and mid-season period. This study is completed with the analysis on the users' thermal comfort in the dwellings, firstly, regarding the minimum requirements stated by the current Spanish regulation (Ministry of Housing 2013) and secondly, according to the adaptive model established by the Standard EN-15251 (CEN 2007).

Finally, the monitoring results will allow to generate energy models whose simulation will give trustworthy results that will be close to the real energy performance of the dwellings.

The first step consists in the construction of the energy models, by means of DesignBuilder software or similar. Energy demand, consumption and evolution of indoor parameters such as temperature and humidity will be obtained. The models will represent completely the dwellings and their contour conditions, including the constructive definition of the thermal envelope and the use and operational schedules. To develop the user pattern, monitoring data will be used (indoor air temperature, CO₂ concentrations and electric consumption) and qualitative information obtained by running a survey amongst the users (occupation habits, ventilation, operation of HVAC systems, use of blinds, etcetera).

The adjustment of the models will be done by analysing the gap between the simulated and the monitored data. In general, the adjustment of energy models is often focused on HVAC energy consumption. However, when the dwelling indoor conditions operate in free-floating, the adjustment will be done regarding indoor air temperature evolution. ASHRAE Guideline 14-2002 (ASHRAE 2002) states the indicators to statistically validate the adjustment of energy models.

3. Case study definition

The aforementioned methodology allows to choose the case study buildings or dwellings that will be later analysed according to the particular conditions of the case study residential stock they belong to. In this work, the application of the methodology hereby presented to the existent housing stock in the Mediterranean climate will be explained.

3.1. Typological and constructive definition

The statistical analysis at building level allows to identify and characterize typologically the case study housing stock, by defining the most representative typological characteristics (Fig. 3) and constructive ones (Fig. 4) from the existent housing stock in a city, in each decade of study.

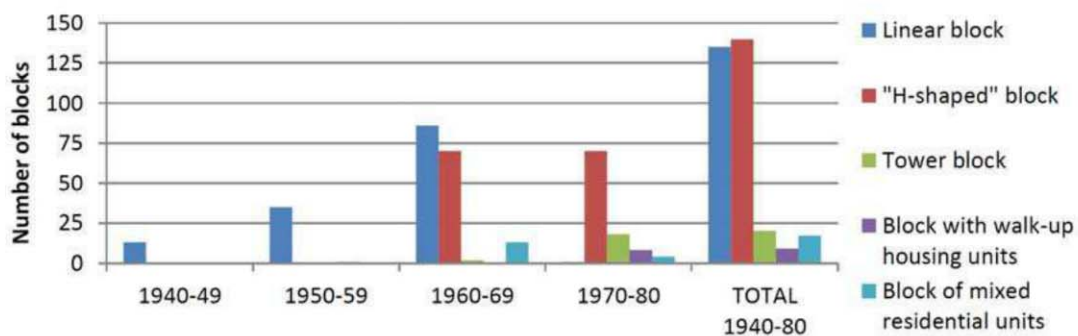


Fig. 3 Evolution of the number of blocks by typology. Application to the city of Cádiz (Martínez-Hervás et al. 2015)

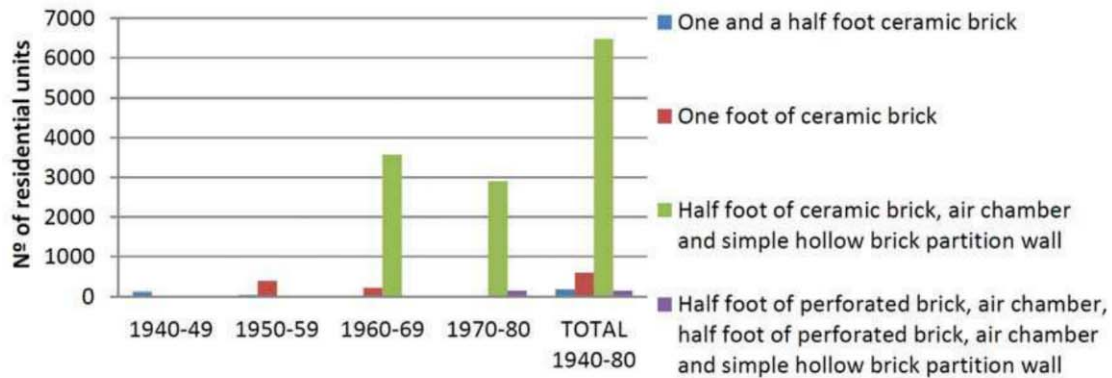


Fig. 4 Evolution of the number of dwellings by façades constructive solution. Application to the city of Cádiz (Martínez-Hervás et al. 2015)

3.2. User pattern

The analysis of monitoring results (indoor air temperature, CO₂ concentrations and electric consumption), together with the information obtained by running a survey, allows to define the particular user pattern of a particular case study dwelling (Fig. 5).

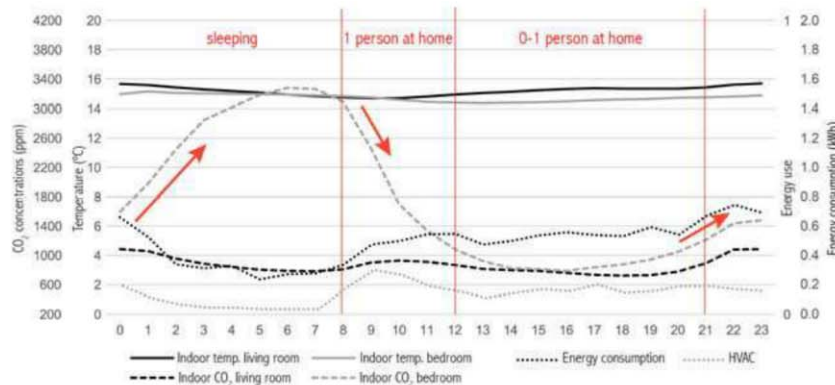


Fig. 5 User patter (winter day). Application to a case study in Seville

The Mediterranean housing stock, that counts on the existence of a high percentage of social dwellings, presents particular cultural and socio-economic conditions that lead to a user pattern that differs from the Building Technical Code established standard (Ministry of Housing 2013).

The energy consumption in the aforementioned social dwellings is lower than expected (Santamouris et al. 2014, Sendra et al. 2013). Users give up getting indoor thermal comfort in their dwellings for economic reasons, arising the so-called “fuel poverty” situations. In general, southern Spanish social dwellings count on local electric devices (such as stoves, splits...) instead of centralized systems for heating or cooling.

Being such a particular user pattern, monitoring and running surveys amongst the users is essential to previously define user habits from the case study dwellings analysed. Without these data, the gap between real and simulated or estimated results become greater (Sunikka-Blank and Galvin 2012).

3.3. Mediterranean climate

Mediterranean climate is generally defined as a mild weather with very hot and dry summers and slightly soft and rainy winters. In Spain, the Mediterranean area is defined by the ensemble of provinces bathed by the Mediterranean Sea and the rest of the Andalusian provinces. However, these climate conditions cannot be generalized to the whole area. The definition of different climate zones by the Building Technical Code demonstrates the existence of an important diversity amongst this territory (Fig. 6).

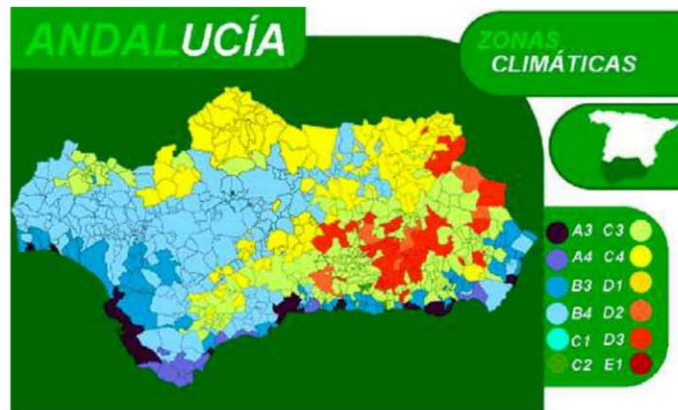


Fig. 6 Climate map of Andalusia (Sánchez de la Flor et al. 2008)

4. Results

Monitoring results, *in situ* tests, surveys to the users and later energy model simulation will allow to the acknowledgement of the current environmental performance and comfort conditions in the housing stock, both in winter as well as in summer. The analysis of the energy behaviour of the residential stock and the detection of the main energy deficiencies, will help to make more adequate decisions and value the energy efficiency of later retrofit strategies.

In this chapter, some results of the three on-going PhD thesis focused on the environmental and energy assessment of the Andalusian housing stock at different scales are shown. This sample allows to understand the potential of the obtained results by applying different empirical methodologies on energy retrofitting research.

4.1. Urban level

The methodology hereby presented has been applied to the city of Cádiz, allowing to generate a GIS database. The GIS platform offers the potential for acquiring general knowledge of the existent residential stock in Mediterranean cities at urban level, both from a typological and constructive point of view, and from an energy angle. It provides a way of presenting, in a very visual way, spatial information together with the available alphanumeric data. In this way, the GIS platform can be very useful for the administrations in charge of sustainable retrofitting planning strategies at urban scale, as it offers a global image of the current energy state of the case study cities (Fig. 7).



Fig. 7 GIS platform. Energy assessment at urban scale

4.2. Building level

The statistical analysis of morphological and constructive characteristics of the case study samples shows the most representative typologies of the considered period. Concretely, in the Mediterranean climate, the most representative typologies are the linear block and the H-block (Fig. 3). Regarding the constructive characteristics of the thermal envelope, the double-layer brick wall prevails (half foot of solid or perforated brick, air chamber and a hollow brick partition) (Fig. 4) (Martínez-Hervás et al. 2015, Domínguez et al. 2016).

The analysis of the estimated energy demand and consumption of the case study samples allows to compare these values with the requirements stated by the current Spanish regulation: The Building Technical Code (Ministry of Housing 2013). This code presents reference values to properly assess the potential for improvement of the residential stock. The energy behavior of the dwellings is often far from the current regulation requirements due to the weak and deficient performance of their thermal envelope (Fig. 8). However, although summer conditions in the south of Spain are known for being very severe, cooling demand values are very close to the limit values required by the Building Technical Code, while heating demand values are five times higher than those stated by the Code (case 5).

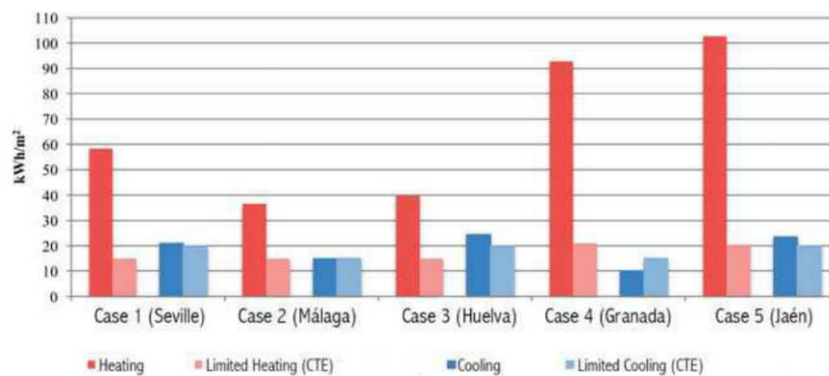


Fig. 8 Example of estimated heating and cooling demands (Escandón et al. 2016)

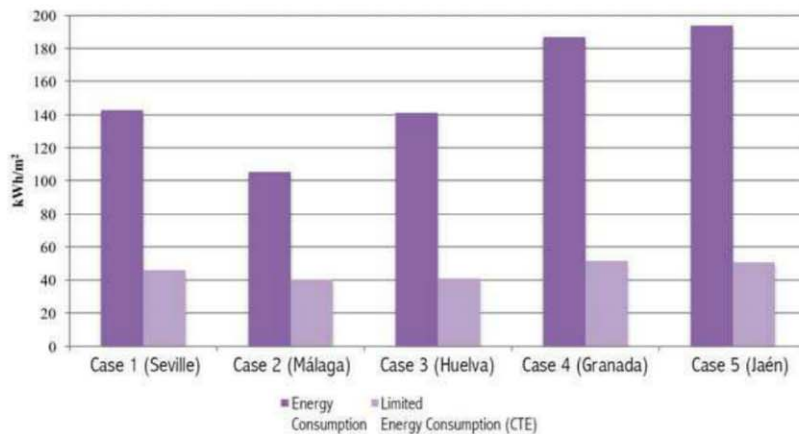


Fig. 9 Estimated energy consumption (Escandón et al. 2016)

Table 1 Energy gradation and CO₂ emissions (Escandón et al. 2016)

	Case 1 (Seville)	Case 2 (Málaga)	Case 3 (Huelva)	Case 4 (Granada)	Case 5 (Jaén)
Climate zone	B4	A3	A4	C3	C4
Energy gradation	E	E	E	E	E
CO ₂ emissions (kg CO ₂ / m ²)	29.4	21.7	28.9	39.1	40.1

The high energy demands, together with the lack of efficient thermal systems, lead to an estimation of the energy consumption that notably exceeds the Code limit values (Fig. 9). Nevertheless, these values are far from real in the southern Spanish social dwelling, due to the fact that the officially acknowledged simulation tools in Spain make use of standard user profiles previously fixed by the Code. Hence, in order to get a more certain analysis of the building energy behaviour, a simulation software that allows to adjust the user profile should be used. In parallel to the energy demand values,

the building energy gradation result amongst the lower bands in the scale established by the Code (Ministry of Housing 2013) (Table 1).

4.3. Dwelling level

In general, monitoring results in the case study dwellings from the south of Spain show that the evolution of indoor environmental parameters looks similar almost in every case: air temperature, relative humidity, CO₂ concentration, thermal comfort and electric consumption.

During winter, indoor temperatures are most of the time out of the comfort band limits (Fig. 10), both by the current Spanish regulation (Ministry of Housing 2013) as well as by the adaptive model stated by regulation EN 15251 (CEN 2007) (Fig. 11, Table 2).

In summer, the sharp oscillations and high values reached by the outdoor temperature are reflected in the indoor temperature values, both in the bedroom and living room. Indoor conditions are significantly far from comfort according to the current Spanish regulation. Due to the summer severity in the Andalusian region, the adaptive comfort model proposed by regulation EN 15251 would not be applicable. An adequate adjustment of the mentioned model to the climate severity in the south of Spain becomes essential.

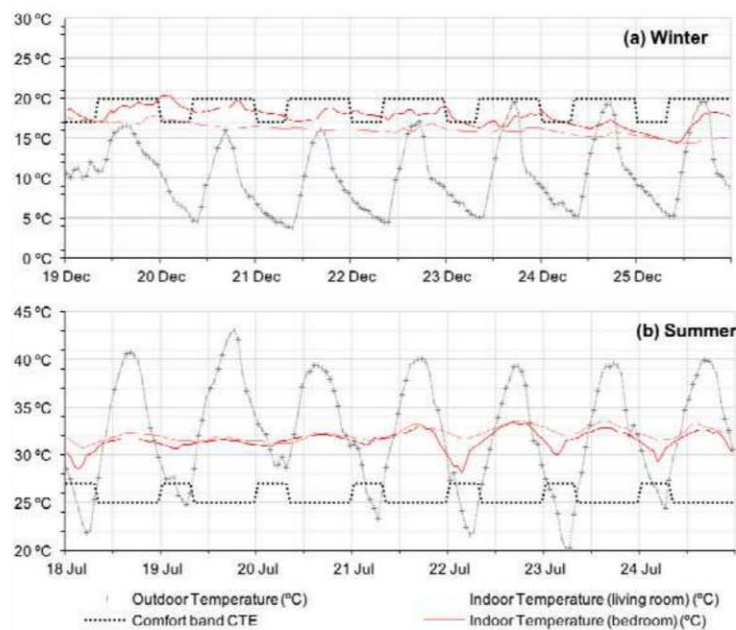


Fig. 10 Evolution of indoor and outdoor air temperatures in a case study dwelling from the B4 climate zone (Córdoba)

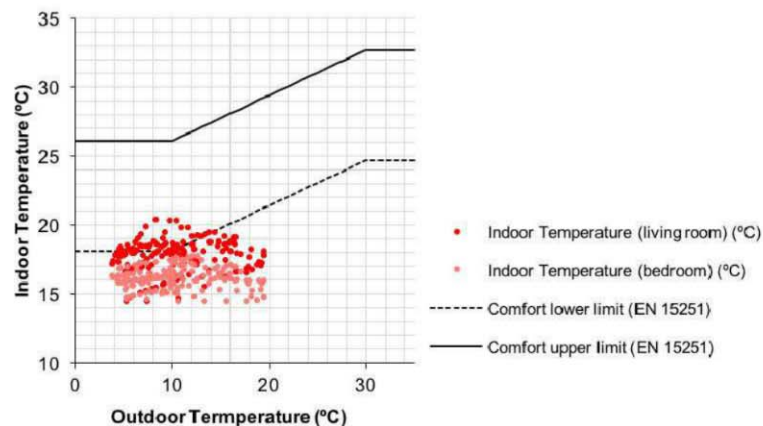


Fig. 11 Comfort range according to regulation EN 15251 (CEN 2007). Indoor thermal comfort assessment during a week in winter in a dwelling under B4 climate zone (Córdoba)

Table 2 Comfort level analysis according to regulation EN 15251 (CEN 2007) during a week in winter in a dwelling under B4 climate zone (Córdoba).

	December 19 th 2016 – December 25 th 2016			
	% occupied hours	% discomfort hours	Standard deviation	% use of heating
Living room	58,93 %	80,95 %	-0,83 %	86 %
Bedroom	36,90 %	100 %	-2,40 %	0 (Not existent)

5. Conclusions

In Europe, an important percentage of the residential stock need to be updated to solve its important deficiencies and lack of comfort. Previous to retrofitting, an environmental and energy analysis of the existing residential stock is needed. To this end, a specific methodology based on monitoring and empirical tests that allow to validate energy simulation tools and predict energy efficiency of retrofitting strategies is essential. This methodology can be applied to different scales of approach: urban, residential ensemble or dwelling.

The use of Geographic Information Systems (GIS) offers the possibility to get a database to define the social housing stock (constructive definition, energy gradation and potential for improvement). This leads to get a global glance of the housing stock composition, and to face the general situation with standard solutions that may be applicable to an important number of cases with a similar casuistic. Moreover, a territorial study of the residential stock depicts the serious deficiencies in the analysed dwellings, with a low energy gradation, mainly ranging between E and G. This tool is very useful to establish the target to address with territorial retrofit plans by future energy policies.

Despite the weather softness of the Mediterranean area, the low energy performance of thermal envelopes in building leads to the lack of comfort inside the dwellings. The sporadic and intermittent use of inefficient local heating devices during winter does not allow to keep indoor conditions between comfort limits. Simultaneously, in summer, high temperatures during the day overheat indoor spaces in the flats, resulting essential the use of natural ventilation during night hours, to heat releasing.

Thermal comfort assessment is done according to a steady-state model set by the current Spanish regulation. However, these models are often very restrictive and do not take into account the users' adaptation to indoor conditions. For this reason, adaptive comfort models become an efficient tool to get a better comfort approach. Research on the adjustment of adaptive models to warm weather conditions is needed to overcome their limitation under very severe summer conditions.

Collected data during the monitoring campaign will be the starting point to obtain adjusted energy models whose simulation results could get close to the real energy performance of the buildings, by reducing in this way uncertainties regarding the user intervention and the constructive definition.

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