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Defining occupancy patterns through monitoring existing buildings

Definiendo patrones de ocupación mediante la monitorización de edificios existentes

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ABSTRACT

Simulation programs are used to calculate the energy performance of buildings. However, numerous studies have shown a gap between calculated and actual thermal performance of buildings. One of the factors that have been identified as a source of uncertainty in building simulations is the occupancy of the building and occupants' behaviour. These parameters are usually defined based on standards or assumed conditions. Thus, this research focuses on the occupants' presence and behaviour in residential buildings. This paper presents an investigation on energy demand via dynamic building simulations and monitoring campaigns. The values obtained from the monitoring campaign were used as input data into the thermal simulation program and a comparison between normative and actual occupancy patterns was performed based on an occupied dwelling in Madrid, Spain.

Keywords: Energy performance, Occupancy patterns, Occupants' behaviour, Occupancy monitoring, Post-occupancy evaluation.

RESUMEN

Para determinar el comportamiento energético de los edificios los programas de simulación dinámica son utilizados como métodos de cálculo. Sin embargo, numerosos estudios han mostrado que existen diferencias notables entre el comportamiento esperado y real de los edificios. Uno de los factores identificados como fuente de incertidumbre en la simulación de edificios es la ocupación y el comportamiento de los usuarios. Estos parámetros son definidos habitualmente con estándares que no reflejan la realidad de los ocupantes. En este artículo, se presenta una investigación sobre la influencia del comportamiento y la presencia de los usuarios de edificios residenciales en la demanda de energía. Para ello se generan modelos de simulación energética cuyos valores de entrada están ajustados con datos monitorizados de edificios reales. El estudio se realiza en dos casos de estudio ubicados en Madrid, España.

Palabras clave: *Comportamiento energético, patrones de ocupación, comportamiento de usuarios, monitorización de ocupación, evaluación post-ocupacional.*

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1. INTRODUCTION

Dynamic simulation tools for thermal performance are used as a method to predict the energy performance of buildings. These tools are employed by designers during the design phase of both new buildings and for renovation projects to evaluate and select the most energy-efficient solutions for the building envelop and HVAC systems. However, a number of studies [1-3] have shown that there are significant differences between the expected and actual performance of buildings. The so-called performance gap decreases the potential of such simulation tools and increases the uncertainty on the results from building simulations regarding energy consumption.

There are a number of factors that influence energy performance in buildings. The International Energy Agency (IEA), in Annex 53 [4], has grouped these factors into six categories that have the most influence on energy consumption: 1) weather, 2) building envelope, 3) HVAC systems, 4) maintenance and operation of systems, 5) occupants' behaviour, and 6) indoor environmental quality. The first three categories are related to variables influencing the energy performance of the building without considering occupancy, and are usually determined using standard parameters in the other three categories, which are related the operation of the building [5]. Therefore, the performance of the building is calculated assuming that all buildings are operated under the same conditions. Taking into account standard parameters, the stochastic nature of occupants' behaviour and its influence on energy consumption are neglected.

Occupants' behaviour influences energy consumption in diverse ways. On the one hand, the presence of people, the use of artificial lightning and the use of appliances and electronics contribute to the internal heat gains of the building. On the other hand, occupants' operation of heating, air conditioning and ventilation systems, have an effect on the internal conditions of the building. The effect of occupants' behaviour on building simulation has been mostly studied in non-residential building [6-8]. However, there is an urgent need to investigate the effect of occupants' behaviour on simulations in residential buildings, given the raising demand for more sustainable buildings [9,10] and given the greater impact that occupants have on low and zero energy buildings [10].

In building simulation, the complex and stochastic behaviour of buildings' occupants is simplified in patterns defined by norms and standards, which do not reflect the singularities of behaviour in residential buildings, are used as input, providing results that do not correspond to reality [11]. In addition, a number of studies have also shown that socio-economic factors such as age, household size and employment situation also have an effect on energy consumption, as well as on the attitudes of users with respect to energy savings [12-17].

The International Energy Agency created Annex 66 in 2013 with the objective of studying occupants' behaviour in building simulations. The Group created a platform, in which 15 countries participate, aiming at defining users' behaviour in buildings, and at establishing a methodology for simulation that allows modelling the influence of behaviour on energy consumption and indoor environment [18].

The objective of this paper is to present a three steps approach to generate occupancy profiles based on monitored data to determine the effect of user related parameters on heating demand in residential buildings. As a first step, occupancy profiles are developed based on measured data to be used as input in building simulation programmes to predict more accurately the energy performance of the building. As a second step, the generated occupancy profiles are compared with profiles defined in the Spanish Building Code (Código Técnico de la Edificación de España). As a last step, the effect of the different occupancy profiles and density on the heating demand is investigated. This approach is applied to two case studies in multi-family residential buildings in Madrid.

2. DATA AND METHODOLOGY

2.1. Methodology

The methodology consists of four steps (Figure 1). First, we determined the characteristics of the selected buildings based on measured parameters, building regulations and commonly employed Spanish databases. A monitoring campaign was carried out to obtain the actual building parameters of both dwellings, regarding the building envelope (thermal transmission and infiltration), energy consumption (total and for individual electrical equipment), subjective thermal comfort (occupants' thermal votes), objective thermal comfort (temperature, relative humidity and CO_2 level) and heating and ventilation occupancy practices.

As a second step, we developed the energy model of only one of the buildings, since our objective is to investigate the effect of different occupancy profiles. The software used for the building simulations is Design builder, which uses Energy+ for the calculations [19]. The monitored data was used as input data in the basic model. Four sub-models (M1, M2, M3 and M4) were developed based on the basic model, in which

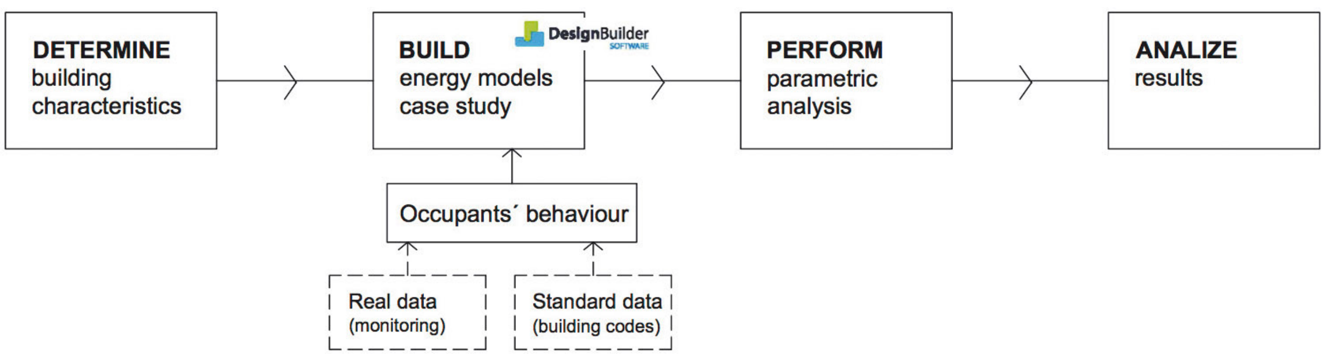

Figure 1. Methodology.

different occupancy profiles and household size were determined based on the monitored case studies, and based on building regulations.

The third step was to carry out a parametric analysis to determine the impact of the different occupancy profiles on energy demand.

Finally, the results of the simulation were obtained, analyzed and the conclusions drawn.

2.2. Case study

Two apartments were selected in the neighbourhood Ciudad de Los Angeles in South Madrid. The buildings, built in 1972, belong to the typical construction carried out between 1950 and 1980 in Spain [20]. The apartments are located in different buildings within a complex of eight apartment blocks with the same construction type. Seven of the eight buildings have been renovated (Figure 2).

One apartment in one of the renovated buildings, and one apartment in the not renovated building were selected to compare their energy performance and to evaluate the effectiveness of the renovation strategy applied. Monitoring equipment was installed in both the renovated (CP17) and the not renovated (CP18) apartments.

The apartments were specifically selected with similar building's characteristics in order to compare and evaluate the effect of different occupancy patterns, without other confounding variables. Both apartments have the same general characteristics, such as construction process, orientation, layout both within the apartment and within the building. In addition, the apartments have the same number and typology of occupants.

The apartments have a useful living area of 63 m2 (Table 1), North-South orientation and are located in a middle level within the building. In the renovated building, the original masonry facade has been retrofitted with a system consisting on a four centimetres layer of expanded polystyrene (SATE system). In addition, the single layer glazing (3 mm) and aluminium frames have been updated by adding an external window with aluminium frame and Climalit 4/6/4 glazing without solar treatment. Both dwellings have central heating with a gas boiler and radiators in all rooms. Table 1 shows the main characteristics of the buildings and the users.

The dwellings were also selected based on the characteristics of the users. Previous work has shown that demography, lifestyle and comfort preferences affect the energy performance of buildings [21]. Apartments with similar occupants' profiles were selected to determine the influence of other occupancy variables. However, these is out of the scope if this paper.

2.3. Data collection: building characteristics and users' behaviour

The monitoring campaign consisted on three types of data collection: 1) measurements on the building envelope; 2) actual electricity consumption; and 3) occupants' behaviour (interviews and questionnaires). The measurements on the building envelope were used to define the building physical parameters, while the actual electric energy consumption and occupants' behaviour were used to define the occupancy patterns.

<u>Building envelope data</u>

Defects on the building envelope can also have a great impact on the energy efficiency of buildings [14,22,23]. Thus, heat transfer and air tightness of the facades were selected as key parameters for this investigation.

Heat transfer was measured with a multi-function device TESTO 435-2, which calculate the heat transfer according to the DIN EN ISO 6946 norm. Heat transfer was measured for 24 hours in January 2015. The measured value for the renovated building was 0.61 W/m^{2}K, similar to the calculated value 0.66 W/m^{2}K.

The air tightness was measured with a blow-door tests for several hours, in March 2015. The measurement was performed on 50 Pa. The results showed a mean value of 0.04 ren/h 1 Pascal for the renovated building. The rest of the parameters for the building simulation were input according to current norms and recognised Spanish databases.

Figure 2. Building case studies and floor plan.

Table 1. Household and building characteristics.

	Refurbished Building (CP17)	Unrefurbished Building (CP18)
Household size	1	1
Age/gender	Elderly woman	Elderly woman
Occupation	Employed part-time	Retired
Type tenure	Owner	Owner
Surface area	$63m^2$	$63m^2$
Construction area	1972	1972
Last renovation	2009/03/24-2011/03/03	Without renovation
Refurbishment features	Double glazing, floor and façade insulation, balcony enclosure	–

Electricity data

Energy consumption was measured to obtain information regarding occupancy practices and occupants' behaviour. A wireless energy meter was installed to monitor the total electricity consumption of each dwelling, and the energy consumption of a selected number of appliances. Energy data was collected from July 2014 to July 2015. In this article, the electricity consumption was used to determine the presence or absence of the occupants at home.

Occupants' behaviour data

Data on the occupants' lifestyle and daily activities were obtained from a number of interviews with the residents. The qualitative data was integrated (triangulated) to the qualitative data on electric energy consumption to determine the daily presence of the occupants, and to define the occupancy profiles for each of the occupants. Interviews were carried out with the residents at the end of each (monitoring) season. The interviews consisted in semi-open questions regarding thermal comfort, attitudes towards the environment and energy saving. During the interviews, the residents self-reported on their habits at home, such as on the use of the heating system, ventilation, cooking, presence at home and use of spaces, and measures to maintain thermal comfort. In addition, an inventory of the daily activities of the users was carried out. More detailed information on data collection and analysis can be found in [21].

The effect of the actual occupancy density on heating demand has been also investigated. Occupancy profiles have been more widely studied in office buildings [24,25], since this factor has a large effect on the energy efficiency of non-residential buildings. In the case studies, the density has been calculated based on the useful living area, and the number of inhabitants. The density in both dwellings is 0.02 per/m². However, if the mean National household size, according to the National Statistics Institute, is taken into account [26], the density would be 0.04 per/m². Thus, the simulations are performed with both values to determine the effect that the different values has on the simulated energy demand.

2.4. Development of occupancy profiles and occupancy density

There are two main approaches to study the relationship between occupants' behaviour and energy efficiency of buildings. The first approach consists on the application of questionnaire surveys and interviews to the residents of the dwellings, and it is therefore of a qualitative nature. The second approach consists on on-site monitoring campaigns and it is quantitative and more objective in nature [27]. In this study a mix-methods approach has been used to determine the occupancy profiles of the case studies.

Each occupancy profile was generated based on the qualitative analysis of the electricity measured in the flat (quantitative data), and the interviews with the residents (qualitative data). Two profiles were developed per dwelling: a 24 hours profile summarising the weekly occupancy, and a 48 hours profile showing the occupancy during the weekends. A study in the United Kingdom shown no difference on occupancy between weekdays and weekends [13], however, in these case studies, large differences were seen during the weekends. For both profiles, the occupancy per hour has been defined according to the mean occupancy per hour for the monitoring period during weekdays, and during weekends.

Figure 3 shows the occupants' presence at home on a typical weekly day for dwellings CP17 (top) and CP18 (bottom). The figures to the left show the total electrical consumption in the dwellings, codified into 0 = no consumption at all, and 1 = some consumption (the electricity use of the refrigerator is not included in this figure). For this research these values are translated into absent from home (no electricity consumption) and present at home (some electricity consumption). The figures show, per hour, the average presence at home on a typical week day (average from Monday to Friday for the whole monitoring period).

The figures to the right, show the occupancy profiles resulting from the triangulation of the electricity consumption data (figures to the right) with the interviews carried out with the residents. In addition, the following criteria was used:

After 22:00 hours the electric energy consumption decreases drastically, suggesting that the residents have gone to sleep.

After 9:00 hours, the electricity consumption increases, indicating that the residents start with their daily routines.

These criteria have been corroborated with the information provided by the interviews carried out with the residents.

Figure 4 and Figure 5 show the same profiles as described before, for the weekends.

2.5. Occupancy profile based on CTE (Código Técnico de Edificación)

Figure 6 shows the occupancy profile defined based on the Spanish normative (Documento Básico de Ahorro de Energía del Código Técnico de Edificación Español [28]). The objective of this profile is to compare it with the data obtained from the

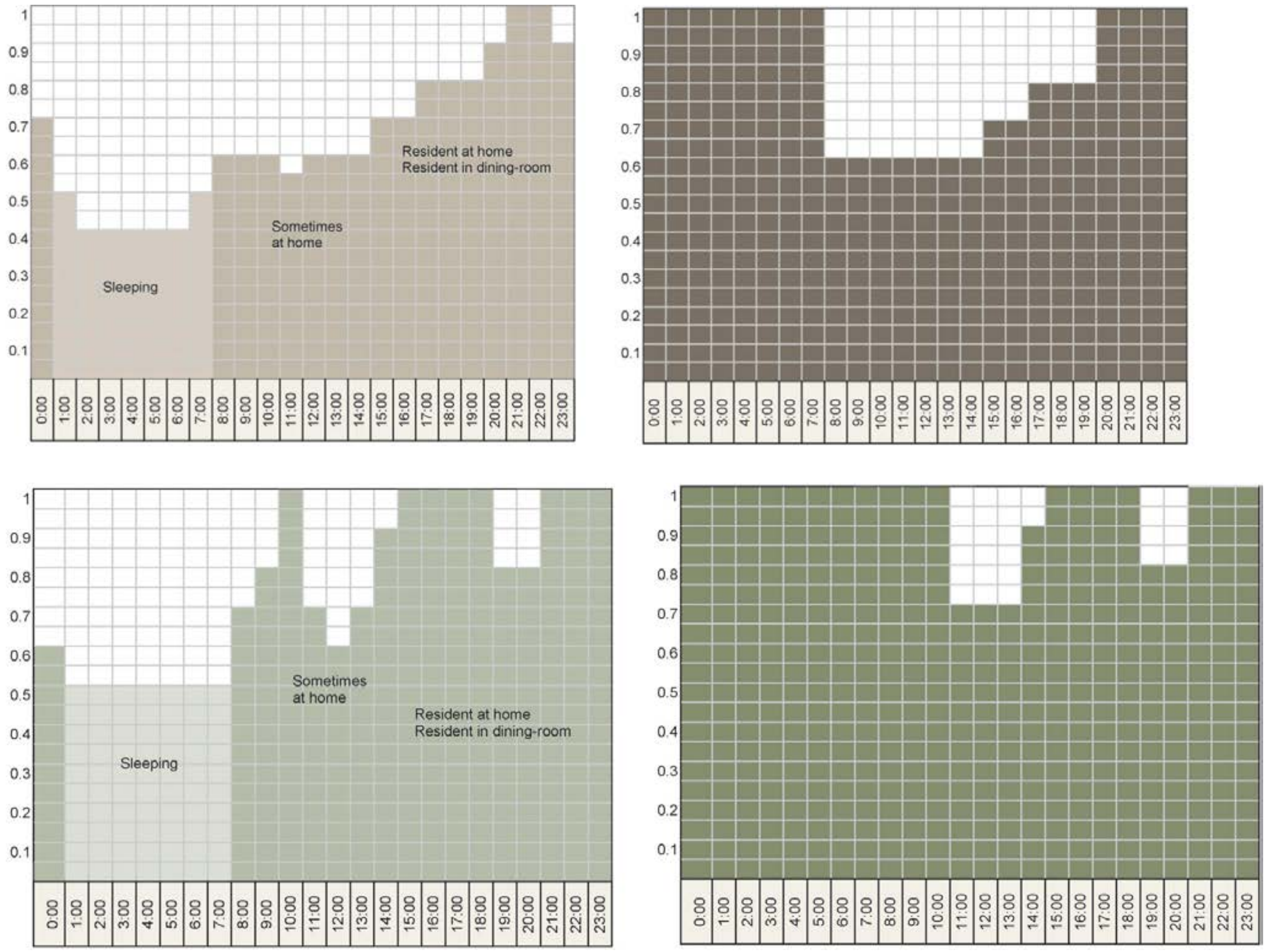

Figure 3. CP17 (above) and CP18 (below). Weekdays. Occupants´ presence: electric energy consumption and interviews (left). Occupancy profile (right)

case studies. The normative defines occupancy profiles based on the type of building, occupation density (low, medium and high) and occupancy period (8, 12, 16 and 24 hours). Only one profile has been defined for residential buildings, while 12 profiles have been defined for non-residential buildings.

2.6. Simulation

To investigate the effect of the different occupancy profiles and household composition (density) on the heating demand, the simulations were carried out only based on the characteristics measured in the renovated building (CP17). The remaining data entered in the model have been obtained from the current regulations and recognized Spanish databases.

Building simulations were carried out variating the occupancy profile and the occupancy density. In this way, the number of variables was limited only to those affected by occupancy.

Figure 7 show the framework in which the submodels are based, indicating the factors investigated per generated submodels.

3. RESULTS

In this section, we present the results of the simulations and their analysis. In Section 3.1, we show the comparison between the occupancy profiles determined with actual monitoring data and the profiles obtained from the Spanish building code. In Section 3.2, the simulated heating demand of each submodel is analysed.

3.1. Occupancy profiles comparison

Figure 8 shows the comparison between the occupancy profiles developed with the monitoring data in the dwellings CP17 and CP18, with the profile obtained from the Spanish Building Code. The profiles from the monitoring case studies show similarities. Both households consists of single elderly women with similar daily routines. The difference between the households is observed during the morning (between 8:00 and 14:00 hours), in which the resident of CP17 works part-time according to the interviews. The resident of CP18 also leaves the house in the morning, but for a shorter period (11:00-13:00 hours).

In comparison, the profile obtained from the Spanish Building Code (CTE) represents a household consisting of a nuclear family. In the profile, this type of household is absent from 8:00 to 15:00 hours; during the afternoon, only a few households' members are back; and during the night, everybody is back home.

Figure 8 also shows the comparison of profiles for weekend days. On the one hand, according to CTE, residential build-

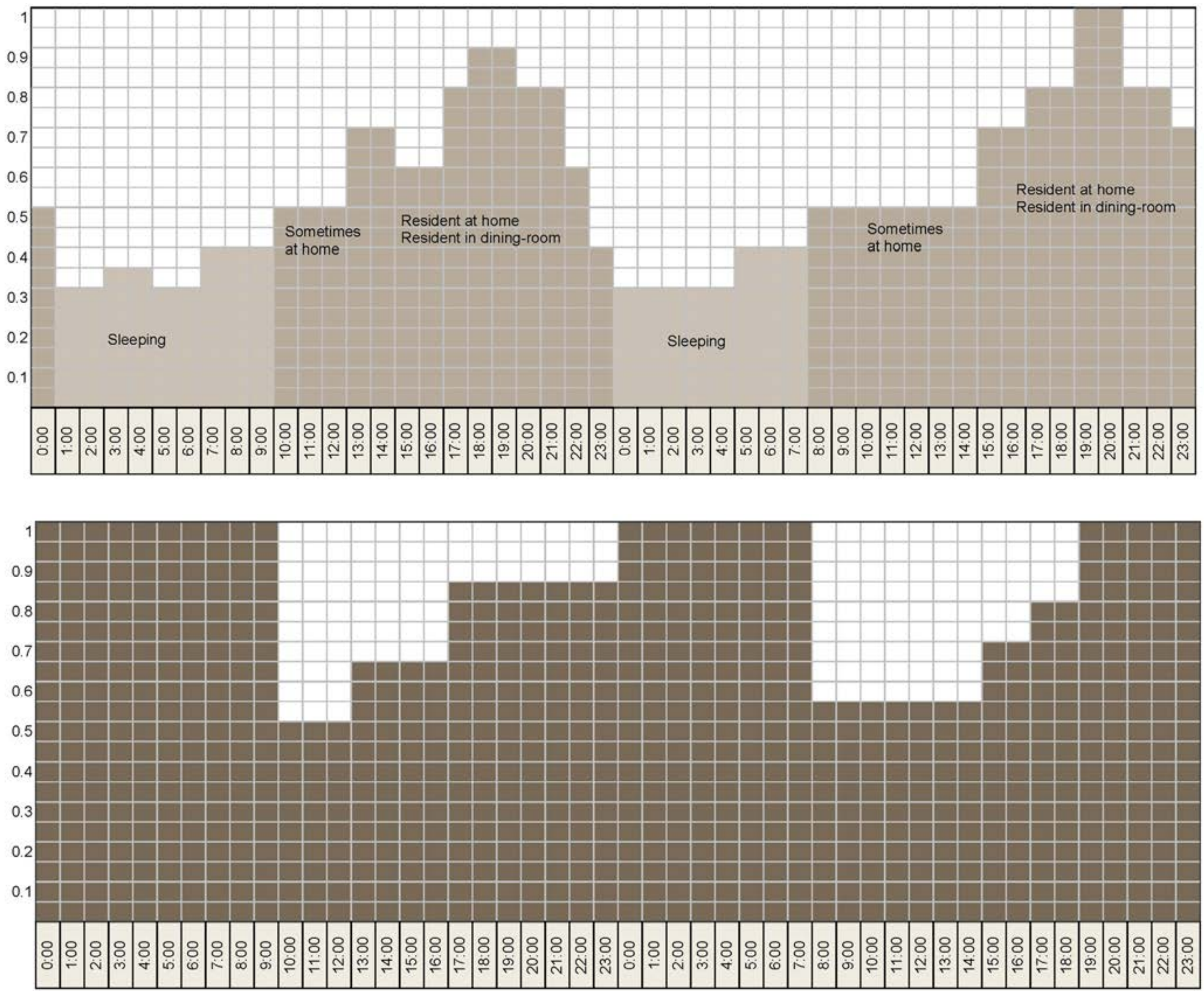

Figure 4. CP17. Weekend. Occupants' presence: electric energy consumption and interviews (above). Occupancy profile (below).

ings have a full occupancy during the whole weekends. On the other hand, the case studies shown very different profiles. The resident of CP17 keeps a similar profile to that followed on weekdays; while the resident of CP18 is usually absent during the weekends and until Monday mornings.

3.2. Heating demand

Table 2 shows the heating demand resulting from each of the simulation models (in kWh/year), the internal heat gains caused by occupancy (in kWh/year), and the relation between the heating demand and the occupancy-related heat gains.

The yearly heating demand range for the simulated dwelling is between 44.7 and 53.7 kWh/m2. The yearly heating period is considered from October 1 to March 31. The highest heating demand is seen in the simulation ran without occupants, which is used as a basis for the comparisons.

In the simulations carried out with the case studies profiles (CP17 and CP18), we see a difference of 1.2 kWh/year on the occupancy heat gains, since the resident of dwelling CP18 is absent on the weekends (22.6 % of the time). The results also show that the difference between the heat gains in the CP18 profile in comparison to the heat gains in the CTE low-density profile, is only 2.1 %. This difference corresponds to the difference on occupancy profiles (i.e. time when the occupants are home). The heat gains in the CTE high-density profile are twice as high as in the other profiles, increasing the importance of the occupancy in the heating demand.

4. DISCUSSION

Building simulations used to determine the thermal performance of buildings are growing in accuracy, however, occupants-related parameters are still simplistic, since they try to unify behaviour and singularities into one single occupancy pattern, independent from socio-economical specificities, or the actual use of the buildings. These assumptions produce often miscalculations in the heating demand calculated in building simulations. Therefore, the use of actual occupancy profiles is a priority to evaluate the actual energy performance of buildings. To accomplish this, it is needed to follow an experimental approach that allows to obtain actual data from building's occupants.

In this investigation, we have confirmed that monitoring occupants' behaviour in buildings, as well as the measurement

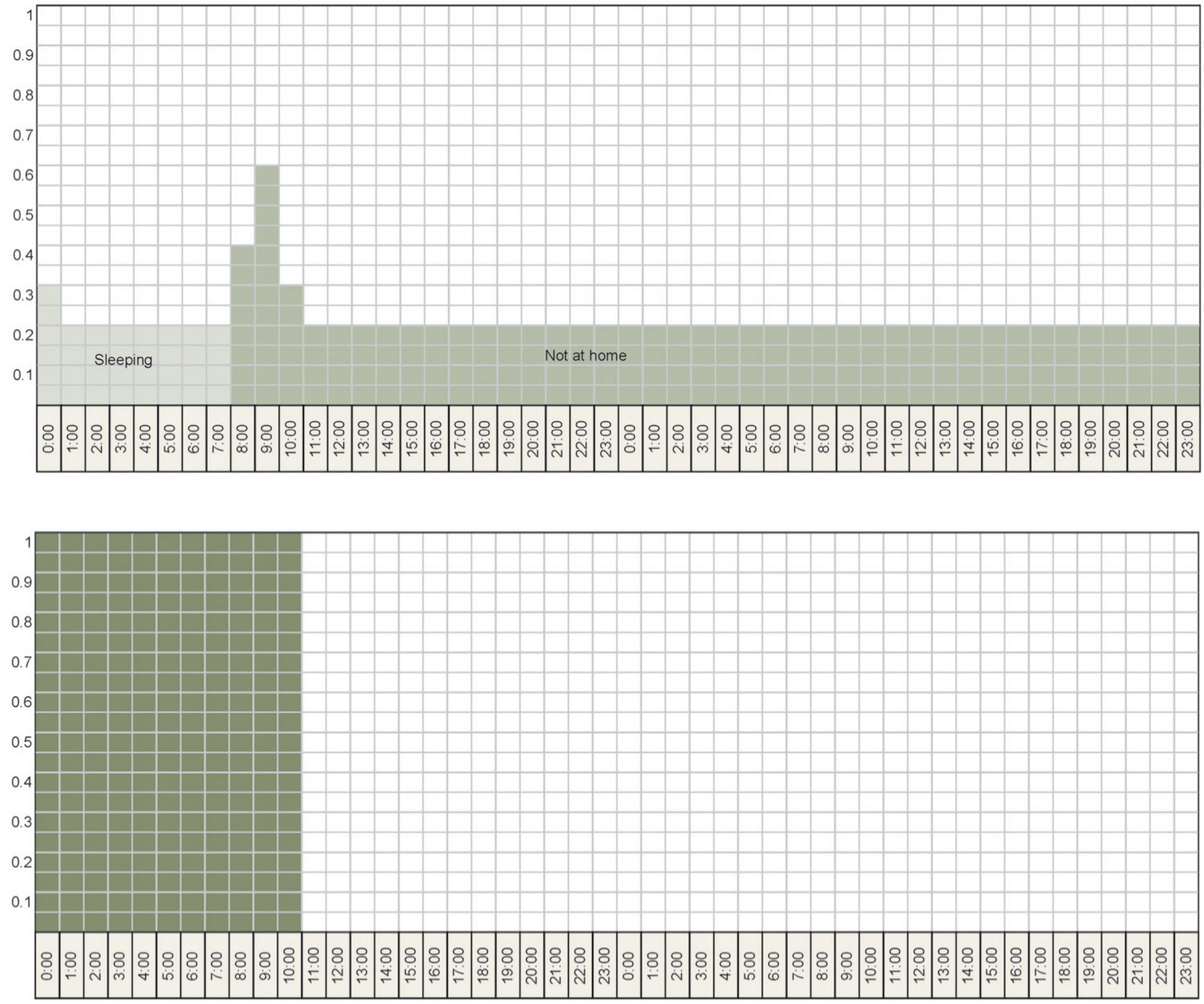

Figure 5. CP18. Weekend. Occupants' presence: electric energy consumption and interviews (above). Occupancy profile (below).

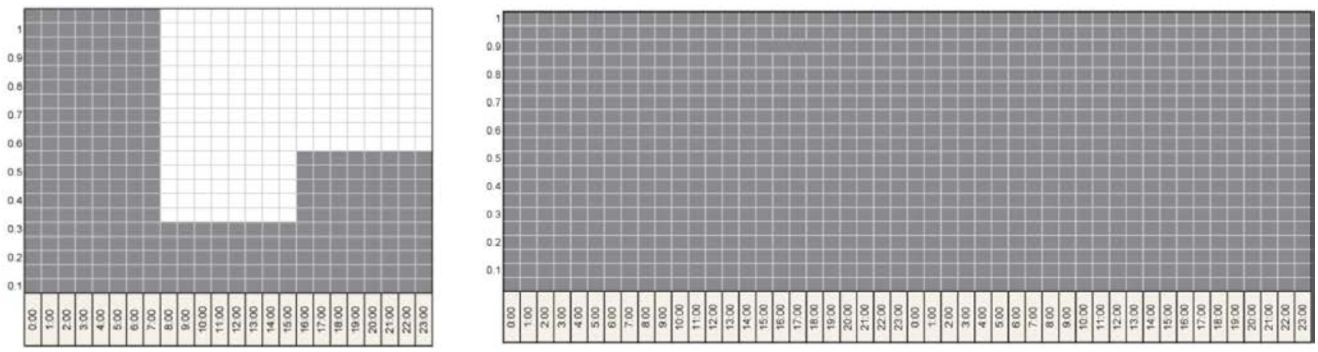

Figure 6. CTE weekdays (left) and weekend (right) occupancy profiles.

of electricity consumption and the application of household surveys allows for the adjustment of simulation occupancy profiles and density to reflect more closely reality, and for the calculation of more accurate performance of buildings. In renovation projects, the optimization of occupancy profiles, adjusted to actual occupants' behaviour, brings us closer to a closer prediction of performance when selecting renovation technologies and approaches. Further adjustments could be made with the measurement of metabolic rate of the occupants, which also has an influence on internal heat gains in building simulations.

A mixed-methods approach, followed in this research, allowed to define actual occupancy profiles for the dwellings, both in terms of occupancy density and occupancy patterns. The approach consisted on the triangulation of the quantita-

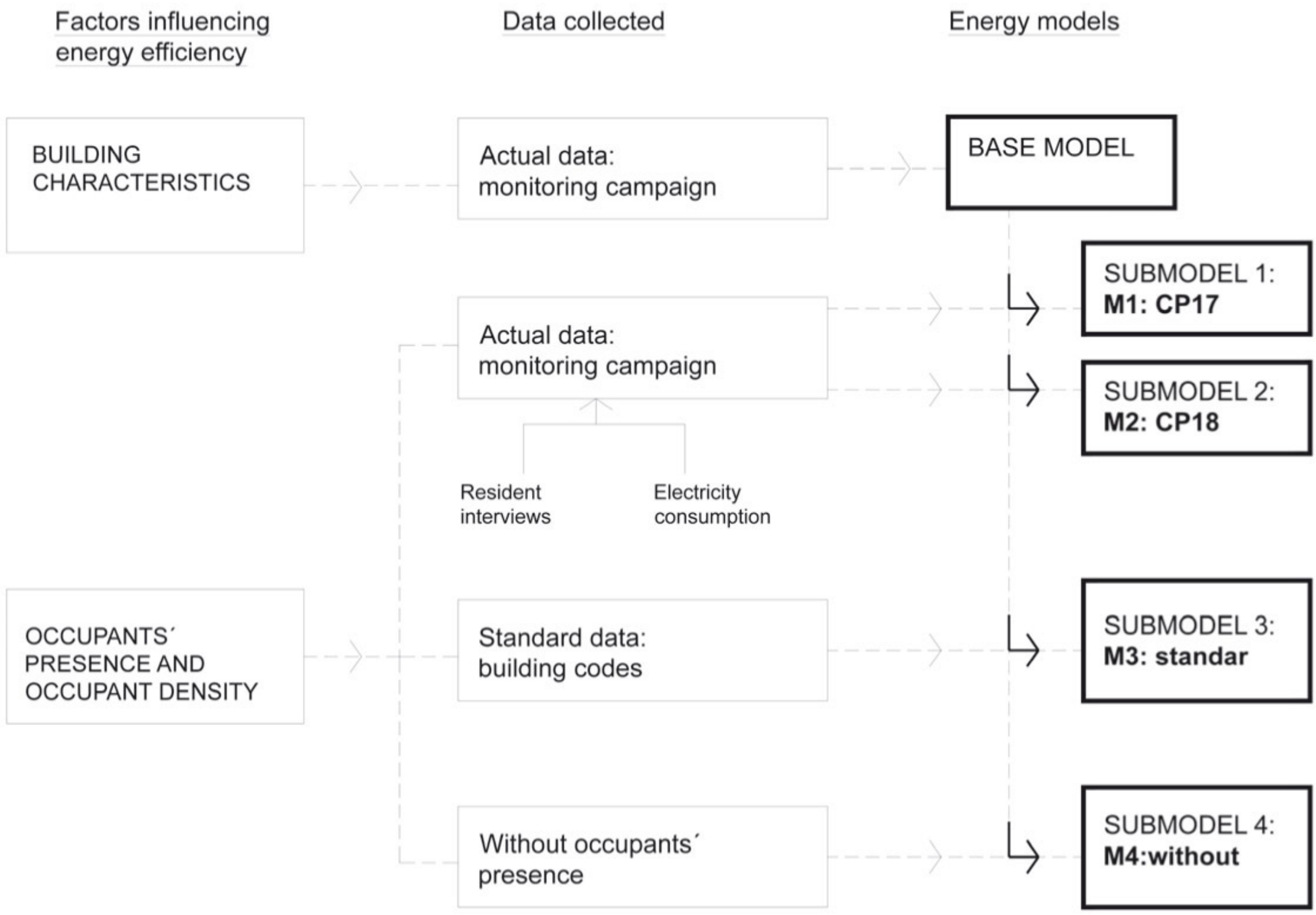

Figure 7. Simulation framework.

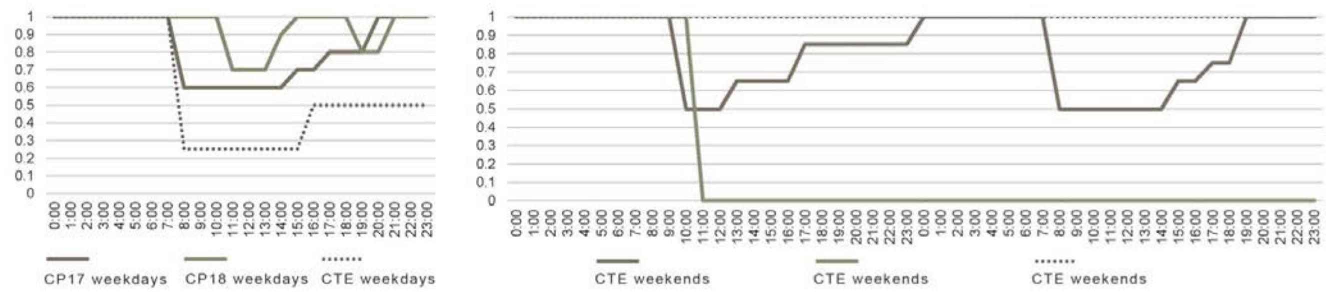

Figure 8. CP17, CP18 and CTE weekdays occupancy profiles (left) and CP17, CP18 and CTE weekends occupancy profiles (right).

tive data obtained from the building monitoring campaign, and the qualitative data obtained from the interviews carried out with the occupants of the dwellings.

It is important to notice that this research only focused on internal heat gains related to the occupants. Further investigation is needed regarding the influence of internal heat gains from the actual use of electrical appliances and artificial lighting. Further investigation should be aimed at the elaboration of more detailed occupancy profiles in which the metabolic activity of the users at different times of the day is considered, as well as the exact location of the occupants within the building [11,15, 29].

It is important to notice that this research only focused on internal heat gains related to the occupants. Further investigation is needed regarding the influence of internal heat gains from the actual use of electrical appliances and artificial lighting [30].

5. CONCLUSIONS

In this research, we defined actual occupancy profiles based on monitoring data from two case studies. These profiles were used as input data on energy simulation programs to define more accurately the influence of occupancy patterns and household size on the heating demand of dwellings. The profiles developed were compared to the profiles provided by the Spanish building code (CTE).

The results showed that occupancy density and occupancy patterns based on the case studies represented from 10 to 23 % of the heating demand, indicating the relevance of these param-

Table 2. Total heating demand, heat gains caused by occupants and relation between heat gains and total heating demand.

Energy submodels by occupancy profiles and occupant density	Total heating demand kWh/heating period	Heat gains by occupants kWh/heating period	Relation between heat gains by occupants and total heating demand
Occupant profile CP17 Occupant density 0.02	−48.6	6.1	12.7%
Occupant profile CP18 Occupant density 0.02	−49.4	4.9	9.8%
Occupant profile CTE Occupant density 0.02	−49.1	5.2	10.6%
Occupant profile CTE Occupant density 0.04	−44.7	10.4	23.2%
Without occupants' presence	−53.7	0.0	0.0%

eters in building performance. This highlights the importance of taking into account actual socio-economic characteristics of the occupants in building simulations. Occupants' characteristics should be adapted to each individual case, for example to the corresponding socio-economical level. In this study, we have followed an experimental approach in which actual data are obtained from buildings and occupants in order to determine occupancy profiles specific for each case study.

The results on the heating demand showed that the highest demand is calculated in the building simulation without occupants and thus, without occupancy related internal heat gains. Regarding the simulations results with the actual occupancy profiles, the heat load of the dwelling CP18 is 1.2kWh/m2/year lower because the resident is absent during the weekends.

The study also shows that increasing the occupancy density from 0.02 to 0.04, figures used in the CTE, the percentage of the heating demand represented by the internal loads increases significantly from 10.6 % to 23.2 %.

Spanish households have changed in the last years. According of data from 2013 [24], 24.2 % of households are single person, 9.9 % being above 65 years old.

It is important to add that the process followed in this paper can be used in individual case studies to understand the specific patterns of the occupants, but they cannot be extrapolated to other cases, since the results are influenced by particular building characteristics and users characteristics. However, by developing a dataset with a large enough number of cases, actual occupancy profiles could be developed, depending in generic socio-cultural and climatic characteristics.

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