Occupancy patterns and building performance. Developing occupancy patterns for Portuguese residential buildings

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ABSTRACT: The construction sector is responsible for enormous environmental impacts. Those are mainly due to the use of materials, energy and land. The impact of a single building is normally directly dependent on the size of the building or in the area of land it occupies. In this article, it is argued that strategies to improve building performance by reducing building size must take into account occupancy patterns of each type of building compartment in order to correctly assess compartment area needs. Nevertheless, occupancy patterns typically found in the literature do not provide enough detail to allow a deep analysis of the use of each type of building compartment. The objective of this study is to propose methods to produce detailed occupancy patterns that allows the assessment of building performance. For this, a questionnaire was developed and tested in the development of preliminary detailed occupancy patterns for Portuguese residential buildings.

Keywords *Building performance; occupancy patterns; environmental impact.*

1. INTRODUCTION

1.1 The importance of occupancy time for building performance

The understanding that occupancy time is of great importance for building performance is somehow common sense. For example, many authors argue that one problem of nowadays cities is the abandonment of city centres (Halleux et al., 2012). Buildings that are abandoned, i.e. with zero occupancy, may be regarded as the most inefficient buildings. In consequence, new city areas are needed to compensate the needs of the population and this promotes urban sprawl (Barbosa et al., 2014a).

A building inside an urban area must accomplish some purpose for the community, such as residential, commercial, office, health care, educational, etc. Each one of these purposes has secondary functions associated. For example, residential buildings provide functions such as sleeping, eating, resting, leisure, working and others. Each one of these functions occupies part of the building during a certain amount of time, but some functions can be provided by several types of buildings. This overlap can be availed to increase building occupancy and thus building performance.

Regarding land use, if for example one building provides functions that makes it become occupied only for a limited time in each day, it is less efficient than other building providing more functions and thus being occupied for longer periods of time. Therefore, buildings should perform several functions to be occupied for longer periods of time and consequently be more efficient in the use of construction areas. The same reasoning can be used for parts of the building. Compartments that are used for short periods are less efficient than other compartments that are used for longer periods. In conclusion, buildings can be more efficient if they are designed taking in consideration the time in which the building and its parts are occupied. Besides this natural notion, only a small number of studies explore the concept of increasing occupancy time to improve building efficiency and none was found including this variable in the assessment method of buildings impact on land use (Barbosa et al., 2014b).

In a previous work by the authors, it is suggested that in order to increase building efficiency and performance, by means of increasing occupancy time of several compartments, the interior design of buildings should be such that allows transformation of compartments over time. This suggestion includes features such as adaptable furniture and moveable walls (Barbosa et al., 2016).

1.2 The use of occupancy patterns to quantify building occupancy

Although the time that each individual spends on different buildings and compartments is unique for every case, average values are often characterized in occupancy patterns or occupancy profiles. These patterns should be analysed in the design of high efficient and sustainable buildings because they allow the quantification of building occupancy. Nevertheless, studies about these patterns are normally only used for accurate calculation of buildings' energy consumption (Kavulya and Becerik-Gerber, 2012) (Oldewurtel et al., 2013). The analysis of human behaviour allows building accurate occupancy models for the prediction of thermal loads and energy needs in buildings. All studies analysed about occupancy patterns agree that realistic time-resolved data on occupant behaviour are

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important inputs to various types of simulations (Wang et al., 2005) (Widén and Wäckelgård, 2010) (Azar and Menassa, 2012) (Clevenger et al., 2014) (Aerts et al., 2014) (López-Rodríguez et al., 2013).

Occupancy patterns are normally displayed in graphs in which the probability of use of the buildings or compartment (occupancy factor: value between 0 and 1) is presented for the duration of one day. The meaning of an occupancy factor of 1 in a given time interval is that the building is always occupied during that interval, while 0 means that the building is always empty.

In most cases, building occupancy patterns are developed for representative occupancy days, but occupancy profiles should consider different patterns for weekends, holidays or empty periods (Motuziene and Vilutiene, 2013). Occupancy patterns can be divided in two main types regarding the depth of the analysis: one considering the occupation of the buildings as a whole, and other considering the occupation of single compartments. Furthermore, regarding the origin of the data, occupancy patterns can be divided between those using average occupancy data from Time Use Surveys (TUS) and those using real data obtained by monitoring. So far, little work has been done to evaluate the sensitivity of these patterns (Davis Iii and Nutter, 2010) but there has been an increase in research in this area in recent years (Duarte et al., 2013).

One problem related with many works regarding occupancy patterns is that they are focused in energy consumption (Oldewurtel et al., 2013). As an example, Richardson et al. developed occupancy patterns for residential buildings in the United Kingdom, using the TUS approach (Richardson et al., 2008), considering values close to zero during the night because although the building is occupied occupants do not spend electricity in this period. In these cases, the occupancy profiles show the overall probability of individuals being at home and active. This type of occupancy patterns is not useful to quantify occupancy regarding the buildings use efficiency.

Nevertheless, other types of models consider occupation during the night instead of activity. For example, Aerts et all (Aerts et al., 2014) developed a probability model based in Belgian TUS that considers occupancy in three possible states: (1) at home and awake, (2) sleeping or (3) absent (Figure 1a). Figure 1b shows a more detailed pattern in which the focus is on the occupants activities (Motuziene and Vilutiene, 2013). This type of occupancy patterns can be helpful to analyse buildings impact on land use. Nevertheless, these patterns can only be used to quantify occupancy considering the building as a whole, since the extrapolation from the activities to the occupancy time of the individual compartments may be subject to bad assumptions and errors.

In typical occupancy patterns of residential buildings, it is verified that people get up in the morning, leaving the house shortly afterwards (values close to zero in the morning), possibly returning for lunch (small peak) and then returning for the evening (values close to 1 during the end of the day and night) (Richardson et al., 2008). Davis and Nutter (Davis Iii and Nutter, 2010) developed occupancy profiles by direct observation and using sensors in North American university buildings (Davis Iii and Nutter, 2010). Analysing the average occupancy patterns for some types of buildings, it is possible to conclude that residential buildings are often empty during a great part of the day while office buildings, schools and others are often occupied during the day and empty during the night. This

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shows the importance of analysing occupancy patterns in order to increase land use efficiency by correctly planning building occupancy.

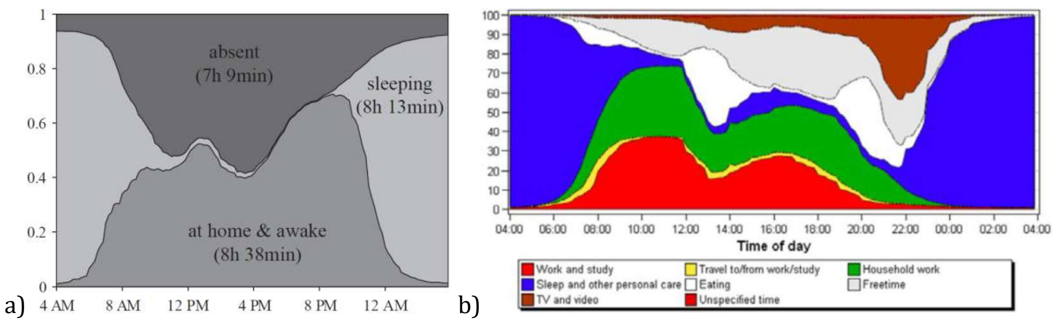

Figure 1. a) Occupancy model that consider building occupation (Aerts et al., 2014); b) Occupancy model that consider detailed activities (Motuziene and Vilutiene, 2013)

There are also occupancy patterns analysing the occupation of single compartments. These are scarcer, typically resulting from monitoring and generally intended for the determination of illumination alignments and for the calculation of internal thermal loads in accurate thermo-dynamic simulations. As an example, Figure 2a shows a low resolution occupancy pattern for compartments of a Spanish house (Motuziene and Vilutiene, 2013) and Figure 2b shows a high resolution occupancy pattern for a large commercial, multi-tenant office building in the USA (Duarte et al., 2013).

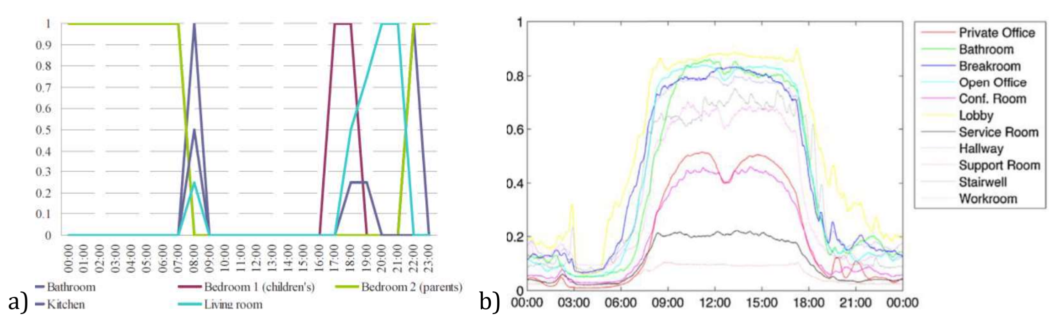

Figure 2. occupancy patterns considering individual compartments for a) a Spanish house (Motuziene and Vilutiene, 2013) and b) an office building in USA (Duarte et al., 2013).

In the work of Duarte (Duarte et al., 2013), surprisingly there were stable high values for occupancy probability of common areas such as lobbies, bathrooms, open office areas, break rooms, hallways, workrooms, and stairwells. This phenomenon was explained in part by the fact that the sensors detected movement by just one person and these spaces have considerable frequent activity during the day (Duarte et al., 2013). This also means that buildings with common areas may have increased efficiency of circulation areas.

Considering this gap in the literature and the absence of detailed occupancy patterns that analyse the occupation of buildings and individual compartments, the objective of this

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work is to develop occupancy patterns for residential buildings, according to the Portuguese reality.

2. METHODOLOGY

In order to develop detailed occupancy patterns for Portuguese residential buildings, there is the need to gather data. For this, a questionnaire was developed and distributed among Portuguese inhabitants. One issue of this method is that detailed information is needed but it must not be hard to understand or fill and it must be fast in order to boost responses and to provide valuable data. Considering this, a simple questionnaire was developed with just 5 questions: 1 - Age; 2 - Gender; 3 – Portuguese region; 4 - Occupancy profile in week days; 5- Occupancy profile in weekends and holidays. The first questions were very fast and easy to answer, being the last 2 questions more challenging. The strategy was to use a table that is quickly understandable and easy to fill (Table 1). The questionnaire is available online at: *https://form.jotformeu.com/51594295289369*.

Table 1. Questions 4 and 5 in the occupancy pattern questionnaire

	Bedroom	Living Room	Kitchen	Bathroom	Other	Outside home
00h00 – 02h00						
02h00 – 06h00						
06h00 – 08h00						
08h00 – 10h00						
10h00 – 12h00						
12h00 – 14h00						
14h00 – 18h00						
18h00 – 20h00						
20h00 – 22h00						
22h00 – 24h00						

Participants were asked to fill the blank cells of each table with a percentage of use of each compartment in each time interval (line). In order to validate responses, it was necessary that each line totalizes 100%.

The questionnaire was distributed online by email and using social media. Because of this, it is impossible to precise the number of persons reached by the questionnaire, but it is estimated that the questionnaire reached a universe of 100 persons. 31 responses were gathered, from which 1 was considered invalid. All the participants were from the Minho and Douro Litoral regions of Portugal. Moreover, 73% of the participants were male and 27 were female; 3% were younger than 20 years old, 77% aged between 21 and 40 and 20% were older than 41 years old.

The data was analysed in order to produce occupancy profiles like the ones presented by Aerts et al. (Aerts et al., 2014) and Motuziene and Vilutiene (Motuziene and Vilutiene, 2013). For that, an occupancy profile was produced by the average values of each valid response to the questionnaire.

3. RESULTS AND ANALYSIS

The answers to the questionnaires allowed the computation of two different occupancy profiles, one for week days (Figure 3) and one for weekends (Figure 4).

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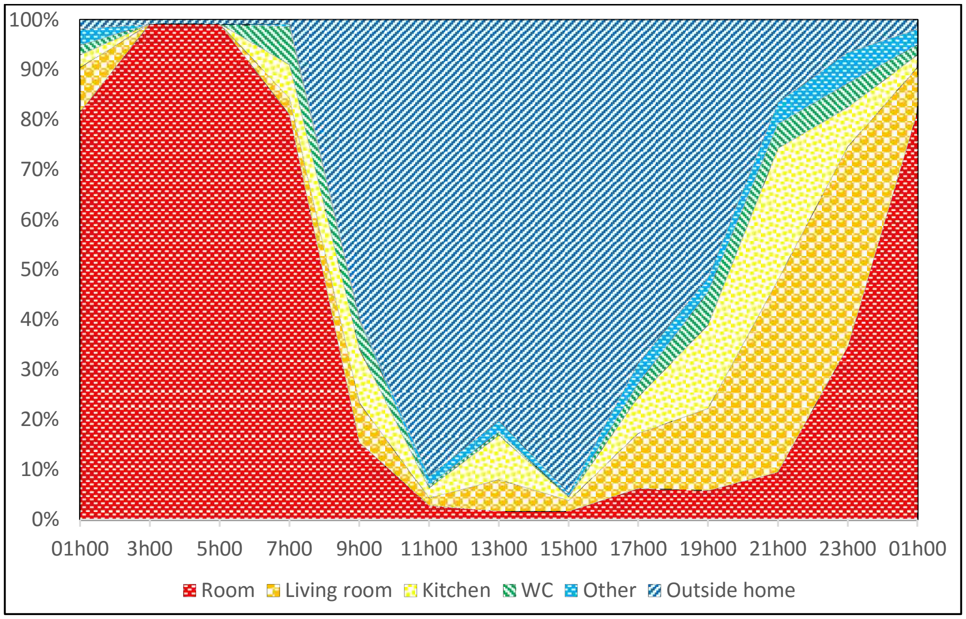

Figure 3. Occupancy profile of portuguese buildings in week days.

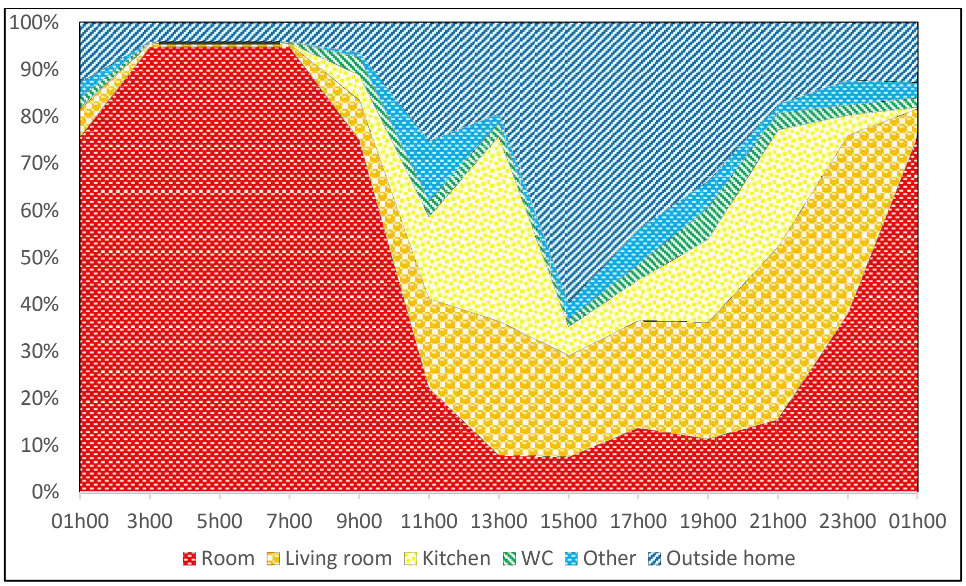

Figure 4. Occupancy profile of portuguese buildings in weekends and hollidays.

The results of this study, as expected, show that Portuguese residential buildings are often unoccupied during the day, mainly in weekdays and occupied during the night. When occupied, the compartment with more prevalent use is the room, followed by the living room and kitchen. Rooms peak occupancy during the night, while living rooms have peak occupancy during late afternoon and early night and kitchens peak occupancy during lunch and dinner time. From the analysis of weekdays and weekends it is possible to conclude that both kitchen and living rooms are more used during weekends and that while normally occupancy is higher in the weekends, occupancy during the night is higher when compared to weekdays. It is also possible to conclude that residents wake up later

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during weekends. Bathrooms and other compartments have minor occupation more or less equally distributed along the day.

4. CONCLUSIONS

In this work, it is argued that building occupancy is an important variable to consider in the design of residential buildings and in the assessment of building performance. The basic concept of this work is that increasing the occupancy of existing buildings, the need for new buildings is reduced, improving the buildings impact on the environment. This paper presents a methodology to the development of accurate occupancy profiles of residential buildings detailed to the level of the compartment and based on questionnaires. This method was tested and the preliminary results proved the method to be simple and effective in the development of occupancy profiles for Portuguese residential buildings both for weekdays and weekends. The results correspond to previous expectations. It is believed that the fact that the questionnaire is easy to fill and takes only 5 minutes in average to answer allowed an increased response rate. Nevertheless, it is necessary to perform additional studies to reach a higher and more representative number of answers to the questionnaire.

4.1 Limitations of the study and future developments

In this preliminary phase of the study, the results of the study could be enriched by adding more answers to the questionnaires in order to provide a more representative sample of the Portuguese population. Three main issues were identified, the gender equilibrium, the approach to the age pyramid of Portugal, and the geographical distribution of the population.

Another issue of this method is that each questionnaire relates to the occupancy profile of one single person, while residential buildings have often more than one occupant. A new method must be developed to allow the development of occupancy profiles of residential buildings using the average household. For this, in a future study, average occupancy profiles for each age group in Portuguese age Pyramid should be used to compute representative occupancy profiles of residential buildings.

Also, in this study it is considered that one person occupying one compartment, uses 100% of its area. While this is false, it is hard to measure that each occupant uses when occupying one compartment. Future studies will have to deal with this difficulty.

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