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Occupant behaviour: a major issue for building energy performance

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Abstract. The building sector in the world is responsible for nearly 36% of the final energy consumption and nearly 40% of total direct and indirect CO₂ emissions. One of the most efficient strategies to reduce the energy consumption in buildings is the estimation and optimization of building energy performance. According to the International Energy Agency IEA-EBC[1], several factors influence the energy performance of buildings; one of the significant factors is the occupant behavior. Recently, there has been growing interest in this field. In this context, different methods have been proposed and developed especially when the traditional methods such as interview and survey are not efficient and sufficient to analyze and to predict the occupant behavior with better accuracy. The main objective of this study is to provide a clear definition of the occupant behavior, a review of current approaches to analyze the occupant behavior and presentation of our research that proposes the possibility of including the occupants as a part of the problem and a solution to the problem. This research is a part of a European project H2020 “Holistic Energy and Architectural Retrofit Toolkit (HEART)”.

1. Introduction

The human behaviour grows into an important approach to integrate in the field of engineering and data science, in order to enhance the accuracy of the results and to develop a complete vision of the deterministic studies. In the domain of the energy building: the largest energy consuming in the world, the occupant behaviour has been highlighted by many studies as a crucial element to understand the energy use in the buildings and then analyze the energy performance of the buildings. The studies have shown that the negligence of the human behaviour in the deterministic approach influences obviously the certitude of the results and hides the power of the human's reactions on affecting several parameters and improving multiple situations. The interest on the behavior of the occupants began in 1978 [2] with a first study in Princeton Socolow [3] which addressed the influence of the behavior of residents on the energy consumption for space heating. Since 2005, studies on this topic have been developed and have resulted in several scientific literatures with an evolution of 20% per year and more significant results. In-depth analysis of the different studies in the literature has allowed us to identify the complexity and sensitivity to conduct research on occupant behavior in a building. The major difficulty lies in the integration of human behavior which is considered to have a stochastic aspect with a deterministic aspect while ensuring a complete study including the various axes concerning the buildings (meteorological conditions, envelope and materials of the building, equipment of the building, systems energetics) and other aspects related to humans (physiological, psychological and social). The objective of this paper is to provide a general review of the research on occupant behaviour in residential building and to present our research in the context of HEART project.

2. Occupant Behaviour: problematic, types and drivers



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The term of behaviour is simplified by Shuqin Chen et al. [4] in his study as a visible action/ reaction to adapt to the ambient environmental conditions. The definition of the occupant behaviour depends mainly on the context of the study, on the objective from the research, and could be defined by different levels of complexity[4]. However, the definition of the parameters related to the actions and reactions of the occupants differs from case to another (for each case study the environmental conditions are different). Even when the conditions are the same, the reactions of the occupants are variable and depends on the different drivers.

Based on the general vision for this research, it can be concluded that significant results are difficult to obtain and require in-depth work, analysis and more detailed research to address all aspects of this topic. On the other hand, the importance of making effort in this subject is indisputable by the specialists in building energy performance. Many scientific problems are defined to encourage the researchers to investigate more in this topic. Firstly, one of the most issues identified, is that the non-consideration of the occupant behaviour in the Building Program Simulation generate a disagreement between the real energy consumption and the simulated results[5]. Usually, the aspect of human behaviour is simplified by a conventional scenario (deterministic or static schedules)[3], ignoring the variety of the occupant behaviour (stochastic and dynamics schedules). Secondly, The lack of understanding of energy related to the human behaviour, the factors influencing the interaction of the occupants in their environment and the identification of behavioral patterns limits the total prediction on energy use in buildings and the complete assessment/evaluation of the impacts of energy saving policies and techniques [1]. Thirdly, the energy practices have a tendency to focus mainly on the technological logic than the social logic, forgetting that this technology is designed to be used and exploited by humans. Thus, it is evident to not have the same results envisaged for the solution, because we neglected the impact of human and the condition of appropriation and conviviality in the context of utilization[6]. Finally, a lack of communication tools and exchange between the manager and the occupants for a long-term management of the different building parameters and a control of the factors influencing the energy performance.

For these reasons, the study of the diversity of the behaviors in different context of buildings, and the behavioral recovery opportunities is important. In addition to that, it is required to take more in consideration the importance of human's behavior in the studies and believe that the occupants are contributors to the building energy performance.

In residential buildings, the occupant behaviour can be defined by the presence and the interaction of the occupants regarding their environment (fig1). Considering the behaviour as an energy behaviour since it affects the energy consumption, it is necessary to notice the different factors that drive the occupants to react and interact. In this respect, an interdisciplinary approach is directly recommended between the environment, physics, time, physiological, psychological, social, cultural and economic factors. Going through many studies in literature, the treatment of the occupant behaviour and its impact on the building energy performance was performed according to several axes. Therefore, three main research approaches can be identified: (a) Data collection and analysis; (b) Occupant behaviour modelling; (c) Energy feedback programs. These aspects are detailed in the following sections with highlighting the several tools considered in different studies. The figure 1 represent a general synthesis of the different aspect of the occupant behaviour research.

3. Data collection: monitoring approach

The monitoring approach is an efficient approach for the analysis of occupant behaviour. Based on the different researchers, the approach can be a study by itself and it can be also a key to develop a model of occupant behaviour and an important data to establish the energy feedback programs. The principle of the data collection is to assimilate the behaviour based on the sensors and communications technologies. To respond to the approach, it is crucial to understand how and what to measure.

In the literature, the definition and classification of the data collection differ between authors in vision and nomenclature. According to the Annex 66 (IEA)[7], one of the important research project on the topic of occupant behaviour, the data collection is conceived in four parts: occupant sensing and data acquisition methods, occupant measurement, validation of the measurement and ethics issues.

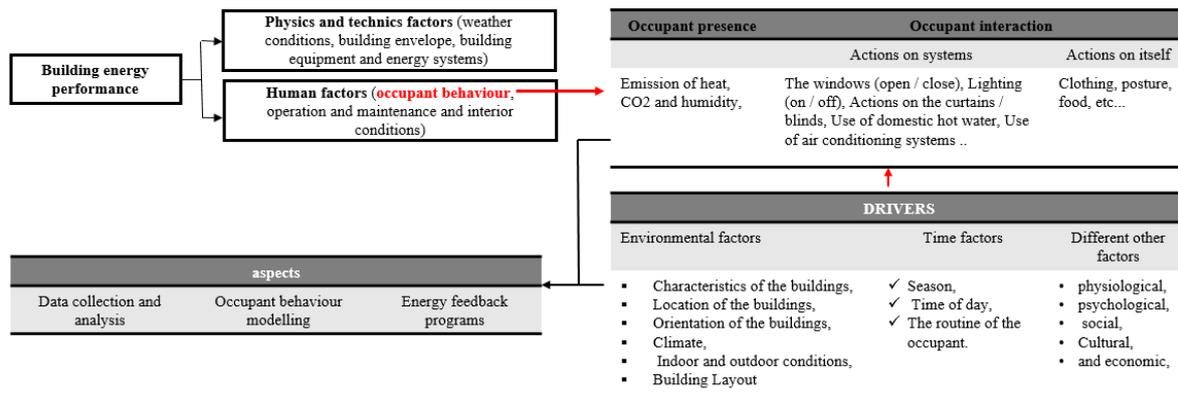


Figure 1. Technical framework on building energy performance, occupant behaviour, drivers and aspects.

In another study, Yan et al.[8]classified the monitoring approaches into three main categories: Observational studies, survey and interviews, and laboratory studies. Otherwise, Guerra-Santin and Tweed[8] divided the monitoring approaches into two main groups: physical monitoring and occupant investigation. The various propositions can be defined and presented with more simplification in table 1.

Based on the literature review and analyses, it is recommended to adopt the following consideration:

- On one hand, the type of the approach is adapted to each research context and objective. It should be pointed out that the residential buildings are characterized by: (1) the variance of occupancy hours and activities, (2) the interaction in residential buildings with occupants and equipment occur in several spaces (contrary to the office buildings where the interaction occurs in single space), and (3) the complexity is more important between the case of occupant present and active, and occupants present and inactive. On the other hand, the specification of the parameters to be monitored and the quantity of the information depends also on the context and on the objective of the study. Generally, three main purposes are identified:
 - Reduce the energy consumption by using energy with more efficiently,
 - Ensure the satisfaction of the occupants in their environment by increasing their thermal comfort,
 - Identification of the impact of the thermal discomfort on the health (mainly for hospitals).
- Ethics issues: monitoring occupants must employ solutions to preserve the identity of the occupants and secure sensitive information. Especially in the residential buildings, the privacy issues are present, and need a serious work and involvement of human subjects (e.g., take an interest to the position of the sensors, because the visible equipment may affect the occupant behaviour).
- Validation of measurements: its concerns mainly the sensors and survey data. Actually, No existing guidelines on how to validate measurements which gives the opportunity to several searches to appear in the field of data certitude[7].

The data collection allow detecting various information about the energy use and human behaviour in their environment. Based on this data, and on different technics of data analysis (e.g., data mining [9], regression analyses [10], machine learning techniques[11]), it is possible to understand accurately the behaviors patterns and integrate the results in the simulation of energy performance of buildings.

Table 1. Synthesis of the monitoring approach for occupant behaviour

<i>(a) Quantitative approach or the physical monitoring (In-situ / laboratory studies)</i>		
Types	Parameters	Sensors
Energy consumption & energy use	Gas, electricity, DHW, cold and heat	Gas meter, electricity meter, heat and cooling energy mete etc.
Indoor environmental quality	Temperature, humidity relative and CO2	Ambient sensors, thermocouple and hygrometer etc.
Outdoor environmental	Temperature, relative humidity, solar radiation and wind speed and direction	Weather station
Occupant behavior	Presence of the occupants, thermostats adjustments, light switching, window and door opening and plug load	Image based, Passive Infrared Contact sensor, smart thermostat, rocker switch, lux meter, plug meter etc.

<i>(b) Qualitative approach</i>	
Parameters	Methods
Occupant behaviour	Questionnaires, interviews, focus group, surveys, diaries, perception and observation, opinions.
Energy use	
Occupant preferences and needs	
Social, psychological and physiological factors etc.	

4. Occupant behavior modelling

The purpose of modeling approach in general is to represent a description and prediction of physical phenomenon, and the effect of changes to the systems [12]. The simplification and realism are the two important criteria for a successful model[12]. The reality of occupant behaviour is diversified and complex. On one hand, the behaviour has a stochastic nature in contrary to the deterministic nature, which is need an estimation of different probability simulations and distributions. On the other hand, the behaviour depends on several factors that affect the behaviour, and represented as drivers in the literature [13][14][15][16].

The principle from the occupant behavior modelling is the comprehension of the correlation between drivers and occupant and thereafter, elaborate a predictive model that take in consideration the behaviors and drivers over time [17].

Many studies have presented several classifications and definitions of the occupant behavior modeling. According to the Annex 66 (IEA)[7], the occupant behavior can be classified under three types: (1) adaptive behavior models, (2)non-adaptive behavior models and (3)occupancy models. Yan Zhang et.al [2] defined the types of quantitative models of occupant behaviour in four categories: stochastic/probability, statistical methods, agent based-modeling and data mining approaches (based on [18] and other references). In another study, the occupant behavior models can be defined by their complexity [19] and classified into different approaches : fixed schedules, data-based models (non-probabilistic), stochastic models (probabilistic) and agent-based models[20]. If this approach is selected in the research, it is important at first to define the purpose of the study, learn more about the different types of models and then select the accurate model for the research.

The elaboration of the model is important, but the application of models is indispensable also. In the literature, the focus is mainly on the implementation of the behaviors models in the building programs simulations. As we mention, one of the main issues is the lack of the accuracy in occupant behavior in the Building Program Simulation, which provide an incomplete prediction for the building energy performance. In this context, the implementation of models that predict the behaviors with more precisely is one an effective solutions to overcome this inconsideration of the occupant behaviors.

Several tools (obXML, obFMU, occupancy simulator) were developed to realize the implementation of the quantitative models on the BPS programs in order to increase the analysis and evaluation of the impact of occupant behavior on building energy performance([7][5][21][19][2][17]).

5. Energy feedback programs

As discussed in the previous sections, several approaches were developed to analyze and predict with better accuracy the occupant behavior and its impact on the energy building performance. In addition to those aspects, the involvement of the occupant to be part of the solution is considered one of the important strategies. The purpose from the energy feedback programs is (1) to give visibility and interpretation of the energy consumption to the occupants, and (2) creation of a tool of communication with the resident to can help them to learn how to control and preserve energy[22]. In this respect, Magali et al. [23] highlighted in their study that the adoption of efficient behavioral practices reduce the energy use by 7.4% on the average.

According to the meta-analysis conducted by Ardalan et al.[22], four approaches were defined and discussed to be a key for the development of energy feedback programs: surveys, analytics, simulation and experiments. These approaches are a key to provide to the energy feedback programmers knowledge about the occupant characteristics (Occupant behavior, needs and preference of the occupants, life style and routine, etc.) in order to define a design to the feedback program with the key parameters depending on the context of utilization. In addition, the experiments is considered also an important approach to evaluate various factors and components of energy feedback programs and, assess the potential for saving energy ([24][25][26]). In the most cases, the intersection between two approaches is present in the research, which allow identifying different opportunities to study in this field.

In the literature, the cellphone based, web-based and in-home display are the new technologically advanced feedback methods [22] developed and cited in the studies.

6. Discussion and conclusion

This study propose an overall perspective of the topic of the occupant behavior with the identification of the important aspects in this field. The occupant behavior as explained is not a supplement axis to study for the evaluation of the energy building performance, but a main and critical factor that should not be neglected.

For our study, three key main approaches were identified for the treatment of the subject of occupant behavior. At first, the monitoring approach is essential for the modeling and the identification of different aspect of human behavior. The data collection is developing more and more by the development of sensors and communication technologies, and provide a huge and delicate data to analyze. However, the main question after the collection part is how we should analyze the database in order to extract the information needed from the research. Secondly, the modeling of occupant behavior that often developed based on stochastic models. Despite this, some studies shown that the suitable model should be deterministic models with the best selection of the scenario of application[7]. There are several aspect to analyze and many techniques for the development of the OB models and its implementation. It is important to underline that the data collection provide a fundamental support to the elaboration of these models, and the adoption of the interdisciplinary approach open opportunities for several studies in the future. Thirdly, the energy feedback programs was identified as an approach for addressing this critical subject. In this respect, we should believe that the occupant can influence negatively and positively the energy use and energy performance. The idea is the creation of a link to communicate with the occupants and to give him the chance to understand more his energy use and then the possibility to improve the behaviour. The intersection between different approaches is defined as a challenging strategy to progress in this field and need a background of different domains.

In the context of our project, two approaches will be used. The data analytics and the energy feedback programs. The monitoring approach will be our key to analyze and understand the occupant behavior in the residential buildings. This will allow a development of methodology of analysis and treatment of data collection. Thus, the elaboration of Key Performance Indicators will be necessary to define a tool (interface) linking occupants and building energy managers. The project supports the

strategy of Zero Energy Building (ZEB) and represent an innovative concept for the rehabilitation of residential buildings by introducing a toolkit that will allow a communication with the occupants in the context of HEART project.

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