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# Occupant presence and behavior: a major issue for building energy performance simulation and assessment.

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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 CO<sub>2</sub> emissions. Reducing buildings energy consumption is an absolute necessity, and one of the most efficient methods is the estimation and optimization of building energy performance. One of the significant factors affecting the building energy performance is the occupant behavior. Recently, there has been growing interest in the occupant behavior field. Within the framework of 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. This research provides a comprehensive characterization of the occupant behavior through, a review of current approaches for occupant behavior analysis. The main key issues and drivers affecting the energy behavior of habitants identified on the literature were synthetized and presented. Furthermore, the paper highlights the necessity of including the energy feedback programs as a main key in the topic of occupants, in order to integrate them in the building performance process.

This research is a part of a European project H2020 “Holistic Energy and Architectural Retrofit Toolkit (HEART)”.

**Keywords:** Building energy performance, occupant behavior, data analysis, occupant modeling, energy feedback.

## **1.Introduction**

The human behavior grows into an important approach to integrate in the field of engineering and data mining science, in order to enhance the accuracy of the results and to develop a complete vision of the deterministic studies. According to the International Energy Agency IEA [1], the building energy performance is affected by (1) technical and physical factors as: Climate, building envelope and equipment and, (2) human factors as : operation and maintenance, interior conditions and occupant behavior. This latter has been highlighted by many studies as a crucial element to understand the energy use in the buildings prior to analyze their energy performance.

The interest in 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. The interest in the human behavior has evolved in a very impressive way the last 10 years. In particular the last year (2019) was the year with more published research. Figure 1 shows the evolution of the published research on the topic of occupant behavior. The elaboration of this analyze was carried out by using Scopus database in the period from 1995s up to December 2019. The term adopted for this research is “occupant or human”, “behavior” and “building”. Thereafter, a verification that all the results are in the domain of building energy performance such as: energy consumption, thermal comfort, indoor air quality, energy renovation, energy modeling and design, lighting comfort and occupant’s satisfaction was necessary. In addition, we checked that the occupant behavior is an aspect considered in the

research and cited as author/indexed keywords for the research published. More than 650 publications were identified in the period targeted and the year of 2019 represents the year where the most published research was identified (figure 1). The majority of them are articles and conference paper, but the review and the book chapter are considered also. This analysis aims to complete and to update the investigation conducted by Bruna F.B et.al and Yan Zhang et.al who have presented the data base of Scopus and Web of Science TM Core Collection – Citation Indexes (SCI-EXPANDED & SSCI)[2][4].

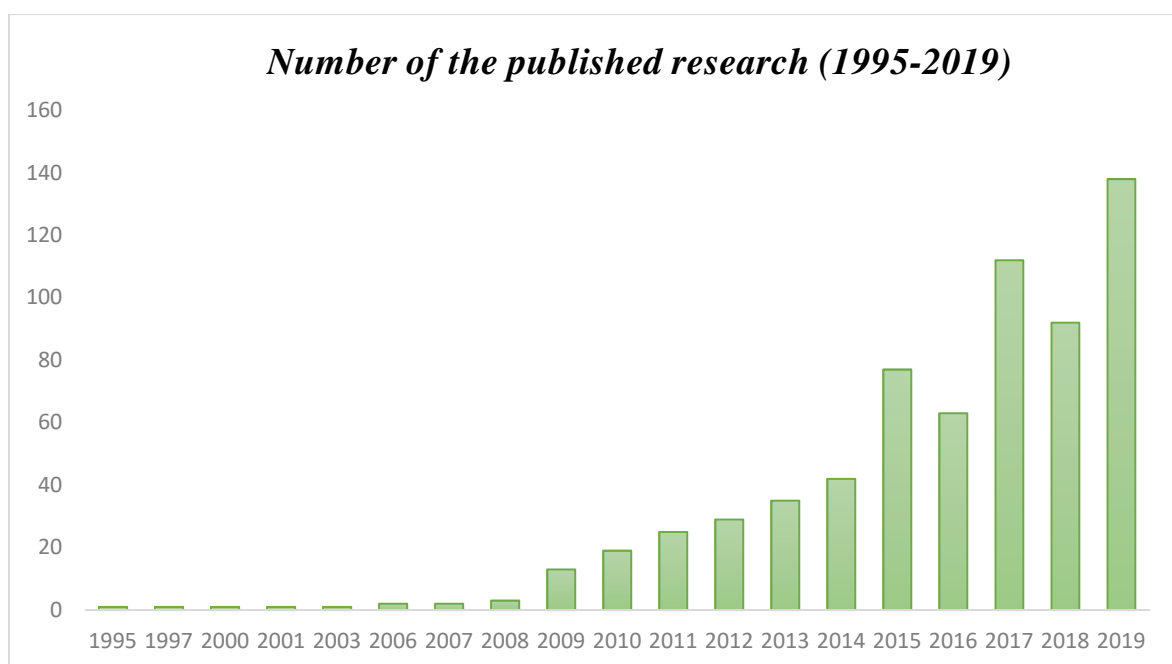


Figure 1: Evolution of the published research for the occupant behavior topic (Scopus).

### **1.1 Scientific issues of the topic:**

The subject of occupant behavior has become a focus in the domain of building energy and almost mandatory to evaluate and predict a complete vision for building energy performance.

In this context, several scientific issues were identified through the literature review:

- What is the most effective method for identifying occupant behavior?[2]
- What are the main factors influencing occupant behavior?[5][6][7]

- What is the level of impact of human factors on building energy performance gap?[8][9][10]
- How can the accuracy of occupant behavior in thermodynamic simulation tools be improved?[11][12][4]
- How can research contribute to the improvement of occupant behavior?[12]
- What is the importance of the social logic in the analysis of this topic? [12][13]

The points mentioned above are identified by the specialists of building energy performance and considered as a principal step to initiate the topic and to encourage the researchers to further investigations. If the issues are well understood, the strategies and the directions to find solutions will be clearer. For this reason, it is crucial that in the first phase we need to address the term of occupant behavior, to give it a clear definition in order to consider the several approaches and methods for the identification of occupant behavior. This principal phase is based on deep analysis of the different studies in the literature, which provides a complete assimilation of the complexity and sensitivity of the topic. The major difficulty of the subject lies in the integration of human behavior which is considered to have a stochastic aspect, with the deterministic aspects of building energy. Consequently, it is important to identify the source of the stochastic aspect of occupant behavior and the principal factors affecting the occupant behavior in the buildings. In addition, it should be noted that the lack of knowledge about the occupant behavior factor limits the total prediction on energy use in buildings and the complete assessment/evaluation of the impacts of energy saving policies and techniques [1].

One of the most issues studied in the literature, is the non-consideration of the occupant behavior in the Building Program Simulation (BPS) generates a disagreement between the real energy consumption and the simulated results. Usually, the aspect of human behavior is simplified by a conventional scenario (deterministic or static schedules)[3], ignoring the

variety of the occupant behavior (stochastic and dynamics schedules) [14][15][16][17]. The purpose is to eliminate the classic method for presenting the occupant behavior in the BPS and to introduce innovative tools and methods that could consider the stochastic nature of occupants in the simulations. Within this vision, several researches were developed in order to increase the accuracy of occupant behavior in the BPS [11][18][19][20]. The deterministic models reflect a phenomenon with its certainty state, and generally the output of the model is identified based on the input and initial conditions fixed. Contrary to the stochastic models where the output is not reflecting the input and characterized by independent random variables. For this reason the occupant behavior is considered with stochastic nature because the behavior of each person is independent and random, and not fixed by any determined equation or rule.

Furthermore, the energy practices tend to focus mainly on the technological and physical logic more than the human and the social logic, forgetting that this technology is designed to be used and exploited by humans. If the designers and the owners of buildings choose to eliminate the human aspect, which includes the social, cultural, economic aspect, the condition of appropriation and conviviality in the context of utilization, then it is evident not to have the same results envisaged for the solution[13]. This issue, leads us to reconsider the communication factor to explore the different sides of the nature of the occupants' lives. The technical and economic barriers are manageable, contrary to the barriers related to human as lack of interest, motivation and knowledge that affect significantly the promotion of energy saving strategies. For this reason, it is crucial that occupants have more knowledge about the energy use in buildings and more specifically how they impact the energy consumption and building performance to increase the level of their interest and motivation regarding this topic [21]. In this context, it is interesting to reconsider the importance of implementing communication strategies, and tools for exchange between the managers, owners of the

buildings and the occupants. This latter, is essential for a long-term management of the different building parameters and a control of the factors influencing the energy performance [22].

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, it is required to take into consideration the importance of human's behavior in the studies and believe that the occupants are contributors to the building energy performance.

### **1.2 Objectives of the study:**

The aim of this research is to provide a general review of the topic of occupant behavior, to address the complexity of the subject in a simple way and to highlight the important aspects of the topic. The detailed objectives are:

- Definition of the occupant behavior and drivers affecting in the residential buildings,
- Presentation of the main research approach presented in the literature of the topic,
- Highlighting the major aspect to consider for the analysis of the subject.

The occupant behavior is defined by the presence of occupants, and their actions and interaction regarding their environment. Figure 2 illustrates some example of the occupant interactions, and the following sections will highlight the definition and drivers of the occupant presence and interaction with a review of the related work in the literature.

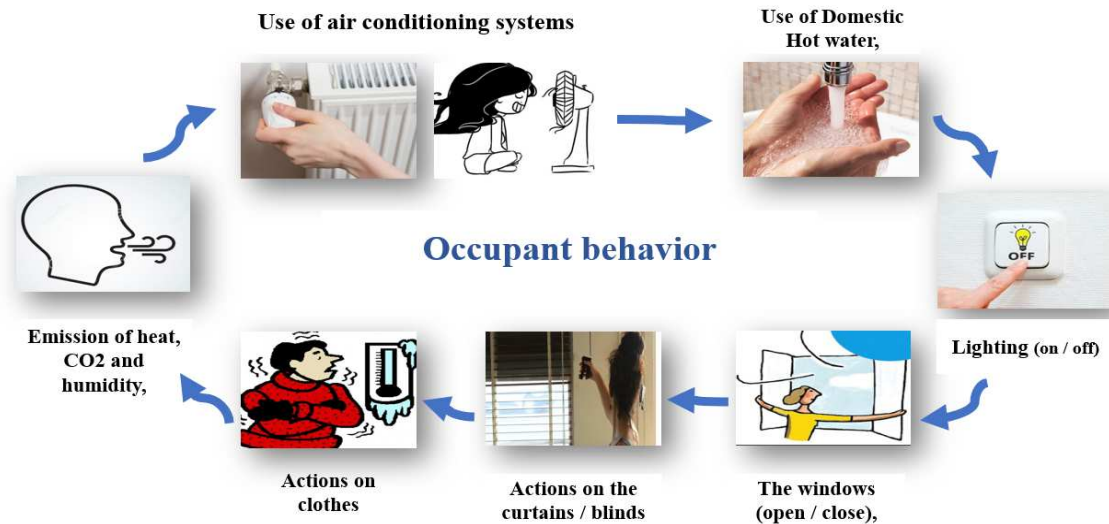


Figure 2: Examples of Occupant interactions in their environment.

## 2. Occupant presence and occupancy profile

The first aspect defining the occupant behavior is the presence of occupants in their households. The presence is described in the research by two main parameters and indicators:

- a) The scenario of presence that reflects the numbers of hours related to the absence and presence of the occupants inside the households and, the nature of the activity.
- b) Occupants profiles that indicates the number of occupants and in some studies the gender and age are important details to consider for higher accuracy.

Physically, the occupants generate CO<sub>2</sub>, humidity and temperature. Specifically, the occupants are considered as a main source of CO<sub>2</sub> generation in room /apartment. For this reason, the CO<sub>2</sub> parameter is considered in the literature the most significant parameter for the identification of the presence/ absence of the occupants and profile estimation[23].

According to A. Persily et al.[24], the CO<sub>2</sub> generation depends mainly on (1) gender, (2) age and (3) type of activity. In his original research, new methodology based on the human metabolism and exercise physiology is presented to estimate the CO<sub>2</sub> generation. The results confirm the necessity of increasing the level of accuracy of this value instead of the standard



values that generalize the same rate of CO<sub>2</sub> generation for all the occupants. Considering that the presence has a direct impact on indoor air quality, occupants' needs and interactions, it is crucial to understand this aspect to better assimilate the scientific issues and the occupants' interactions.

The studies have shown that the negligence of human behavior in the deterministic approach influences obviously the certitude of the results and hides the power of human's reactions on affecting several parameters and improving multiple situations. One of the most important issues impacting the evaluation of building energy performance is the accuracy of presence scenario instead of the conventional scenario utilized in the frequent studies. For this reason, it was crucial to propose methods, models and tools that allow the identification of occupant presence and estimate the occupancy number. Several studies were developed in this context; and they can be classified into two categories: (1) physical models/white box and (2) machine learning/statistical/black-box models. A large work has been developed in this field, for example: the Feature Scaled Extreme Learning Machine FS-ELM has been cited by Chaoyang et al.[25], as discrete-time dynamic model that allows an estimation of occupant presence based on the function that links the CO<sub>2</sub> data, the venting level and the past occupancy level. In another study[26], dynamic neural network model were presented in the context of an experiment measurement in a single room. In this context, other methods are important to be discussed and developed such as the proxy methodology [27], estimators with different level of complexity and filtering [28], and the Gsforest model presented and developed by Yaping Zhou et al.[29]. A grey box model was developed recently combining the physical and statistical models for increasing the accuracy of room occupancy [30]. Besides the modeling, the occupant measurements are also available, but with a limited usage especially in households for privacy issues. Accordingly, the majority of the research were developed for the offices and laboratories where the collaborators can work and contribute

comfortably to the measurements. In this respect, several studies were adopting data driven technics to identify and predict the occupancy presence and schedules[31][32].

### **3 Occupants' interactions:**

The term of behavior is simplified by Shuqin Chen et al. [33] in his study as a visible action/ reaction to adapt to the ambient environmental conditions. The definition of the occupants' interactions depends mainly on the context of the study, on the objective from the research, and could be defined by different levels of complexity[33]. 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 different drivers.

#### **3.1 Occupant Behavior: factors and drivers**

A comprehensive analysis of the subject requires the necessity of the identification of several factors/drivers affecting the energy occupant behavior. The identification of these latter is a purpose for different approach research, because it allows a better apprehension of behavior patterns and an improvement of building energy performance analysis. But also, to identify the energy behavior gaps and consider it for future strategies and solutions to minimize energy consumption in buildings.

The behavior considered as an energy behavior because it has a significant impact on the energy consumption. The reaction and interaction of occupants regarding the sources of energy consumption depends on various factors that can be categorized in three principal categories: environmental, time and other varied factors. The environmental factors concern all the technical drivers related to the interior and exterior climatic conditions, building characteristics and building equipment. Moreover, the season, life routine and day time are also considered as main drivers affecting the occupant presence and interactions [32][24]. The

impact rate of those drivers on energy occupant behavior is correlated and rely as well on the social, cultural, economic, physiological, psychological drivers that reflect the preferences and needs of each occupant [39]. The drivers are considered the source of occupant motivation and need creation. When the factors/drivers are present, the occupants need to achieve a thermal comfort, air indoor quality, lighting and acoustic comfort and other various needs and preferences. These latter drive the occupants to interact and react with their environment to satisfy their needs.

Figure 3 presents the process of occupants' interactions from drivers to actions. Regarding, the windows opening/closing actions, a study was developed profoundly by Valentina Fabi et al. [6] reveals the drivers influencing the windows opening with a classification into: physical environmental, contextual, psychological, physiological and social drivers. The need of ensuring thermal comfort is important for occupants. In this context, the studies show that the main drivers for windows actions are: the indoor and outdoor conditions (example, the window is opened if the exterior temperature is lower than interior temperature). For this reason, the windows opening is the common behavior in summer [22]. Besides, ensuring a good level of indoor air quality is also a center of interest for habitants, so the opening of windows is frequent in bedroom and kitchen [40]. In addition, the season and also the day routine of occupants; which vary from an occupant to another corresponding to the preferences and needs of each occupant; plays a crucial role on windows actions [13][8].

The use of heating is as well a fundamental research focus of the topic, especially that European statistics of 2017 indicates that space heating presents 64% of final energy consumption in households in Europe and the same percentage is indicated for France [41] [42]. A. Rinaldi et al.[22], shows in his research that the use of heating is connected to the construction year of buildings[8]. For the oldest buildings the use of heating systems is frequent and evident, contrary to the new buildings where the occupants prioritize at first

actions on clothes and windows. Ensuring the thermal comfort is a goal for the majority of the occupants, this subjective goal depends on several drivers such as: characteristics of buildings, cultural, physiological and psychological factors. These latter affect differently not only the use of heating systems, but also the lighting and ventilation. Nevertheless, the habits and lack of knowledge and awareness about the systems, are considered a strong barrier to adopt effective measures and affects the proper use of heating systems [43] [44] [39].

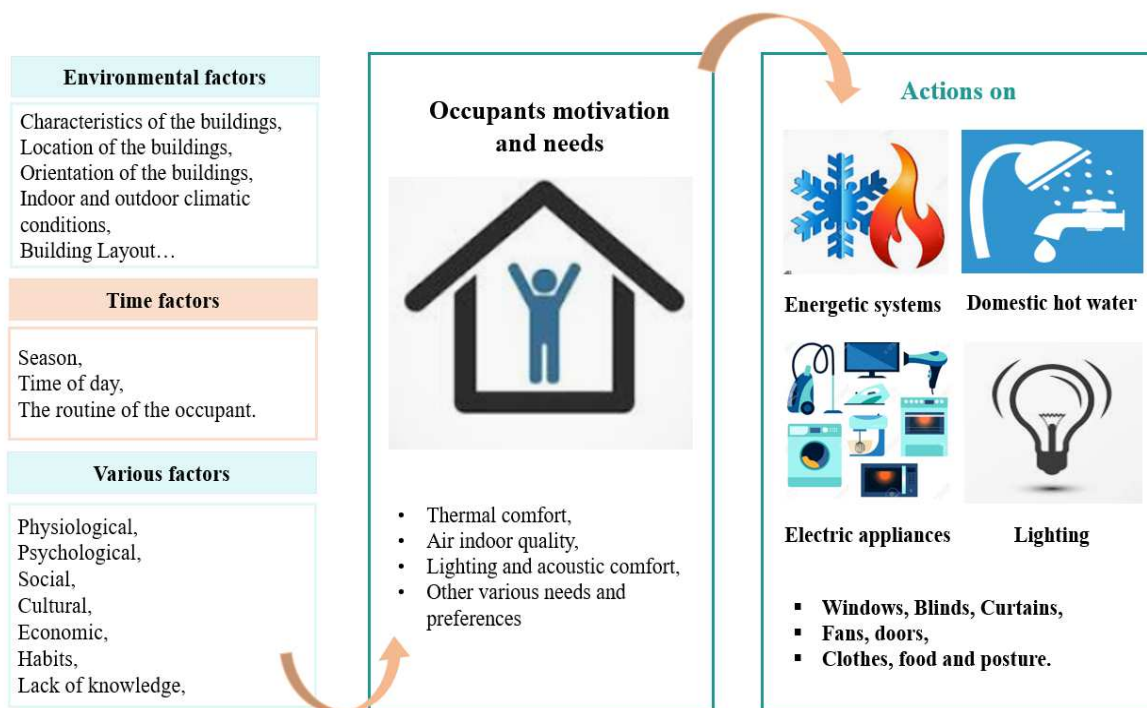


Figure 3: Layout of drivers, needs and occupant behavior actions.

Concerning the actions on lighting, blinds and shading, the visual stimuli is the main parameter affecting these interactions. A significant correlation was identified between illuminance, glare and solar radiation and lighting switching, blinds and shading use. In some studies, the thermal parameter is able to present a further need and driver [39]. The exploration about the windows, lighting, air conditioning systems actions has more researcher's attention than others actions, as fans, doors and thermostats use. The reason is the different impact of each action on building energy consumption.

Finally, and in the respect of all the information discussed above, an interdisciplinary approach is directly recommended between drivers, needs and actions. Specifically, between

the drivers, which the majority have a clear correlation and create a direct effect on needs and on actions.

### **3.2 Occupant Behavior: analysis approach and modeling**

Going through many studies in literature, the treatment of the occupant behavior 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 behavior modeling; (c) Energy feedback approach. These aspects are detailed in the following sections with highlighting the several methods considered in different studies.

#### ***3.2.1 Monitoring approach and data analysis:***

The monitoring approach is an efficient approach for the analysis of occupant behavior. Based on the different research, the approach can be a study by itself and it can also be a key to develop a model of occupant behavior and an important data to establish the energy feedback programs. The principle of the data collection is to assimilate the behavior 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)[11], one of the most important research on the topic of occupant behavior, the data collection is conceived in four parts: occupant sensing and data acquisition methods, occupant measurement, validation of the measurement and ethics issues. In another study, Yan et al.[20]classified the monitoring approaches into three main categories: Observational studies, survey and interviews, and laboratory studies. Otherwise, Guerra-Santin and Tweed [34] divided the monitoring approaches into two main groups: physical monitoring and occupant investigation. Based on the various classification proposed by researchers, a synthesis of the monitoring approach, measurements methods and tools are presented in table1. Thus, it is

important to adopt the following consideration so that the data collection and analysis approach can be successful:

- 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 occupant 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: (1) Reduce the energy consumption by using energy with more efficiency, (2) ensure the satisfaction of the occupants in their environment by increasing their thermal comfort, and (3) 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 behavior).
- Validation of measurements: it concerns mainly the sensors and survey data. Actually, there are no guidelines on how to validate measurements which gives the opportunity to several searches to appear in the field of data certitude[11].

The process of data collection allows a detection of various information about the energy use and human behavior in their environment. Based on this data, and on different technics of data analysis, it is possible to transform data to pertinent information in view of understanding

accurately the behaviors patterns. Thereafter, the global objective is to exploit information in the multiple methodologies for assessing the building energy performance, but also to develop other methodologies related to the improvement of occupant behavior identification and contribution to increase occupant awareness regarding the energy use in buildings.

Table 1: Synthesis of the monitoring approach for occupant behavior.

<i>(a) Quantitative approach or the physical monitoring (In-situ / laboratory studies)</i>		
<b>Types</b>	<b>Parameters</b>	<b>Sensors</b>
<b>Energy consumption &amp; energy use</b>	Gas, electricity, DHW, cold and heat	Gas meter, electricity meter, heat and cooling energy mete etc.
<b>Indoor environmental quality</b>	Temperature, humidity relative and CO <sub>2</sub>	Ambient sensors, thermocouple and hygrometer etc.
<b>Outdoor environmental</b>	Temperature, relative humidity, solar radiation and wind speed and direction	Weather station
<b>Occupant behavior</b>	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>		
<b>Parameters</b>	<b>Methods</b>	
<b>Occupant behavior</b> <b>Energy use</b> <b>Occupant preferences and needs</b> <b>Social, psychological and physiological factors</b> <b>etc.</b>	Questionnaires, interviews, focus group, surveys, diaries, perception and observation, opinions.	

- **Related work to data analysis and mining:**

The second phase after the data collection phase is the operation of data analysis technics[35].

The data analysis process can be performed into 4 main phases after the data collection phase.

Firstly, it is recommended to clean data to prepare a data base well organized and structured.

Afterwards, the identification of data analysis methods to analyze data, and finally conclude

knowledge and pertinent information and identify the exploitation context of results (Figure 4).

One of the actual efficient tools is the data mining method. This latter is considered a very progressed technology and divided into two main groups: (1) supervised/ predictive analysis that consists on a predefinition of the knowledge targeted and, (2) unsupervised/descriptive analysis based on exploration and discovering unknown information and knowledge of data collected[36][37]. The unsupervised analysis is more adopted in the monitoring approach which objective is to identify the behavior patterns through the measurements and the data collected. Contrary to the supervised analysis that aims to develop models and functions of occupant behavior ( Section 3.2.2)[38].

The main technics of data mining identified in the literature are the clustering, association rule mining, sequence and motif discovery and anomalies detection. The regression and classification models are the most used technics for the predictive analysis[39][40][41].

Multiple research investigation was developed in order to analyze the connection between occupant behavior and energy consumption in buildings. The objectives from this investigation are various and crucial regarding the development of the building energy performance. The potential of energy waste patterns was identified by Jun Li at al.[42], and considerable findings about energy savings are performed especially regarding the lighting and appliance usage. The same objective is developed in another study by using clustering, association rule mining and prediction model. In this latter, a potential of saving almost 21% of total energy consumption can be achieved by only the modification of occupants' energy use habits[43][44]. Furthermore, data mining technique is employed for the identification of drivers affecting the behavior patterns concerning the windows opening and closing [45] [46], mechanical ventilation systems[47][48] and the HVAC systems[49][50] . The multivariate regression analysis is identified as an efficient method to process qualitative data and identify



the preferences and needs of occupants regarding the use of HVAC systems[8]. Besides, a systemic procedure based on data collection and analysis was developed by Zhun Yu et al.[51] in order to evaluate the impact of occupant behavior on energy building consumption.

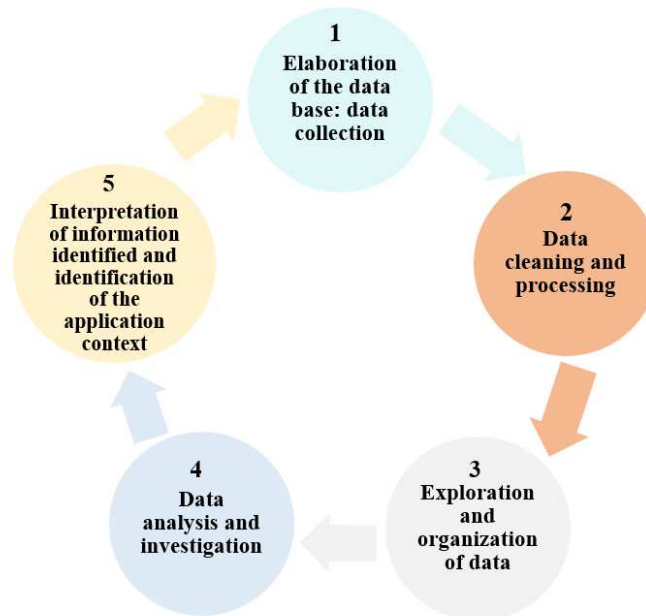


Figure 4: The principal phases for data analysis process.

### 3.2.2 Occupant behavior modeling

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 [52]. The simplification and realism are the two important criteria for a successful model[52]. The reality of occupant behavior is diversified and complex. On one hand, the behavior has a stochastic nature in contrary to the deterministic nature, which needs an estimation of different probability simulations and distributions. On the other hand, the behavior depends on several factors that affect the behavior, and represented as drivers in the literature [7][6][53][54].

The principle from the occupant behavior modeling is the comprehension of the correlation between drivers and occupants' interactions. Thereafter, elaborate a predictive model that take in consideration the behaviors and drivers over time [12].

Many studies have presented several classifications and definitions of the occupant behavior modeling. According to the Annex 66 (IEA)[11], 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 behavior in four categories: stochastic/probability, statistical methods, agent based-modeling and data mining approaches ( based on [55] and other references). In another study, the occupant behavior models can be defined by their complexity [4] and classified into different approaches : fixed schedules, data-based models (non- probabilistic), stochastic models (probabilistic) and agent-based models[18]. 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.

Fixed schedules were the most representation form of occupant's schedule used as direct input in building programs simulation. Based on the building type and on statistical analysis, or on long-term patterns an estimation of daily profile is fixed and used on the program for reflecting the presence and absence of occupants[12]. The data-based models are based on data analysis and learn observation, in order to transform data to new information and they are considered as non-probabilistic models[56]. By contrast, the probabilistic/ stochastic models are based on probabilities functions of various outcomes using random parameters. This latter, represents the possibility of modeling the behavior with taking in consideration the several influencing factors. The most complex models are the agent-based models for their capacity to model complex phenomena. These types of models aim to simulate and predict the several actions/interactions of individuals and it take into consideration their influence on buildings. Moreover, the resolution of the models depends on stochastic modeling which give it a large size and high complexity[18].

The elaboration of the model is important, but its application is indispensable also. In the literature, the focus is mainly on the implementation of the behavior's models in the building programs simulations. As we mentioned, one of the main issues is the lack of the accuracy in occupant behavior in the Building Program Simulation, which provides an incomplete prediction for the building energy performance. In this context, the implementation of models that predicts the behaviors with more precision is an effective solution 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 in order to increase the analysis and evaluation of the impact of occupant behavior on building energy performance([11][14][19][4][2][12]).

#### **4. Energy feedback approach**

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 most important strategies. The purposes from the energy feedback approach are (1) to increase the awareness of occupants about energy consumption, (2) integrate the habitants to contribute to the energy efficiency strategies, and (3) the creation of a tool of communication with the resident which can help them to learn how to control and preserve energy[57]. In this respect, Magali et al. [58] 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.[57], four approaches were defined and discussed to be a key for the development of energy feedback approach: 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 approach/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 ([59][60][61]). In the most cases, the intersection between two approaches is present in the research, which allows identifying different opportunities to study in this field. In the literature, feedback systems are essential to highlight the specific recommendations about energy savings opportunities to occupants. The cellphone based, web-based and in-home display are the new technologically advanced feedback methods [57] developed and cited in the studies.

## **5. Key findings and perspectives:**

The building sector is considered the primary source of the energy consumption in France and in the majority of European countries[62]. For this reason, the necessity of defining one of the major factors influencing the building energy performance is crucial. The proposed research aims to provide a synthetic (i) definition of the occupant behavior in buildings and (ii) indication of the main approaches to consider for the occupant behavior analysis. Based on the several researches carried out in this topic, the following outcomes are obtained:

- The human behavior is characterized by two aspects: (1) the presence of occupants inside the buildings which reflects their CO<sub>2</sub> emissions, the humidity and temperature. This first aspect was the only point considered in the BPS for the assessment of building energy performance and was known by the conventional scenario and fixed schedules. The presence of occupants leads to (2) the occupants' interaction with their environment. The use of the various systems in buildings (HVAC, windows, stores,

lighting and DHW) affects the energy consumption and creates a partial consumption related to the occupants' needs and preferences.

- The approaches adopted for the analysis of human behavior factor are various and divided in this research into three categories: monitoring approach, occupancy modelling and energy feedback programs. Firstly, the monitoring approach was evaluated as the most accurate technique to identify the behavior but in the same the most complicated approach to realize regarding ethics and privacy issues. Secondly, the occupancy modelling was conceived as an important key for simulating the behavior, especially the stochastic methods that give the phenomena more precision and exactitude. Finally, the energy feedback programs were identified also in this research as an essential method to consider for the essential need of integrating occupants in the process and give them the possibility to contribute to the energy savings potential.
- The complexity of the subject doesn't reside only in the stochastic nature of behavior, but also in the interdisciplinary framework that should be developed to achieve a complete assessment of the topic. The psychological, physiological, societal, cultural, economic and individual motivational drivers give to the topic multiple dimensions and impact reliability of the analysis while it doesn't take into consideration all the factors influencing the behavior.
- The human behavior in residential and tertiary buildings are affected by the same motivational drivers, the differences are the schedules of presence / absence, type of the systems and the access given to the occupants for their manipulation.
- The important characteristic in this approach is the possibility to complement an approach by the other one. The monitoring approach can be a very important input for occupancy modelling and energy feedback programs.

- Despite the several researches developed in this topic and in the solutions identified in the improvement of building energy performance, the lack of analyzing the human behavior before designing the solutions and the technologies is considered as a major barrier to ensure the efficiency of the applied strategies. For this reason, the integration of the occupants in the studies and in the process must become a priority approach exactly as the other approaches.

The elaboration of a structured knowledge in this topic is the key factor for the development of a scientific procedure for future activities research in the domain of building energy performance. In the context of HEART project, three objectives were specified:

- Assimilate the human behavior in the case of residential buildings by exploiting the developed databases;
- Developing an analysis framework to identify the motivational drivers regarding the case studies;
- Rethinking the necessity of integrating the occupants by creating an energy feedback tool. The concept is ensuring the adequacy and the efficiency of solutions considered to increase the energy savings potentials.

These three objectives combine the employment of the monitoring approach and the energy feedback programs. This combination aims to (1) benefit from the accuracy of measures gathered and (2) use all the knowledge obtained from the measures to develop a communication tool with the occupants in order to optimize their energy use in residential buildings.

The tool will be evaluated in the case studies of HEART project and the impact of occupant feedback on building energy performance will be assessed.

## **6. Conclusion**

This study proposes 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.

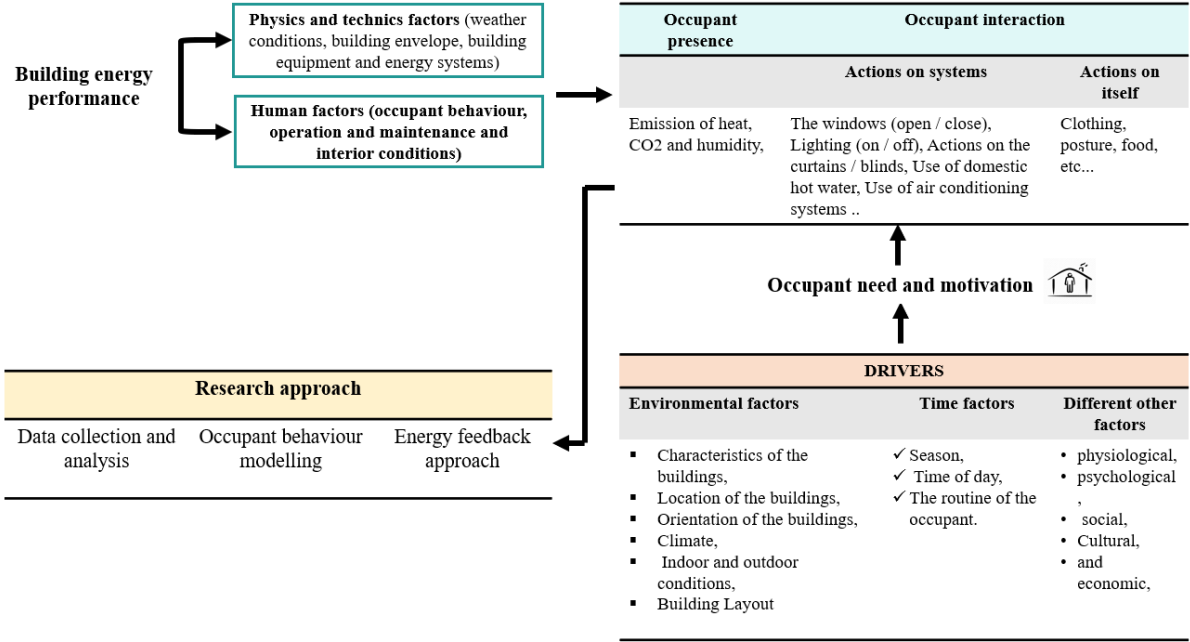


Figure 5: Technical framework on building energy performance, occupant behavior, drivers and aspects.

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 aspects 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, modeling the behavior of occupants who are characterized by a stochastic nature. Despite this, some studies indicate that the suitable model should be deterministic models with the best selection of the scenario of application[11]. There are several aspects 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 approach was identified as an efficient method 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 them the chance to understand more his energy use and then the possibility to improve the behavior. The intersection between different approaches is defined as a challenging strategy to progress in this field and need a background of different domains. Figure 5 represents a synthesis of the aspects and approaches analyzed in this work.

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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