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Review Article

Occupant Behavior: A "New" Factor in Energy Performance of Buildings - Methods for Its Detection in Houses and in Offices

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Abstract: The role that occupants have on energy consumption and performance of buildings is known, but still requires a great deal of research. In this paper, the most common techniques to detect occupancy and occupant behavior in buildings are categorized with their advantages and disadvantages. Being the buildings characterized by different energy usage, the presentation of the studies that applied surveys and monitoring campaigns is conducted with differentiation between residential and office buildings.

Keywords: *occupant behavior; occupancy detection; energy consumption; residential buildings; office buildings*

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0 Introduction

According to IEA, buildings are responsible for 40% of the final energy consumption[1]. Energy consumption of buildings changes with their intended use. In fact, the consumption due to heating is predominant in residential buildings; whereas, energy spent on lighting is greater in commercial buildings [Figure 1]. To address the challenges of climate change, the three main sectors (buildings, transport, and industry) need to develop effective strategies to reduce their share of fossil fuel use for energy supply. Europe has identified in construction the key sector for smart and sustainable growth. Strategies and tools aimed at promoting sustainable construction initiatives are encouraged, and therefore buildings more energy-efficient, more comfortable, and less wasteful in terms of raw materials are incentivized. In many of the developed countries, in fact, the design tends toward Nearly Zero Energy Buildings based on the 2010 European energy performance of buildings directive[2].

Despite the contribution that can be obtained from the use of innovative materials and technological innovations, an important impact on the performance of the "building system" will derive from the interaction between the occupant and the technical systems. The effect of the users on the energy performances of buildings is nevertheless understated and simplified in design, construction, operation, and retrofit of buildings, and this explains why the studies about the human factor inserted in the building sector registered an increase of approximately 230% in 10 years and of 30% in the past years[4].

In general, the total energy consumption of buildings is the result of an interaction among architecture, engineering, installations, and users and it is important to take into account the simultaneous action of all these variables. In addition, occupants who have no control over the comfort parameters of their internal environment are more unsatisfied than people that have control[5]. On the other hand, it is not certain if the occupants are actually aware of using the equipment from an energy point of view. In fact, different researches reported that similar or identical buildings, but with different occupancy and occupant behavior, have a significant disparity of energy consumption[6,7]. Furthermore, the energy-saving potential due to occupant behavior ranges between 10% and 25% for residential buildings and 5–30% for office buildings[8]. A summary sketch of the way in which occupant actions and activities influence the energy consumption in buildings is shown in Figure 2.

A deep knowledge of the driver factors determining occupant behavior and the modeling of the use of equipment are fundamental for reaching energy saving, optimization of comfort, and respect for environmental resources.

Before tackling the problem of occupant behavior, however, it is important to understand how to study and detect the occupancy. Based on the level of detail in which we are interested, six spatial and temporal properties can be used to describe occupancy information[9]: Presence, location, track, activity, identity, and count. The first three properties provide information about when occupants are present, in which room they are, and the movement history across the different rooms; the other parameters produce information on what activity people are carrying out, who is in each room, and how many people there are.

0.1 Occupancy and behavior detection

Researchers of Annex 66[10] grouped the methods to study occupant and occupancy in buildings into four categories: *In situ*, survey, laboratory, and virtual reality [Figure 3]. The first three methods are the most developed. In general, *in situ* method is suitable for long-term studies; the use of existing buildings does not need a laboratory, and it allows to obtain realistic data of occupants at a relatively low cost by means of one sensor or sensor fusion. On the other hand, the main drawbacks are represented by the sample size, the location availability, and the sensors positioning. Survey method aims to collect quantitative response

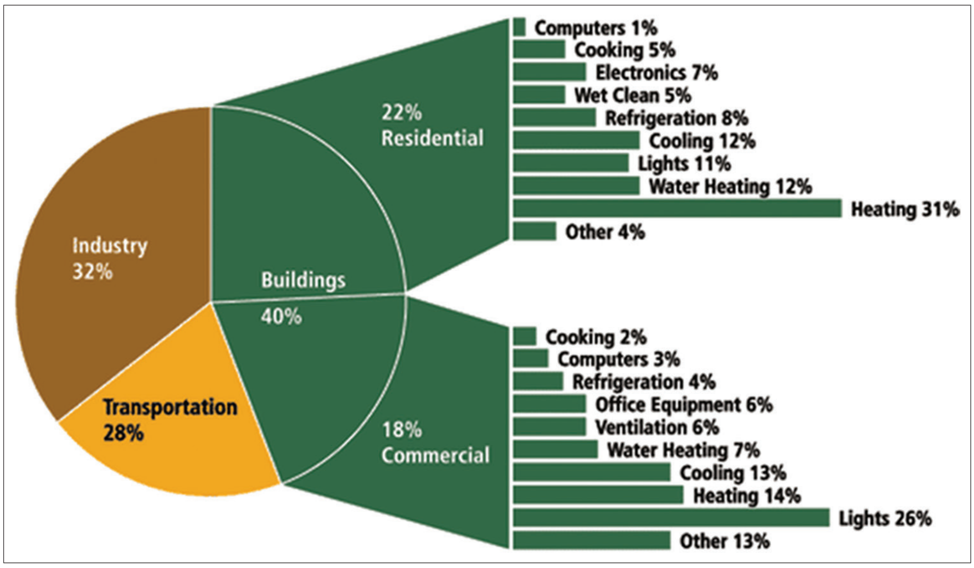

Figure 1. Energy consumption by sector[3]

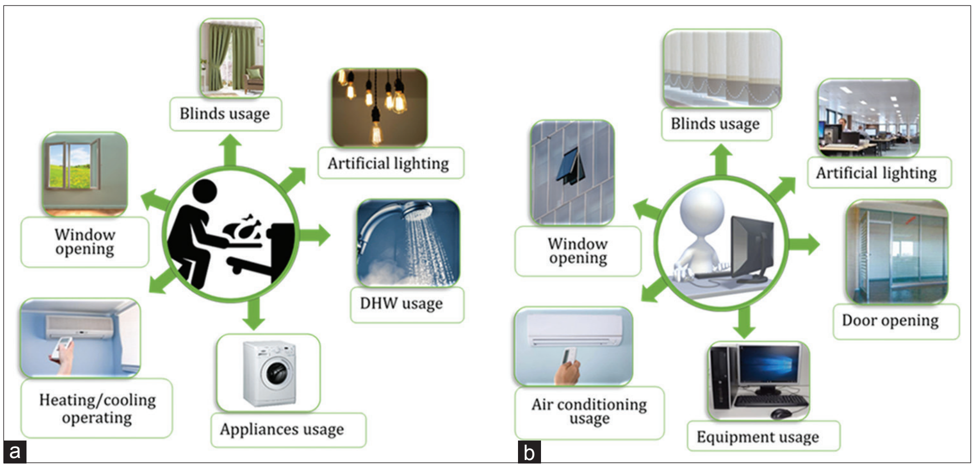

Figure 2. Occupant actions and activities influencing energy consumption in (a) residential buildings and (b) office buildings

Figure 3. Occupant measuring methos: (a) in situ, (b) laboratory, (c) survey, and (d) virtual reality[10]

useful to generalize results from a sample to a population. Surveys allow for monitoring variables and some aspects that sensors may be incapable to measure. In fact, the survey method can be used alone by questionnaire or in combination with physical data collection by sensors. *In situ* studies lead to having a wider vision of occupants in buildings and provide a cost-effective solution for obtaining a large sample size and also useful information. Laboratory method, having an almost total control over the indoor environment, provides to study occupant in a detailed manner. On the other hand, this method requires the construction of a special laboratory with all the furniture to make it as real as possible. Furthermore, occupants can feel observed with negative impacts on the results. Virtual reality is a method not yet so developed and still limited to only visual and acoustics sector.

In this paper, the most common methods for occupancy detection conducted by survey and measurements are presented. The analyzed techniques can be used both in residential and in office buildings, but generally with a different aim. The authors will address the issue for residential and office buildings separately, by highlighting purposes and findings in each sector.

1 Detection in residential buildings

Families characterized by a different number of family members, education level, lifestyle, and demographics produce different energy consumption. In fact, energy consumption in residential buildings is strongly influenced by occupants' behavior and actions. Literature about this topic is continuously increasing but still limited. Usually, the research addresses on actions triggered from only one environmental influence. It would be desirable to enlarge the study to multiple and combined environmental factors because some parameters can also contrast within decision, such as the wish of air renewal (window opening) against the outdoor noise (window closing). The development of this analysis allows for adding a building management system that could adjust the operation of the dwelling to its occupancy features and for achieving true building intelligence and high energy efficiency.

1.1 Questionnaire survey

The questionnaire survey is the most common and useful method to analyze occupancy and occupant behavior in residential buildings. Figure 4 synthesizes the basic information that can be obtained by this tool. The repartition in sections can be dictated by the aim of collecting information about physical, sociodemographic, and behavioral variables. In particular, physical parameters allow to define the climatic context, the construction typology, the heating/cooling/DHW systems, and equipment; sociodemographic parameters lead to describe composition, education, and income of families; occupant's behavior should be detected by means of detailed schedules. To integrate the occupant behavior in energy calculation, there is a need to have hourly presence schedules for each group of rooms with similar activity type and systems usage schedules. In particular, occupant profiles can be defined by considering how

1 OCCUPANT

- Number of family members
- Employment
- Education level
- Age
- Income

2 BUILDING AND SYSTEMS

- Location
- Type of house
- Year of construction
- Surface area
- Structure (walls, windows, and room numbers)
- Energy sources and consumption
- Heating and cooling systems
- Domestic hot water

3 USAGE

- Occupancy (presence at home, presence in each room, and activity)
- Heating system (set point temperature and hours of daily operation)
- Cooling system (set point temperature and hours of daily operation)
- Lighting and appliances
- Domestic hot water (bathroom/kitchen, frequency and duration of use)
- Windows opening
- Blinds

Figure 4. Information obtained by the survey in residential buildings[12]

people occupy the building, use the systems, and how they interact with devices (windows, blinds, lighting, and appliances)[11].

A questionnaire survey was used by the authors Carpino *et al*.[12] to collect information about families and to obtain typical occupancy profiles of residential buildings located in Southern Italy. Using hourly time schedules, three levels of occupancy (high, medium, and low) and different sub-categories of high occupancy (morning, afternoon, and intermediate) were individuated by processing the gathered data from 80 families. Buildings energy consumption was also investigated with regard to occupancy categories, and correlations were found. Portuguese researchers[13] also proposed a questionnaire to develop accurate occupancy profiles. In particular, hourly profiling was detailed at room level and by splitting the analysis into weekdays and weekends.

Others sources can be used in addition to data collected through targeted surveys, such as data derived from national time use surveys (TUS). Several studies, based on national TUS databases, are available in literature and follow different approaches to define occupancy and consumption patterns. For example, Belgian TUS[14] were applied to develop a probabilistic model which generates three realistic occupancy states: At home and awake, sleeping, and absent. Swedish TUS were used[15] in combination with appliances electricity load to develop a stochastic model for generating both realistic activities patterns and power demand patterns. The authors[16] validated a stochastic model by means of French TUS with the aim to accurately predict residential building occupants time-dependent activities. British TUS were the inputs[17,18] to define high time-resolution occupancy profiles able to reproduce when occupants likely use home appliances, lighting, and heating.

1.2 Measurements

Occupancy monitoring in residential buildings is usually developed using passive infrared (PIR) sensors, magnetic reed switches or cameras. Monitoring campaign in residential building is a technique not as developed as in office buildings, but it is possible to find some case studies in the literature. The authors[4] installed environmental sensors (indoor temperature, relative humidity, and CO_2) in a Portuguese multi-family building for detection of occupant actions in the different rooms of the houses such as windows opening, showering, heating, and cooking.

Unfortunately, not always there is the availability of households to install sensors in their houses for research purposes. Despite the limited development of this approach in old buildings, several studies and projects were designed for modern smart buildings. For example, measurements were conducted[19,20] with the aim of obtaining occupancy states from metered electricity usage. This kind of implementation is clearly limited to modern buildings already equipped with smart meters and smart plugs. Another technology, nowadays in fast development, is represented by mobile phones that can be used for tracking occupants and predicting the expected arrival to activate the heating system by smart controls[21]. This technology can be a potential help for households to manage their heating system remotely and give notice of long absences or changes in their schedule[22].

Within the project iSpace, iDorm is a two-bedroom apartment located in the campus of the University of Essex (United Kingdom) with an installation of sensors, gadgets, and actuators. All the furnishings are fitted with intelligent gadgets that can detect and learn the occupant behavior. The intelligent gadgets communicate with each other, allowing groups of agents to coordinate their actions. The agent can intelligently remember the user habits under particular environmental conditions, and then it makes changes to the environment accordingly[23].

eDIANA[24] (embedded systems for energy efficient buildings) aimed to develop a platform able to provide real-time measurements, integration, and control. The target of eDIANA platform was to improve energy efficiency and optimize household energy consumption; in fact, users can express their preferences and drive the platform toward energy consumption optimization.

AIM[25] is a project that involved different Europeans countries. The goal of the project was to develop a technology for profiling and optimizing the energy consumption patterns of home appliances, and providing examples related to three application areas: White goods, audio/video equipment, and communication equipment.

2 Detection in office buildings

Energy consumption in office buildings is mainly due to a twofold contribution: Consumption caused by work equipment and that one that assures healthy and comfortable internal environment for the occupants. It is recognized that occupants play a key role in the energy use of office buildings and they are often perceived as one of the main causes of underperforming buildings. Thus, it is necessary to understand the factors influencing energy intensive occupant behaviors and to incorporate them in building design[26].

2.1 Questionnaire survey

The structure and contents of questionnaires used for investigations in offices change with respect to those formulated for housing. The interdisciplinary cross-country survey used by D'Oca *et al.*[27] can be considered as an example to have a reference for the general frame of a questionnaire. It analyzed: Occupant motivational drivers regarding interaction with shared building environmental controls (thermostat setting, windows, blinds, and artificial lighting); group dynamics such as perceived social norms and intention to share controls; occupant perception about the ease of use of control systems; and occupant perceived comfort, satisfaction, and productivity. A summary sketch of the questionnaire content is shown in Figure 5.

Over the past decade, several research groups have focused on comfort in office buildings by considering the occupant perspective. As stated in the study of Antoniadou and Papadopoulos[28], by considering the multi-parametric nature of comfort, it is necessary to examine the acceptable level of all the environmental conditions (thermal, visual, and acoustical comfort, and air quality). Different studies were conducted within the European research project HOPE by means of a questionnaire focused on this issue. In particular, the authors[29] found that being influenced by several personal, social and building factors, the perceived comfort is much more than the average of perceived

1 COMFORT AND SATISFACTION	2 CONTROL AND ACTIONS	3 WORKSPACE
• Thermal • Visual • Acoustic • Air quality	• Decision on the devices control • Shared control • Perceived productivity	• Building (envelope and year of construction) • Office (private, shared, cubicle, …)
4 BEHAVIOR		**5 DEMOGRAPHICS**
• Windows opening/closing • Blinds opening/ closing • Thermostat setting • Lighting usage		• Work position • Hours of work • Age • Gender • Nationality • Level of education

Figure 5. Information obtained by survey in office buildings[27]

indoor air quality, noise, lighting, and thermal comfort responses. The authors[30] obtained correlations between buildings with more personal control on temperature and increased thermal comfort. They also found that the combination of control options allows having occupants with less building-related symptoms. Researchers elsewhere noted that occupants' age, body constitution, and gender influence their comfort perceptions. As discomfort can also affect the health of workers, it is important assuring, for both genders, satisfaction with the ambient conditions. Elaboration of data collected in the study of Karyono *et al*.[31] demonstrated that comfort perceptions vary with gender, body mass index, and ethnicity. Furthermore, in the study of Indraganti *et al*.[32], gender differences were found. In particular, females, young subjects, and people with low body mass index had higher comfort temperatures than males, older people, and obese occupants.

2.2 Measurements

Nowadays, data acquisition devices and sensors for gathering building performance information, such as energy consumption and comfort data, are very common in office buildings. An overview of the most common sensing technologies for occupant detection was conducted by the authors[33]. They classified the available techniques into six categories: Image-based, threshold and mechanical, motion sensing, radio-based, human-in-the-loop, and consumption sensing. These categories were evaluated using nine metrics: Cost, deployment area, collection style, power type, sensing range, accuracy, data storage, data sensed, and deployment level.

Usually, occupants of office buildings spend most of the time seated. For this reason, the authors[9] monitored a conference room using chairs equipped with sensors. Results show that the system is capable of providing fine-grained occupancy information to improve demand-driven control measures in buildings. In Li *et al*.[34], Radio-frequency identification (RFID) sensing system was utilized to occupancy detection by obtaining accuracies of 62% and 88% for mobile occupants and stationary occupants, respectively.

Several of the occupancy sensors used in buildings are often useful only for one issue and have several limits. For example, video cameras are usually used for security reasons; thus, the recordings can be analyzed by computer software or observed by humans. In general, this technology is not accepted by workers for privacy reasons and because they feel observed; in addition, the interpretation of recorded images can be difficult. Some authors, such as Chen *et al*.[35] suggested as a possible solution the crowdsourcing technique which requires that each occupant signs the presence in the analyzed area. Other authors, instead, suggested placing near the door a computer with a simple software where the occupants can note when they enter or leave the room[36]. PIR sensors are low cost and easy to deploy but present several drawbacks: If occupants are static, it is possible a wrong detection because they are limited to movement[37]; cold or warm air flows can be interpreted as motions determining false positives[38]. RFID technology is another useful solution for occupancy detection. The main issues are the acceptability of this technology by the workers and their predisposition to being monitored throughout the working day, besides RFID needs a tag to each occupant and can be the problem of the visitors who could enter without the tag[39,40].

Each sensor has properties and limitations; thus, the sensor fusion technique can improve the performance of occupancy estimation and detection by compensating the drawbacks of each sensor[37]. In fact, different studies are available in the literature. For example, the authors[41] developed an experimental apparatus for occupancy detection by means of a system able to collect data of different nature: Environmental indoor parameters (air temperature, relative humidity, carbon dioxide, and volatile organic compounds), actions (opening and closing of windows and door, and usage of air conditioning), and electric power for office equipment. Sensor fusion technique to detect the number of occupants was also investigated[42]. The experimental set-up consists of a wired sensor gas detection network, which measures carbon dioxide, carbon monoxide, total volatile organic compounds, outside temperature, dew point, and small particulates; a wireless ambient-sensing network which measures lighting, temperature, relative humidity, motion detection, and acoustics; and an independent CO_2 sensor network.

In different studies, the accuracy in modeling the occupancy was calculated with and without sensor fusion obtaining more robustness for occupancy prediction using this technique[43]. In particular, the authors[35] calculated accuracies in terms of the first arrival and last departure and terms of presence/absence. They obtained better results with sensor fusion in both cases. In accordance with other studies, also in the study of Ekwevugbe *et al*.[44], where the occupancy was determined by means of both infrared camera and manually observations, better results were obtained.

3 Conclusions

The most common techniques for occupancy and occupant behavior detection are presented by underlining the specific applicability, the typology of provided data, and the final achievable information. In particular, the authors considered the potentiality of investigations conducted by survey and measurements both in residential and office buildings.

In fact, there has been a continuous growth of studies focused on the aforementioned topics. This stems from the ever-increasing demand for energy efficient buildings and from the challenge to ensure that energy performance predicted during the design phase will be achieved after the building become in use.

The knowledge of occupant behavior is critical for buildings energy saving due to its influence on the performance of envelope and systems. Residential and office buildings present differences in both the consumption and the energy usages. An often heard explanation is that occupants have more control of the systems in residential buildings compared to the office buildings, where people are more interested in comfort than in energy bills.

With regard to occupant behavior, there is still a lot of work to do, also about the interdependency of different drivers for comfort-related behavioral actions. Furthermore, it would be necessary to educate people to correct use of systems from an energy point of view. Trained occupants could contribute to achieving energy saving targets instead of undermining the improvements provided by efficient building components.

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