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Significance of Occupant Behaviour on the Energy Performance Gap in Residential Buildings

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Abstract: Buildings are an important part of worldwide efforts to reduce energy consumption and mitigate greenhouse gas emissions that contribute to climate change. Despite recent technological developments in the area of energy consumption reduction, energy use is on the rise, highlighting the significance of considering occupant behavior with regard to controlling energy consumption and supporting climate resilience. Energy performance of residential buildings is a function of various aspects such as properties of the building envelope, climatic location characteristics, HVAC system, and, more importantly, occupant behavior and activities towards energy utilization. This study carries out a comprehensive review of the impact of occupant behavior on reducing the energy performance gap in residential buildings since residential buildings account for 70% of building floor area around the globe. Findings have revealed that a dearth of literature on occupants' behavior scholarship leads to inaccurate simplifications in building modeling and design. Thus, there is a strong need to obtain appropriate occupant behavioral data to develop strategies to close the energy performance gap as much as possible to achieve better energy efficiency in residential buildings to contribute to resilience and sustainability. Findings have also revealed a lack of objective and subjective data on occupants' behavior towards energy efficiency in residential buildings. In response to these gaps, the current paper has proposed a conceptual framework for occupant behavior toward a modification of thermal comfort to reduce energy use. Based on the findings of this paper, understanding the variety of factors influencing occupants' behavior should be considered a major influential factor in the design and retrofit of residential buildings with a view toward long-term resilience and sustainability.

Keywords: energy performance gap; occupant behavior; residential buildings; energy efficiency; sustainability; resilience



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1. Introduction

Occupant behavior is nowadays acknowledged as a main source of discrepancy between predicted and actual building performance; therefore, researchers attempt to model occupants' presence and adaptive actions more realistically [1,2]. A study by Pereira and Ramos (2019) [1] concluded that a key aspect in developing more advanced energy-efficient buildings is to consider occupant behavior in the whole development process. Many studies have demonstrated the substantial potential of efficient energy saving in buildings by considering occupant behavior in order to contribute to sustainability and resilience [2]. According to Carlucci et al. (2020) [3], one of the main sources of uncertainty in determining the actual energy consumption of buildings is occupant behavior. There is a lack of research that adequately addresses the different aspects of occupant behavior as well as the latest developments in this field [3,4]. This issue will be explored in this paper. Gunay et al. (2013, p. 234) [5] highlighted that "occupant behavior is one of the major factors influencing the energy efficiency of buildings and contributing to uncertainty in building energy use prediction and simulation". In Australia, cooling and heating

contribute to almost 40% of the building's total energy consumption [6], and achieving energy conservation goals by focusing purely on technological advancements without considering building occupants' energy-related behavior will not be enough to support resilience to adapt to and mitigate climate change [7].

Several studies [8–12] have concluded that whilst almost half of the building's energy consumption is related to building envelope characteristics and utilization of the building equipment, the crucial remaining half is influenced by occupant behavior. As a result, the challenge of properly achieving energy reduction targets in buildings as a means of contributing to resilience and sustainability is partly technological and partly related to human behavior [10,11]. Several other studies [13,14] highlighted the importance of increasing people's environmental awareness to improve their thermal comfort leading to a reduction in energy consumption. Gupta and Chandiwala (2010, p. 126) [15] defined the energy performance gap as "... the gap between expected and actual thermal energy consumption in buildings that highly depends on the human factor", which points to the energy use implications of occupant behavior. At the moment, the understanding of occupant behavior in building design is inadequate, which leads to unrealistic assumptions and simplifications in building modeling and analysis [16,17]. The lack of reliable building occupant data has been suggested by many studies [16–20] as a significant reason for the limited understanding of the impact of occupant behavior on energy conservation and mitigation of greenhouse gas emissions [20]. As a result, there is a strong need to obtain occupant behavior data in order to develop strategies to reduce the energy performance gap as much as possible to achieve long-term climate resilience and sustainability.

As the first step in addressing this need, this paper has focused on the importance of considering the influence of occupant behavior on the energy performance gap in residential buildings to achieve the highest level of thermal performance in buildings. Residential buildings account for 70% of building floor area around the globe, while the condition and efficiency of a large part of the residential stock still need attention [20,21]. In order to close the energy performance gap as much as possible in order to achieve better energy efficiency in residential buildings, this paper has proposed a conceptual framework for occupant behavior towards the modification of thermal comfort. This paper has also recognized the absence of comprehensive occupant data as the major reason for finding limited evidence by other researchers for the impact of occupant behavior on the energy performance gap with a view toward long-term resilience and sustainability.

This paper has adopted a narrative literature review methodology to answer the main research question: What is the significance of occupant behavior in reducing the energy performance gap of residential buildings? In this approach, information is collected and interpreted with reflective summaries of findings, with the literature being described and analyzed from a contextual and theoretical point of view. To answer the research question, first, the importance and effects of occupant behavior on the amount of energy that can be saved in buildings have been presented in Section 2. Section 3 proposes a conceptual framework for occupant behavior towards the modification of thermal comfort to reduce energy use to close the energy performance gap as much as possible to achieve better energy efficiency in residential buildings, and the final conclusions are drawn in Section 3 of this paper.

Energy consumption in buildings is influenced by both building-related factors and occupant-related factors, and the latter can apply as much as or have even more impact than the former [21]. In other words, human dimensions act as significantly as technological measures in maximizing the energy performance of buildings [22]. Several studies [8–11,16] have concluded that occupant behavior has a direct and significant impact on building energy consumption. Further studies [23–25] have shown that considering occupant behavior in the building development process is as important as the quality of the building envelope and equipment.

A Cambridge University (UK) study proposed that attention to occupant behavior change can increase the energy savings in buildings by 200% [26]. Educating occu-

pants of residential buildings could increase satisfaction with internal conditions [27]. Pilkington et al. (2011) [28] claimed that every single occupant could have a significant effect on energy efficiency and environmental impact.

2. Significance of Building Occupant Behavior on Thermal Energy Consumption in Residential Buildings and Reducing the Energy Performance Gap

A vast majority of people believe that corporations and the general public have to act much further to safeguard the environment for the sake of future generations [29]. The majority of people in different societies are not sure whom to rely on to make informed decisions to protect the environment. Trust in varied societies depends upon several factors, including people's ideas about whether or not the organization in question is honest in their communications and information or if they are truly concerned about keeping the environment safe and fair when it comes to making their own decisions toward public interests [30]. According to Vasi (2009) [29], it is realistic to consider people as bounded rationally, as they do not go through every detail when it comes to making a decision.

When discussing energy saving and protecting our planet, many researchers agree on few issues. For instance, Chen et al. (2015) [30] claimed that the energy efficiency of buildings is related to different factors such as climatic location characteristics, HVAC system, and, more importantly, occupant behavior and activities towards energy utilization. It is important to comprehend the connection between the building user's lifestyle and their energy consumption behavior to maintain or increase the building's energy efficiency [30].

There are only limited studies in the field of economics that have focused on the connection between human behavior and energy consumption [31,32]. Fischer et al. (2012) [33] presented societal change priorities in terms of a pyramid (Figure 1). Based on their proposed pyramid, applying changes to the categories at the top of the pyramid (e.g., management and policy actions) can be faster and easier but less profound compared to the categories at the bottom of the pyramid (e.g., personal and community values). They pointed out that all the social sectors, regardless of their place in the pyramid, need to collaborate on those changes simultaneously to enable the momentum for social change to spread up and down the pyramid. Ultimately, intense changes are going to be essential to make human behavior sustainable.

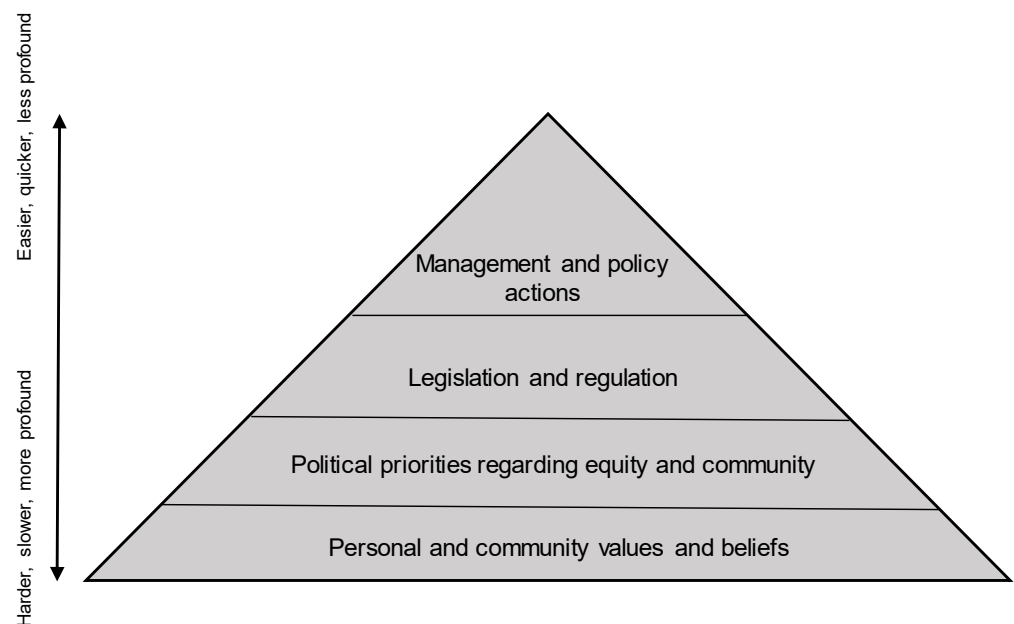


Figure 1. Societal change priorities in terms of a pyramid (after Fischer et al. 2012) [33].

According to Vasi (2009) [29], a survey showed that the public is generally concerned about environmental issues and energy consumption. Guerra-Santin and Itard (2010) [34] established a bond between energy consumption, building characteristics, and occupant behavior. As shown in Figure 2, the finding of their study revealed that analyzing household types and building characteristics in conjunction with occupant behavior result in a better understanding of the influence of the occupant on actual energy consumption and the energy-performance gap. They also found out that household characteristics, as well as the occupants' perceptions, values, and motives, are major determinants of the occupant behavior in relation to energy consumption. Energy-saving advice can also be tailored to specific household types.

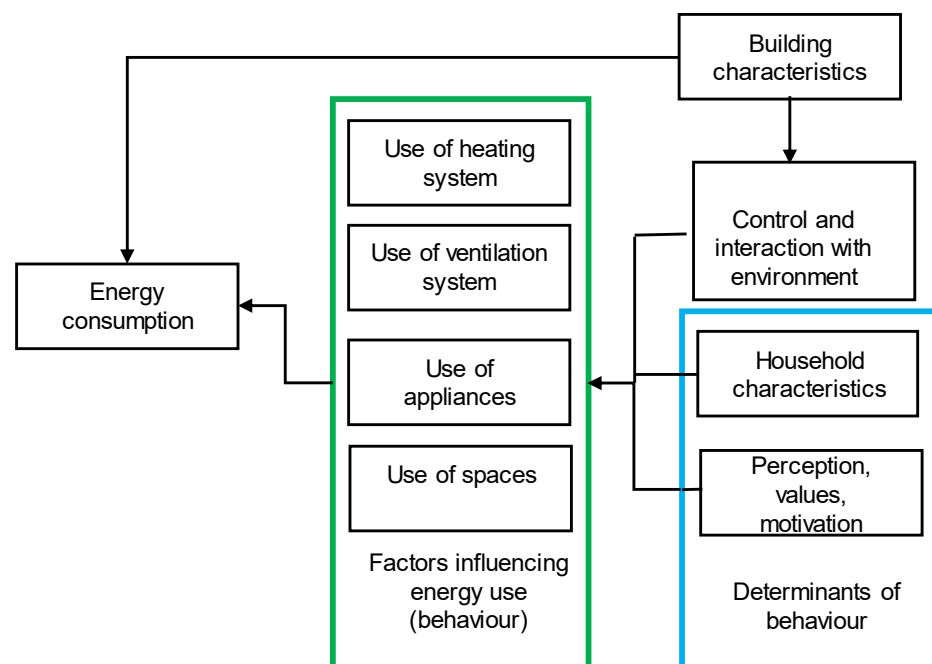


Figure 2. Relationship between energy consumption, building characteristics and occupant behavior (after Guerra-Santin and Itard 2010 [34]).

Several studies [14,35,36] highlighted the importance of increasing people's environmental awareness to improve thermal comfort for them, leading to a reduction in energy consumption.

Several studies [1,2,6,37,38] have stated that “the most highlighted gap in the literature is related to understanding the underlying social norms and priorities as well as the behaviors of households when approaching modification of thermal comfort to increase energy efficiency and sustainability in their homes.” Therefore, it is important to study and understand those priorities, behaviors, and norms since they are firmly connected to particular sustainable and efficiency-related outcomes [6]. A number of researchers [38–40] specifically recommended the collection of in-depth data in the area of occupant behavior in future work. According to Carlucci et al. (2020) [3], one of the main sources of uncertainty in determining the actual energy consumption of buildings is occupant behavior. There is a lack of research that thoroughly covers the different aspects of occupant behavior as well as the latest developments in this field [4]. The need for data collection and interpretation on building occupant behavior in relation to energy consumption has been explicitly highlighted in the current literature [1,17,18].

3. Proposed Conceptual Framework

As highlighted in the previous sections, there is a strong need to obtain appropriate occupant behavior data to develop strategies for closing the energy performance gap as much as possible to achieve the highest level of thermal performance in residential buildings. In order to address this need, this section proposes a conceptual framework for occupant behavior towards the modification of thermal comfort to reduce energy use. According to Krajhanzl (2010, p. 252) [41], “a pro-environmental behavior (PEB) is defined as an individual’s behavior that is generally or according to the knowledge of environmental science, judged in the context of the considered society as a protective way of environmental behavior or a tribute to the healthy environment”. PEB implies taking actions that reduce the damage to the environment [42]. Kollmuss and Agyeman (2002, pp. 239–240) [43] defined pro-environmental behavior as “a type of behavior that a person deliberately chooses in order to minimize the negative impact of their actions on the environment”. In the past couple of years, the common research topic for many researchers has been the motives and barriers to adopting PEB by people [41,42].

3.1. Theory of Planned Behavior (TPB)

Ajzen (1991, p. 118) [44] indicated that “the Theory of Planned Behavior is a widely accepted behavioral model for explaining and predicting behaviors through considering three core constructs: attitudes, subjective norms and perceived behavioral control”. These three constructs have been the front and center of the developed conceptual framework in this study. Armitage and Conner (2001) [45] mentioned that according to ‘Web of Science’ core collection, TPB is one of the most focused and widely used studied behavioral models. It has been the theoretical basis for 1311 research works since 1985 [46]. Considering the merits of the Theory of Planned Behavior (TPB), this theory has been explored as the conceptual framework’s theoretical underpinning in this study.

3.2. Developed Theoretical Frameworks Based on TPB for Studying Occupant Behavior

Adopting TPB as the theoretical basis, Blok et al. (2015) [47] carried out a comprehensive study on employees in the workplace at Wageningen University, the Netherlands. By adopting an online survey, people were invited by email to take participate. A total of 411 participants with equal gender distribution took part in the survey. After collecting and analyzing the data using Stata v12.1 software, Blok et al. (2015) [47] pointed out that TPB is fully capable of explaining PEB in the workplace. They have also concluded that the most significant factor in determining PEB in the workplace is the intention to act. Similarly, Belafi and Reith (2018) [48] studied occupant behavior with respect to energy use in six universities across Hungary, adopting the Theory of Planned Behavior (TPB). The result of the research highlighted the lack of motivating factors to act confidently toward pro-environmental behavior in the workplace.

Leeuw et al. (2015) [49] carried out a similar study based on TPB on high school students. Using survey questionnaires, they targeted high schools in Luxembourg. Analyzing the survey data, they highlighted that the attitudes toward PEB and intention to act had been the most significant factors affecting the pro-environmental behavior of the students.

3.3. A Conceptual Framework

All the mentioned studies in Section 3.2 have adopted TPB to understand occupant behavior in the education sector in Europe and carried out functional research in the area of PEB. Therefore, to study occupant behavior in residential buildings, this paper has adapted the methodology and framework used by Blok et al. (2015) [47] and Leeuw et al. (2015) to develop a conceptual framework.

In this paper, according to TPB developed by Ajzen (1991) [44], three core constructs of TPB, including attitudes, subjective norms (SNs), and perceived behavioral control (PBC), are utilized to examine building occupant behavioral intention to act pro-environmentally. Several researchers (e.g., Ajzen 1991 [44]; Blok et al. 2015 [47]; Leeuw et al. 2015 [49]) have

pointed out that these three major constructs directly influence the behavioral intention to act pro-environmentally.

Figure 3 illustrates the conceptual framework diagram for occupant pro-environmental behavior towards modifying thermal comfort to reduce energy use.

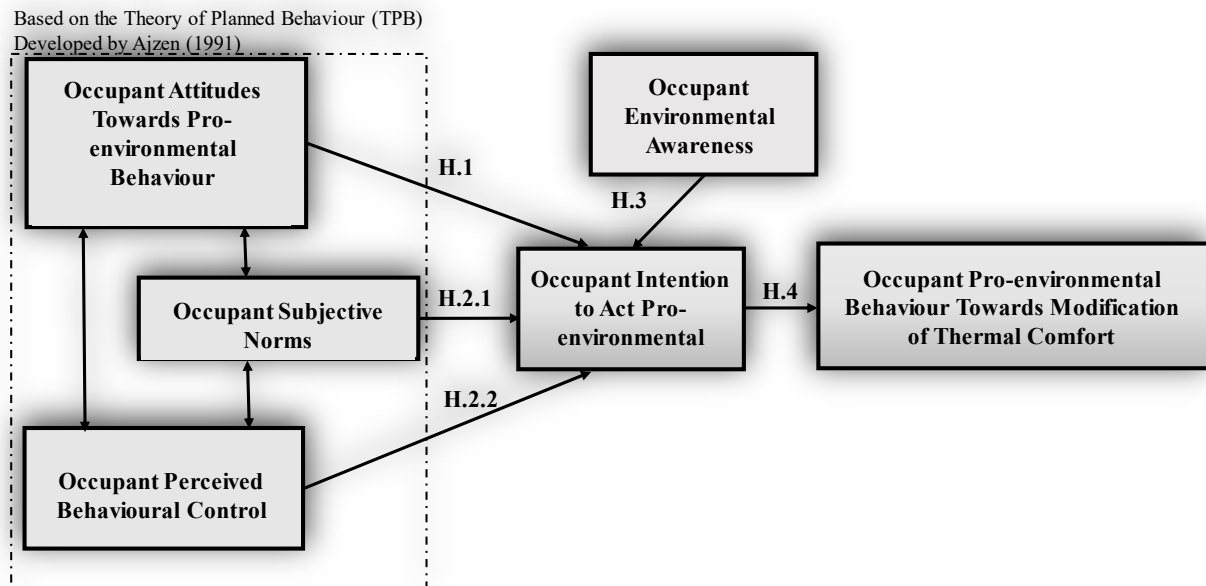


Figure 3. Proposed conceptual framework.

In the presented conceptual framework, the relationship between different items has been established using the following hypotheses:

Hypothesis 1. *Attitudes towards behaving pro-environmentally has positive impact on the occupant intention to act pro-environmental.*

Several researchers [50–53] have demonstrated that attitudes towards a certain behavior can have a constructive and direct impact on the behavioral intention of individuals. The same is applicable to the context of building occupant behavior.

Hypothesis 2.1. *Subjective norms positively influence the occupant intention to act pro-environmental.*

Subjective norms are defined in the literature as a community force to involve or not to involve in some behaviors [51]. In practical terms, the endorsement or condemnation of surrounding people creates a strong motivation for the intention to act. Synodinos and Bevan-Dye (2014) [53] stated that subjective norms have a strong and positive impact on encouraging energy conservation. For instance, the family members can encourage individuals' energy-saving behavior, such as checking whether the thermostats are set correctly at home every time they feel cold or hot.

Hypothesis 2.2. *The occupant intention to act pro-environmental is positively impacted by occupant perceived behavioral control.*

According to Ajzen (1991) [44], people's behavior is regularly subjected to the existence of means (e.g., time, money, knowledge). Those means function as constraints for the adoption of certain behaviors. Schultz and Oskamp (1996) [54] mentioned that people with high perceived behavioral control are more inclined to behave pro-environmentally.

Hypothesis 3. *Awareness of negative consequences of not behaving in pro-environmental manner encourages the occupant intention to act pro-environmental.*

Understanding the negative consequences of not behaving pro-environmentally is defined as environmental awareness [55]. Kollmuss and Agyeman (2002) [43] and Harland et al. (2007) [56] showed that awareness of the necessity of adopting pro-environmental behavior (e.g., conservation of energy), motivates individuals to be more receptive to behave pro-environmentally.

Hypothesis 4. *Intention to act pro-environmental has positive impact on PEB towards modification of thermal comfort to reduce energy use.*

The relationship between the intention to act pro-environmentally and its impacts on PEB has been studied by several researchers [53,55,56]. Those studies have indicated that the intention to act pro-environmentally has a positive impact on PEB towards energy conservation. As a result, the intention to act pro-environmentally can also have constructive effects on PEB towards the modification of thermal comfort to reduce energy use.

4. Conclusions

Based on several studies, it is understood that one of the main sources of uncertainty in determining the actual energy consumption of buildings is occupant behavior. By adopting a narrative literature review methodology, this paper highlighted the significance of considering occupant behavior to close the energy performance gap to contribute to climate resilience and sustainability. There is a lack of research that thoroughly covers the different aspects of occupant behavior as well as the latest developments in this field. Several studies indicated that whilst almost half of the residential building's energy consumption is related to building envelope characteristics and utilized equipment, the crucial remaining half is influenced by occupant behavior. As a result, the challenge of properly achieving energy reduction targets in residential buildings is partly technological and partly human behavior related.

This paper has also recognized the absence of comprehensive occupant data as the major reason for finding limited evidence by other researchers for the impact of occupant behavior on the energy performance gap. As a result, there is a strong need to obtain appropriate occupant behavior data to develop strategies for closing the energy performance gap as much as possible to achieve the highest level of thermal performance in buildings with a view toward long-term climate resilience and sustainability.

In order to address this need, this paper has proposed a conceptual framework for occupant behavior towards the modification of thermal comfort to reduce energy use. The authors of this paper are gathering and studying occupant behavior data related to energy use in residential buildings to understand the nature of occupant behavior leading toward an intention to modify thermal comfort to reduce energy consumption related to residential buildings and to develop a framework that highlights the elements of occupant behavior that can be addressed to encourage pro-environmental behavior. Employing and interpreting the occupant behavior data related to energy use in residential buildings, the proposed conceptual framework in this study will be numerically validated and further developed. The validated and developed framework and the obtained data will be published in the subsequent papers by the authors.

It is highly recommended that understanding the variety of factors influencing occupants' behavior should be considered a major influential factor in the design and retrofit of residential buildings. By obtaining appropriate occupant behavior data and proposing appropriate changes in the daily life routines and behavior of the occupants, the energy performance gap can be significantly reduced. Consequently, long-term support for climate resilience and sustainability will be provided.

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