

Roles of Occupant Behavior in Supporting Residential Energy Efficiency

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Residential buildings are among the largest energy consumers worldwide, making residential energy efficiency an essential component of sustainable development and climate change mitigation. Whereas technological improvements have improved building energy performance, growing evidence suggests that occupant behavior plays a decisive role in determining actual energy consumption levels. This study intends to examine the role of occupant behavior in supporting residential energy efficiency through a comprehensive literature review. The findings indicate that occupant behavior significantly affects residential energy use and can either enhance or undermine the effectiveness of energy-efficient technologies. The review also identifies several intervention strategies that can promote energy conservation, including monetary rewards, personalized home energy audits, and comparative feedback programs. Among these, personalized feedback and community-based approaches demonstrate greater potential for sustaining long-term behavioral change, while financial incentives are generally more effective in the short term. The study concludes that achieving meaningful and lasting reductions in residential energy consumption requires an integrated approach that combines technological improvements with behavioral interventions. Incorporating occupant behavior into energy-efficiency policies and residential design strategies is therefore important for promoting sustainable energy use and decreasing environmental impacts.

Keywords: Behavior, Energy Efficiency, Residential, Strategy

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1. Introduction

The increasing demand for energy and the growing concerns over climate change have made energy efficiency a critical issue in the built environment. Residential buildings account for a significant proportion of global energy consumption and greenhouse gas emissions, making the housing sector an important target for energy conservation initiatives. Buildings are a major source of energy consumption. During the workday, workers generally spend more time in the office than at home. Therefore, energy savings by building users will have a significant impact and help to reduce carbon emissions. One way to reduce this problem is through energy conservation. To reduce energy consumption and address this issue, several energy conservation measures have been implemented, including increasing energy efficiency, using renewable energy, and encouraging individuals to conserve energy in their daily lives [1]. Among these measures, encouraging individuals to conserve energy has been considered a direct and effective method [2]. Unlike energy conservation measures that rely on technology, approaches focused on user behavior can significantly reduce energy use quickly and at a low cost.

Residential buildings have become a key focus of energy-saving efforts due to their substantial contribution to overall energy demand. Although technological interventions, including the adoption of energy-efficient appliances and renewable energy technologies, have been widely implemented to improve building energy performance, growing evidence suggests that occupant-related factors play a key role in determining actual energy consumption levels. Occupants influence energy use through their daily routines, operational practices, and interactions with building systems, thereby affecting the effectiveness of technological

energy-saving measures. Consequently, behavioral approaches to energy conservation have gained increasing attention as a complementary strategy for enhancing residential energy efficiency. Such approaches delivers the potential to achieve significant energy savings in a relatively short period while requiring minimal financial investment compared to technology-based interventions.

Occupant behavior is a fundamental component of adaptive thermal comfort in residential buildings. To achieve and maintain satisfactory indoor thermal conditions, occupants continuously interact with and adjust their surrounding environment. Common adaptive actions include window operation, fan usage, the operation of cooling and heating systems, and modifications in clothing insulation. These behavioral responses not only contribute to thermal comfort but also have a substantial impact on residential energy consumption and building performance [3]

A comprehensive understanding of the psychological determinants of consumers' and prosumers' energy-saving behaviors is essential to maximizing the effectiveness of collective energy conservation efforts. Equally important is the identification of behavioral strategies that encourage individuals to make conscious energy-use decisions and foster the development of long-lasting sustainable practices [4]

Previous research has shown that energy-saving solutions remain heavily focused on structural and operational savings, such as replacing or adding energy-efficient equipment. However, installing energy-efficient equipment and increasing energy efficiency are still not enough to reduce energy consumption, especially in long-term savings due to the rebound effect. An example of this rebound effect phenomenon is when individuals realize that using air conditioning in a room uses less energy, then using the AC for a longer period of time becomes something that is considered normal [5][6]

This article examines the role of occupant behavior in supporting residential energy efficiency through a theoretical review of the relevant literature. By exploring the behavioral factors that influence household energy consumption and identifying strategies that promote energy-saving practices, the study seeks to provide a conceptual understanding of the relationship between human behavior and residential energy performance. The findings are expected to contribute to the development of more comprehensive energy-efficiency frameworks that integrate both technological and behavioral dimensions. One way to mitigate this problem is through energy conservation. To reduce energy consumption and address this issue, several energy-saving measures have been implemented, such as increasing energy efficiency, utilizing renewable energy, and encouraging individuals to conserve energy in their daily lives [1]

2. Literature Review And Problem Statement

Energy-saving behaviors are defined as everyday practices and household habits focused on specific reductions in energy use. Households decide how warm to keep their homes in the winter and how cool to keep them in the summer; they decide whether to leave lights and appliances on or off; they choose the water temperature for washing their clothes; and they decide which dishwasher cycle to use. Whether actively or passively, households make decisions about how to use their major energy systems [7]. Energy conservation is a strategy to optimize energy use by reducing unnecessary consumption. This practice does not only reduces energy waste but also supports the government's efforts to expand electricity access by allocating energy supplies more equitably to underserved areas [8].

In terms of location, energy consumption in tropical regions tends to be higher than in other climate zones due to elevated outdoor temperatures. According to the Building and Construction Authority of Singapore, this condition leads to a significant reliance on air-conditioning systems for indoor cooling. A notable example can be observed in Singapore, where, despite considerable efforts to promote energy conservation, building electricity consumption reports from 2008 to 2017 still indicated an increase of

approximately 25%. This trend highlights the challenges of reducing energy demand in tropical climates, where cooling requirements constitute a substantial portion of household and building energy use [9]

Previous research also notes that lifestyle is recognized as an important determinant of energy consumption behavior. The comfort and convenience provided by energy use often discourage individuals from adopting energy-saving practices, leading many to favor maintaining existing consumption patterns rather than reducing their energy demand [2].

According to Martinsson et al., it is generally assumed that individuals with higher incomes are less likely to engage in energy-saving behaviors in their daily lives. This assumption is based on the belief that high-income individuals have fewer financial incentives to reduce their energy consumption. However, Martinsson's study suggests otherwise, indicating that individuals with higher incomes may, in fact, exhibit a greater tendency to adopt energy-conservation practices. Furthermore, Martinsson explains that the relationship between individuals' environmental attitudes and their energy-saving behavior is complex and difficult to define precisely. While positive environmental attitudes may encourage energy conservation, the extent to which these attitudes translate into actual behavior is influenced by a variety of interacting social, economic, and psychological factors [10]

The association between environmental attitudes and energy-saving behavior is multifaceted and remains challenging to define precisely. According to Gedenne, environmental attitudes are influenced by various interrelated determinants, including environmental norms, environmental beliefs, perceived drivers and barriers to pro-environmental action, and social influences. Together, these factors shape individuals' environmental perceptions and behavioral intentions, thereby affecting their engagement in energy-conservation activities. The relationships among these determinants are summarized in the framework shown below.

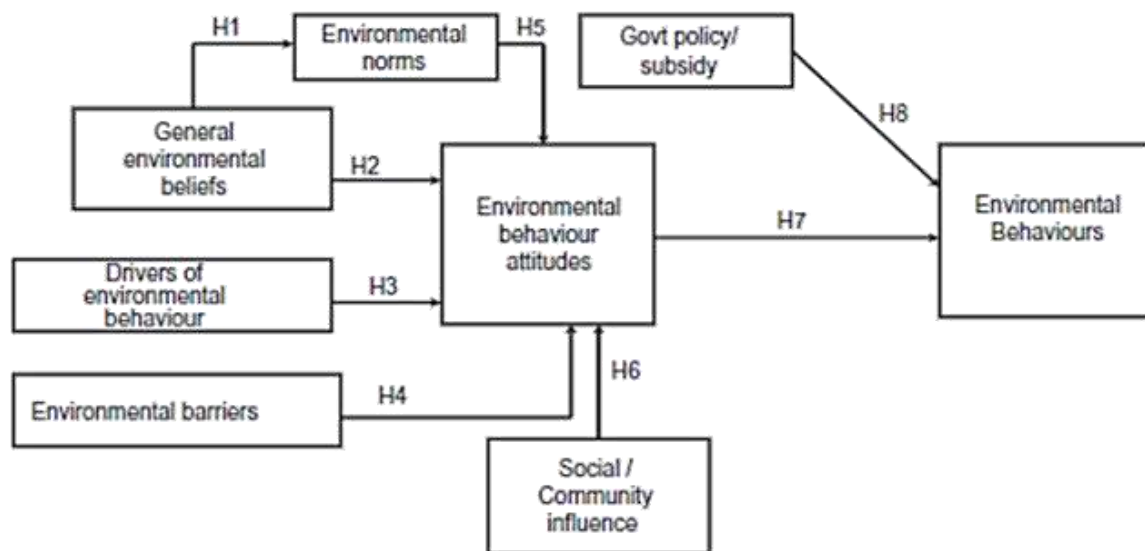


Fig 1. Framework of Factors Influencing Environmental Attitudes

According to Jan Krajhanzl, several stages should be considered when examining the factors that influence individuals' environmental attitudes:

1. Understanding the system of factors influencing individual environmental behavior by identifying and compiling concepts that promote awareness and orientation toward relevant environmental issues.
2. Systematically identifying the factors that influence environmental behavior and their interrelationships. This can be achieved through observation, activity tracking, analysis of behavioral patterns, and conducting interviews to gain a deeper understanding of environmental behavior.

3. Evaluating key factors that have the potential to exert significant influence on the environmental behavior of broader social groups, thereby identifying the most critical determinants of pro-environmental actions [11]

3. Method

This study employed a systematic literature review (SLR) approach to examine the role of occupant behavior in supporting residential energy efficiency. The review was conducted through a structured process of identifying, screening, evaluating, and synthesizing relevant scholarly literature. Scientific publications were retrieved from major academic databases, including Scopus, ScienceDirect, Web of Science, and Google Scholar.

The literature search was performed using combinations of keywords such as “occupant behavior,” “energy-saving behavior,” “residential energy efficiency,” “household energy consumption,” “energy conservation,” “adaptive thermal comfort,” and “behavioral intervention.” To ensure the relevance and currency of the reviewed studies, only articles published between 2015 and 2025 were considered. The search was limited to peer-reviewed journal articles published in English.

The selected literature was analyzed using a thematic analysis approach. The studies were categorized into several themes, including determinants of occupant behavior, adaptive thermal comfort practices, psychological factors affecting energy use, behavioral intervention strategies, and the relationship between occupant behavior and residential energy performance. The findings from these studies were then synthesized to develop a comprehensive understanding of how occupant behavior contributes to residential energy efficiency and to identify research gaps for future investigation.

4. Results and Discussion

Individual Behavior Toward Energy Saving

One of the most widely recognized theories for examining the variables that influence human behavior is the Theory of Planned Behavior. This theory is based on the assumption that individuals make rational decisions and choose options that they perceive to offer the greatest benefits while incurring the lowest costs. Accordingly, the theory proposes that an individual's behavior is directly determined by their behavioral intention, which is, in turn, influenced by three key variables: attitude, subjective norms, and perceived behavioral control. These factors collectively shape an individual's intention to perform a particular behavior and ultimately affect the likelihood of that behavior being carried out [12]

Human behavior significantly influences current climate change and global environmental conditions. To date, discussions related to environmental issues have often suggested that environmentally unfriendly behaviors are primarily caused by a lack of knowledge and concern about the environment. However, further research has demonstrated that numerous factors contribute to individuals making irrational decisions, which can, in turn, have adverse effects on the environment. These findings indicate that environmental behavior is not solely determined by knowledge or awareness. Rather, it is shaped by a complex interplay of psychological, social, economic, and contextual factors that influence how individuals make decisions and respond to environmental issues [13]

Factors Influencing Energy-Saving Behavior

a. Ethical Standards

People's willingness to save electricity is significantly influenced by their ethical standards. Ethical values shape individuals' perceptions of what is right and wrong and serve as an important foundation

for decision-making in everyday life. These values often guide behavior in various contexts, including interpersonal relationships, professional conduct, and attitudes toward environmental protection and resource conservation [14].

a. Attitude

There is a positive correlation between individuals' attitudes toward electricity conservation and their perceived behavioral control regarding the intention to save electricity. In other words, individuals who view energy conservation favorably are more likely to perceive themselves as capable of controlling their electricity usage. This sense of control enhances their intention to engage in electricity-saving practices and increases the likelihood of translating those intentions into actual behavior [2].

Energy Saving Intervention Strategies At Home

The promotion of energy-saving behavior in residential environments can be supported through the implementation of three intervention strategies.

a. Monetary Rewards

Incentives have been shown to produce a significant impact on behavior. From a psychological perspective, individuals are generally more influenced by receiving rewards than by being subjected to penalties for a particular behavior. Therefore, monetary rewards represent an appropriate intervention strategy for encouraging energy-saving practices. Households that successfully reduce their monthly energy consumption may be provided with incentives, such as direct financial rewards, monthly electricity bill subsidies, or tax reductions. These measures can serve as effective motivators for promoting sustained energy conservation behavior [15]. Households that receive incentive-based interventions tend to demonstrate higher percentages of energy savings compared to those that do not receive incentives. However, a limitation of this type of intervention is its reduced effectiveness in the long term. Over time, individuals may become accustomed to the incentives provided and perceive that they have sufficient financial resources to return to their previous patterns of energy consumption [16]

b. Home Audits

In this intervention, a customized energy audit is conducted for each household. One of the main advantages of this approach is that participants receive information that is specifically relevant to their circumstances, rather than being overwhelmed with general information that may not apply to their particular household conditions. Based on a previous case study, one year after the audit, the household under investigation achieved a 1–2% reduction in gas consumption compared to other households. Two years after the audit, these energy savings increased to approximately 4%. Furthermore, households that underwent the energy audit reported that they continued to engage in energy-saving practices over time, indicating the potential for sustained behavioral change. [17]

c. Comparative Feedbacks

This intervention involves the formation of a community or small group in which members regularly discuss energy conservation practices. By sharing information and evaluating each other's energy-saving achievements, this strategy is expected to foster a sense of competition and social comparison among participants. Such dynamics may motivate individuals to reduce their energy consumption further, as they seek to demonstrate their energy-saving performance to other members of the group. Additionally, the exchange of experiences and best practices within the group can enhance participants' awareness of energy conservation and encourage the adoption of more sustainable energy-use behaviors [17]

Discussion

The reviewed literature consistently demonstrates that residential energy consumption is influenced by a combination of psychological, social, and contextual factors. While the Theory of Planned Behavior identifies attitude, subjective norms, and perceived behavioral control as key determinants of energy-saving intentions, several studies suggest that these factors do not operate independently. Instead, they interact with ethical values, environmental awareness, household characteristics, and external interventions to shape actual energy-saving behavior. A comparison of previous studies reveals that attitude is among the most frequently identified predictors of energy conservation behavior. Individuals who possess positive attitudes toward environmental protection are generally more willing to reduce electricity consumption and adopt energy-efficient practices. However, favorable attitudes do not always translate into actual behavior. This finding supports the existence of the attitude-behavior gap, in which individuals express concern about environmental issues but fail to consistently engage in energy-saving actions.

These findings suggest that no single intervention strategy is sufficient to achieve long-term residential energy efficiency. Financial incentives may be effective for initiating behavioral change, whereas information-based interventions and social comparison mechanisms are more effective in sustaining energy-saving practices. Therefore, an integrated approach combining economic, informational, and social interventions is likely to yield the most significant and enduring energy savings.

Based on the reviewed literature, occupant behavior can be conceptualized as the result of interactions among internal factors (ethical standards, attitudes, environmental awareness, and perceived behavioral control) and external factors (monetary incentives, energy audits, and comparative feedback mechanisms). These factors influence energy-saving intentions, which, in turn, affect actual household energy-saving behavior and ultimately contribute to residential energy efficiency. This conceptualization highlights that improving residential energy performance requires not only technological solutions but also behavioral interventions that address both individual motivations and social contexts.

5. Conclusion

This review highlights that occupant behavior is a critical determinant of residential energy efficiency and should be considered alongside technological solutions in efforts to reduce household energy consumption. The findings indicate that energy-saving behavior is influenced by a combination of psychological, social, ethical, and economic factors, including attitudes toward energy conservation, ethical standards, perceived behavioral control, and external social influences. Consistent with the Theory of Planned Behavior, positive attitudes and stronger perceptions of behavioral control are associated with higher intentions to engage in energy-saving practices, which, in turn, affect actual energy-use behavior.

The review further demonstrates that various intervention strategies can support residential energy conservation. Monetary incentives are effective in encouraging short-term reductions in energy use, whereas personalized home energy audits and comparative feedback mechanisms show greater potential for fostering long-term behavioral change. These findings suggest that sustainable residential energy efficiency is more likely to be achieved through integrated approaches that combine economic incentives, information-based interventions, and social engagement strategies.

From a theoretical perspective, this study contributes to the growing body of knowledge on residential energy efficiency by synthesizing evidence on the relationships among behavioral determinants, intervention strategies, and energy-saving outcomes. The proposed conceptual framework provides a comprehensive understanding of how internal factors and external interventions interact to influence occupant behavior and residential energy performance. From a practical perspective, the findings offer

valuable insights for policymakers, energy providers, housing developers, and building managers in designing behavior-oriented energy conservation programs that complement technological improvements. This study is subject to several limitations. First, the findings are based solely on previously published literature and therefore depend on the scope, quality, and geographical coverage of existing studies. Second, the review does not quantitatively evaluate the effectiveness of different intervention strategies through meta-analysis. Third, variations in cultural, socioeconomic, and climatic contexts across studies may influence the generalizability of the findings.

Future research should focus on empirical investigations of occupant behavior in specific residential contexts, particularly in developing countries, where the behavioral dimensions of energy efficiency remain underexplored. Further studies may also evaluate the long-term effectiveness of integrated intervention strategies and investigate how emerging smart-home technologies, real-time energy feedback systems, and behavioral nudges can enhance residential energy conservation. Such efforts would contribute to the development of more effective and context-sensitive approaches to achieving sustainable energy use in the residential sector.

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