



Perceptual and Behavioral Determinants for Optimizing Energy Performance in Buildings: A Study of Maladaptive Human Interactions

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ABSTRACT

The persistent discrepancy between predicted and actual building energy performance has highlighted the need to better understand the role of occupants in shaping operational energy outcomes. While technological advances have significantly improved building efficiency, human behavior remains a critical yet often underestimated determinant of actual energy consumption. This study investigates the behavioral and environmental factors influencing lighting-related energy use in office environments, with particular emphasis on environmental concern, flexibility of energy-control systems, and responsive occupant behavior. Drawing upon theories from environmental psychology, behavioral science, and architectural research, a mixed-method approach was adopted comprising naturalistic observations, structured behavioral observations, and a survey-based investigation. Fieldwork was conducted within contemporary office environments. Following exploratory observations across multiple workplaces, a case-study office building was selected for detailed investigation. The study involved 77 participants representing a range of professional roles, including administrators, engineers, programmers, and researchers. The findings indicate that environmental concern alone does not adequately explain adaptive energy-related behavior. Instead, occupants' responses emerge through the interaction of personal values, environmental opportunities, spatial perception, and the accessibility of environmental control systems. Flexible lighting-control mechanisms, including adjustable blinds and decentralized lighting controls, were found to encourage greater engagement with daylight and more responsive lighting-related actions. Conversely, social dynamics, workplace norms, and limited environmental control frequently constrained adaptive behavior despite occupants' awareness of energy-saving opportunities. The study argues that occupants should be regarded as active participants in building performance rather than unpredictable sources of variation. The results demonstrate that improving building energy performance requires an integrated human-centered approach in which architectural design, environmental affordances, and behavioral determinants are considered alongside technological efficiency measures. By supporting environmental awareness, user autonomy, and adaptive interaction, buildings can more effectively reduce the performance gap and achieve long-term sustainability objectives.

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1. Introduction

The optimization of building energy consumption through an understanding of human behavior has gained increasing importance in recent decades. Early work by Maloney and Ward (1973) identified “maladaptive human behavior” as a contributor to environmental degradation, laying the foundation for subsequent research on the behavioral dimensions of energy use. Numerous studies across environmental psychology and sustainability research demonstrate that everyday human actions have significant potential either to enhance or undermine environmental outcomes (DuNann Winter & Koger, 2004; Steg & Vlek, 2009; Tudor, 2011). Although overall building energy consumption does not always correlate directly with pro-environmental attitudes, adaptive human actions and individual conservation strategies continue to be critical areas of inquiry.

A central mechanism through which humans influence building performance is spatial perception—how individuals interpret light, material contrast, temperature cues, and other environmental signals within the built environment. Architectural elements have the capacity to trigger efficient or inefficient behaviors (Abrahamse & Wokje, 2005), making perception a key mediator between environmental conditions and behavioral outcomes. Understanding how perception transitions into attitudes and, ultimately, behaviors provides insight into why occupants respond differently to similar environmental conditions.

Multiple non-architectural parameters also shape behavior. At the individual level, environmental concerns, value structures, personal norms, and beliefs influence the tendency to engage with energy-saving opportunities. At the environmental level, the availability, accessibility, and flexibility of control systems determine whether occupants are able to act on their intentions. A broad literature base—spanning psychology, sociology, anthropology, and environmental sciences—has examined these behavioral determinants, identifying personal values (Collins, Steg & Koning, 2007; Karp, 1996; Stern, 2000), beliefs and norms (Stern et al., 1999; Schwartz, 1977; Harland, Staats & Wilke, 1999; Nordlund & Garvill, 2003), socio-economic parameters (Pothitou et al., 2016), and social influences (Gifford & Nilsson, 2014; Nolan & Schultz, 2014), as well as egoistic and altruistic incentives (Berenguer, 2007), as important predictors. However, convergent approaches focusing exclusively on personal factors fall short of explaining the full complexity of human behavior, as adaptive attitudes arise

from the interplay of cognitive, environmental, and habitual components.

Environmental attitudes themselves are multifaceted, latent constructs that cannot be observed directly but must be inferred from decisions and actions (Stern, 1992; Dunlap & Jones, 2002). Measurement tools—such as self-reports, implicit assessments, and widely used scales including the Ecology (E) Scale (Maloney & Ward, 1973), the Environmental Concern (EC) Scale (Weigel & Weigel, 1978), and the New Environmental Paradigm (NEP) Scale (Dunlap & Van Liere, 1978; Dunlap et al., 2000)—all agree that environmental attitudes consist of cognitive, affective, and behavioral components. Dunlap and Jones (2002) further classify attitude measures into four categories based on topic range and expression type, offering a structured approach to understanding environmental dispositions.

Aligned with this framework, the present study employs a single-topic, multiple-expression structure focusing on responsive lighting consumption. Three major components guide the analysis:

- a) individual cognition, representing personal environmental concerns;
- b) facility effect, reflecting access to and flexibility of lighting controllers;
- c) responsive behavior, referring to the actual actions taken by occupants.

These three determinants—environmental concerns, flexibility of controllers, and responsive behavior—form the conceptual basis of the paper and are reviewed in depth in the following chapters.

2. Environmental Concern and Adaptive Behavior

The effectiveness of environmental concern in shaping environmental attitudes has been one of the most widely examined topics in research on adaptive attitudes. In this paper, environmental concern refers to one’s interpretation of general environmental problems based on personal values and beliefs, whereas environmental attitudes denote personal beliefs that translate into behavioral intentions. According to the hypothesized relationship between spatial perception and responsive behavior, two key variables—personal environmental concern and the flexibility of light-controllers—have been shown to positively influence individuals’ actual behavior towards energy consumption in buildings.

Numerous studies have examined the link between environmental concern and environmental attitudes, most of which build on Schwartz's model of human values (Schwartz, 2012). Schwartz's framework identifies core personal values that are consistent across cultures. Understanding these basic human motives is essential for interpreting how environmental values are formed. The Environmental Motives Scale (EMS) is one of the most widely used tools for quantifying motivations behind environmental concern (Coral, 2011). The EMS is grounded in Stern's Value–Belief–Norm (VBN) theory, which posits that environmental concerns stem from beliefs and deeply held value systems (Stern, 2000).

Most measurement systems for environmental motives agree on three categories of environmental concern based on VBN values:

1. Egoistic values, focused on personal benefits
2. Social–altruistic values, focused on other people
3. Biospheric values, focused on nature and ecological systems

These categories are supported by major contributions in the literature (Stern & Dietz, 1994; Kalof, 1993; Stern et al., 1999). Environmental actions derived from these motives differ accordingly. For example, an individual may rely on natural lighting to save money or improve personal well-being (egoistic), conserve resources for future generations (altruistic), or reduce carbon emissions to protect ecosystems (biospheric). Understanding distinctions among these values enhances the ability to explain what drives people to act on environmental issues (Schultz & Zelezny, 2003).

As environmental conservation has become a global priority, governments and organizations have increasingly used campaigns, workshops, and educational programs to promote resource management. These messages typically highlight collective benefits for society and the environment. However, the VBN model suggests that personal benefits also play a crucial role in encouraging environmentally responsible actions.

A large body of research posits that values are relatively stable and resistant to change (Schwartz & Bilsky, 1987; Schwartz & Bilsky, 1990). These studies do not deny that values influence behavior but question whether targeting values directly is an effective strategy for changing environmental actions. Other research shows that human behavior is not always driven by expressed concerns; environmental concern does not necessarily predict

behavior. Many such studies rely on self-reported concerns rather than underlying values, making them vulnerable to bias. Consequently, verbal declarations alone are not considered reliable indicators of true environmental motives.

Value-based incentives may nonetheless influence whether individuals adopt active or passive energy-related behaviors. Research on interventions promoting green electricity over fossil fuels in households shows that financial incentives can produce both short-term and long-term behavioral changes. However, similar effects are less likely in workplace environments, where financial incentives are rarely a primary motivator. Instead, other egoistic values—such as workplace reputation, social approval, or improved health—may encourage environmentally responsible behaviors.

3. Flexibility of Control Systems

Buildings are often considered fixed and static entities—designed either to be environmentally friendly or not—and capable of interacting with environmental conditions either actively or passively. However, this view fails to acknowledge the dynamic nature of the building's primary “living characters”: its occupants. In addition to responding to climatic changes, architecture must possess a certain degree of flexibility that allows it to adapt to and interact effectively with its users. Between the two dynamic variables of climate and mobile occupants, architecture acts as a mediator that enables controlled interaction. The extent to which architectural and dependent elements allow occupants to modify spatial settings such as lighting and temperature defines the “flexibility of light-controllers,” which constitutes the second confounding variable examined in this study.

The notion of “better lighting” has been widely used as a persuasive marketing strategy within the construction and design industry. Lighting has significant impacts on human physical and psychological well-being, prompting architects to consider parameters such as illuminance, uniformity, colour temperature, thermal influence, and visual contrast in their design processes. However, the flexibility of lighting-control mechanisms—whether for natural or artificial lighting—remains an undervalued aspect of design.

Lighting adjustment equipment, including manual or electronic blinds and centralized or decentralized lighting switches, plays a substantial role in influencing electricity consumption, particularly in commercial buildings where occupants with different preferences, lifestyles, and comfort thresholds share the same spaces. Requirements

for lighting adjustment may range from the use of manual blinds to electronic shading systems, distributed switches, and layout decisions involving interior design and building orientation.

Artificial intelligence (AI) has increasingly been incorporated into interior design and façade systems through recognition algorithms and predictive controls. Despite some successful projects in AI-based lighting systems, long-term results have often fallen short of expectations. This is largely because such systems typically fail to consider occupants as dynamic agents whose intentions, habits, and perceptual interpretations cannot be fully predetermined.

Architectural lighting design significantly influences spatial perception. Beyond illuminating a space, lighting contributes to physical and psychological comfort. Concepts of visual comfort have been described in prior research as “a predictable experience” (Tiller, 1993) and “a shared experience” (Flynn, 1973). Although standards for office lighting outline general comfort ranges, variations in tasks, visual requirements, and interior surface characteristics lead to diverse lighting needs. For instance, the lighting required for computer work differs from that required for paperwork. Additionally, perceptions of lighting vary based on colour, surface reflectance, and interior material contrast, all of which influence whether occupants favour natural or artificial light.

Individual control over lighting—whether by adjustable blinds or distributed switches—provides users with a sense of autonomy over their spatial climate and increases the likelihood of active environmental engagement. Observations in two office buildings in Tehran illustrate this: in one case, occupants blocked natural light with improvised materials and relied heavily on artificial lighting, while in the other, adjustable window shades enabled individualized control, allowing occupants to manage natural light effectively.

Conflicts over optimal illuminance or thermal comfort are common in shared spaces. Multiple studies demonstrate that office workers exhibit varied lighting preferences even when performing identical tasks (Veitch & Newsham, 2000). While building regulations and sustainability strategies may prescribe uniform artificial lighting levels, user preferences often diverge from standard requirements. In one study, office users rated the ability to control lighting with an average score of 4.2 out of 5, highlighting its importance (Moore, Carter & Slater, 2002). Further research confirms that individual

lighting control enhances overall environmental satisfaction (Veitch et al., 2010).

Patterns of lighting-controller use differ between large open-plan offices and small private offices. O’Brien and Gunay (2014) found that occupants in shared spaces often adopt coping strategies, such as avoiding lighting adjustments to reduce the risk of conflict with colleagues, even when discomfort is experienced. Similar findings were also reported by Moore et al. (2002). Such behavioural tendencies indicate the influence of social dynamics on environmental interaction.

Given that contrasts in lighting directly influence spatial perception, excessive uniformity in indoor microclimates may disconnect occupants from their environment. Smaller offices without open plans typically benefit from task-based lighting strategies that prioritize natural lighting. The growing trend toward desk-sharing and flexible workplaces further reinforces the need for adaptable and individualized lighting solutions.

Lighting is therefore an essential component of interior environmental design, influencing both user comfort and the operational energy profile of buildings. Beyond its functional purpose, lighting serves as a behavioral interface between occupants and the built environment. As previously discussed, the flexibility of lighting controllers—whether in the form of adjustable blinds, task-oriented lighting, or distributed switching systems—plays a decisive role in shaping how occupants regulate their surroundings. This flexibility determines the degree to which individuals can exercise control over daylight availability, glare prevention, heat gain, and the intensity of artificial lighting.

Current research continues to investigate how the presence or absence of such flexibility affects human behavior in shared environments, particularly within open-plan offices where social norms, group dynamics, and interpersonal sensitivities can inhibit active engagement with environmental controls. In these contexts, architectural elements capable of supporting intuitive adjustments—such as easily reachable blinds, individually dimmable luminaires, or user-centered control interfaces—act as active design features that promote responsive and energy-conscious behavior. When occupants are able to negotiate their visual and thermal comfort through small adaptive actions, buildings are more likely to achieve optimized passive energy performance.

Examples of these interactions include adjusting blinds to balance daylight use with heat gain, modifying shared

lighting in response to changing occupancy patterns, and reducing artificial lighting levels when daylight is sufficient at specific workstations. Each of these behaviors illustrates how architectural affordances, perceptual interpretations, and behavioral tendencies converge to influence energy demand in real time.

Ultimately, the degree of lighting-controller flexibility provided by architectural and systems design has a direct impact on whether occupants behave actively—adjusting conditions to support passive energy savings—or passively, relying on default artificial lighting regardless of environmental potential. This interplay between environmental affordances and human behavior forms a critical dimension of building performance and leads directly into the next chapter, which examines responsive behavior as a key determinant of optimized energy performance.

4. Methodology

A mixed-method research design was adopted to investigate the behavioral determinants of lighting-related energy consumption.

Naturalistic Observations

The first stage involved disguised naturalistic observations conducted within multiple contemporary office environments. These observations sought to identify spontaneous occupant interactions with lighting conditions, movement patterns, and environmental adjustments. Observations documented the frequency and nature of lighting-related actions, reasons for workstation departures, responses to daylight availability, and variations in environmental interaction across different spatial settings.



Fig.1 Participants expressing their opinion on their lighting condition

Structured Observations

The second phase consisted of structured weekly observations. An observational action diary was developed to systematically record behavioral responses under varying environmental and organizational conditions.

Observed actions were categorized according to physical movement requirements and environmental interactions. This process enabled the identification of recurring behavioral patterns and key study variables.



Fig.2 Monitoring four participants adjusting their lighting

Survey Investigation

Fifteen office buildings meeting predefined selection criteria were approached. Eligible buildings ranged between 1,000 and 3,000 square meters and accommodated approximately 80 to 150 employees.

Two organizations agreed to participate. One computer programming company occupying approximately 1,440 square meters and employing more than 110 on-site workers was selected as the primary case study.

A total of 99 employees were invited to participate in the survey, of whom 77 agreed. The final sample included administrators, engineers, programmers, and researchers. Female participants represented 44.2% of the sample, while male participants represented 55.8%. Most respondents were between 25 and 44 years of age and worked more than eight hours per day.

5. Findings

The observational phase revealed substantial variation in occupants' interactions with lighting systems despite similar environmental conditions.

Many participants demonstrated awareness of daylight availability yet continued to rely heavily on artificial

lighting. This finding suggests that environmental awareness alone does not necessarily produce adaptive behavior.

Behavioral responses were strongly influenced by environmental affordances. Occupants were more likely to engage with environmental opportunities when lighting-control mechanisms were visible, accessible, and easy to operate. Adjustable blinds and decentralized lighting controls encouraged greater interaction with natural lighting conditions and reduced reliance on artificial illumination.

Social factors also influenced behavior. In shared office environments, occupants frequently avoided adjusting lighting conditions to prevent disrupting colleagues or creating interpersonal conflicts. Such observations indicate that behavioral outcomes are shaped by both physical and social dimensions of the workplace.

The findings further suggest that responsive behavior emerges from the interaction of environmental concern, environmental opportunities, and individual perceptions rather than from any single determinant.

6. Discussion

The results support the proposition that occupant behavior represents a fundamental component of building performance. Environmental concern contributes to adaptive attitudes, yet concern alone is insufficient to explain behavioral variation. The translation of environmental values into action depends on the presence of environmental opportunities and the willingness of individuals to engage with them.

The study also highlights the importance of environmental control as a mediator between attitudes and actions. Occupants are more likely to engage in adaptive behavior when buildings provide opportunities for meaningful environmental intervention. Flexible lighting-control systems therefore play an important role in supporting energy-conscious behavior.

These findings challenge approaches that rely exclusively on technological solutions for improving building performance. Instead, the results suggest that effective sustainability strategies must integrate technological efficiency with behavioral understanding and user-centered design.

7. Limitations

This study was conducted within a single organizational context and focused primarily on lighting-related

behavior. Consequently, caution should be exercised when generalizing findings to other building types and cultural settings. Future research should examine larger and more diverse populations and incorporate additional dimensions of adaptive behavior.

8. Conclusion

Human behavior constitutes a critical yet often overlooked component of building energy performance. Environmental concern, spatial perception, and lighting-controller flexibility collectively shape occupants' responses to environmental conditions. Buildings that support awareness, flexibility, and user engagement are more likely to facilitate adaptive energy-saving behavior and reduce the gap between predicted and actual performance.

Achieving sustainable building performance therefore requires a shift from technology-centered approaches toward integrated human-centered strategies that recognize occupants as active participants in environmental performance rather than passive consumers of energy.

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