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Framework to investigate energy conservation motivation and actions of building occupants: The case of a green campus in Abu Dhabi, UAE

Elie Azar *, Hamad Al Ansari

Masdar Institute of Science and Technology, United Arab Emirates

HIGHLIGHTS

- A framework is proposed to assess occupants' energy saving motivation and actions.
- Data is collected from 227 occupants of a green campus in Abu Dhabi, UAE.
- Principal Components Analysis (PCA) and multiple linear regression models are used.
- Occupants' energy saving awareness and motivation do not directly lead to actions.
- Demographics and reported sources of motivation are important drivers of actions.

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ABSTRACT

Significant energy savings can be achieved in buildings by altering how occupants use and operate various building systems. The first step to successfully inducing such change requires a thorough assessment and understanding of the actual drivers and motivators of existing behaviors. The current literature on energy conservation behaviors in buildings presents significant limitations including: (1) the availability of data on human behavior in buildings; (2) the lack of consideration of various behavioral drivers (e.g., social, environmental, and economic); (3) simplified data analysis methods, which overlook combined effects of behavioral drivers; and (4) limited scopes of work to either residential or commercial buildings, overlooking potential synergies between the two. This paper aims to fill the stated gaps in the literature by proposing a comprehensive data collection and analysis framework to investigate the energy conservation motivation and actions of people in individual or groups of buildings (e.g., community or city). The framework is illustrated through a case study on a green campus located in Abu Dhabi, United Arab Emirates (UAE). Data was collected from a total of 227 campus users or residents, followed by descriptive and statistical analyses using Principal Components Analysis (PCA) and multiple linear regression models. Results indicate that energy saving awareness and motivation do not directly translate to actions, particularly at the workplace where a correlation coefficient of only 0.083 is observed. Factors such as respondents' demographics, the level of control over building systems, and motivation drivers (e.g., financial, social, and environmental) highly affect energy saving actions and need through consideration for effective human-focused energy conservation strategies.

1. Introduction

1.1. Background

The current world energy crisis is forcing governments to evaluate the energy performance of their various sectors, especially the building sector, which accounts for more than one-third of the global demands for energy [1]. Building energy efficiency has therefore been a central focus of research over the past decades, resulting in the development and deployment of low-energy design and technologies, building standards, and green labeling and certification mechanisms [2–4]. Despite the mentioned efforts, buildings consistently consume more energy than the estimates made during the design phase [5,6]. Discrepancies between predicted and actual energy consumption typically exceed 30% and can reach up to 100% in some instances [7–9].

* Corresponding author at: Department of Engineering Systems and Management, Masdar Institute of Science and Technology, P.O. Box 54224, Abu Dhabi, United Arab Emirates.
E-mail address: eazar@masdar.ac.ae (E. Azar).

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In recent years, the observed discrepancies have motivated the need to investigate other non-technical drivers of energy consumption in buildings, especially how occupants control and operate various building systems [10–12]. Recent studies confirm that occupancy energy use patterns, also referred to as energy consumption behaviors, can have a significant impact on building energy performance [13,14]. Common behaviors include – but are not limited to – controlling equipment and lighting usage, adjusting thermostat set points, opening windows and doors, and hot water usage [15]. For instance, a study by Azar and Menassa [10] estimates a potential energy savings in United States (US) office buildings at 21% if occupants adopt simple actions such as adjusting thermostat set point temperatures by few degrees and reducing equipment and lighting use during unoccupied building periods. Similarly, the Carbon Trust [16] estimates that simple occupancy actions can reduce the energy operation costs in buildings by 20% at little to no capital costs.

In parallel to quantifying the impact of human actions on building performance, there is an equally urgent need to evaluate and map the drivers of current energy consumption behaviors [17–19]. This step is essential to devise focused strategies or interventions that aim to alter current behaviors and promote energy conservation practices among occupants [20,21]. Examples of common strategies include energy saving education, green social marketing campaigns, and feedback mechanisms providing occupants with information about their energy consumption patterns [22–24]. However, despite promising results, most studies are showing inconsistent or unsustained energy savings, which are in large part due to the complexity of analyzing and understanding the energy use decision-making process that occupants follow [24–26]. For instance, if economic factors are the primary drivers of occupants' decision to save energy (i.e., the cost of utility bills), a simple educational campaign might not be sufficient to alter current consumption patterns. Similarly, in a building with sensor-controlled lighting systems, occupants might not be able to save on lighting energy even with the right motivation and intent to do so. In summary, the failure to account for various drivers of occupancy behavior is believed to be a main limitation to more efficient and sustained energy savings [24–26].

1.2. Problem statement

Despite the highlighted need to investigate and understand energy consumption behaviors in buildings, the literature lacks empirically-driven occupancy data collection and analysis frameworks that can achieve this goal [27]. As detailed in the upcoming section, the few studies on drivers of occupancy actions in buildings present major limitations including: (1) the lack of relevant data on human behavior; (2) the lack of consideration of different key behavioral drivers of energy consumption (e.g., social, environmental, and economic); (3) simplified methods of data analysis (e.g., descriptive analysis without a thorough evaluation and quantification of individual and combined effects of behavioral drivers); and (4) limited scopes of work to either residential or commercial buildings, overlooking potential synergies between the two [7,21,28–31]. In summary, the approaches and methods used in the current literature have failed at effectively measuring and evaluating the energy consumption behaviors of building occupants. Consequently, they cannot be used to guide strategies that aim to alter and improve current energy use patterns.

1.3. Objectives

This paper proposes a comprehensive data collection and analysis framework to thoroughly evaluate the energy consumption behaviors of building users both at their work and home environments. Specific objectives of the framework include: (1) assess the awareness, motivation, and actions taken by occupants towards saving energy in their various built environments; (2) identify and quantify key relationships between the studied factors (i.e., does one factor contribute or lead to the other factors?); and (3) identify drivers that can alter current behaviors and help actively reduce energy consumption. The framework is demonstrated through a case study on a green university campus located in Abu Dhabi, United Arab Emirates (UAE), where data was collected from 227 campus users or residents.

The contributions of this work are significant as the proposed framework is generic and can be applied to any individual or group of buildings. Decision-makers, such as building owners, engineers, and policy makers, can use the framework to benchmark the energy consumption behaviors in their buildings and design targeted occupancy-focused energy conservation strategies. Researchers on energy efficiency in buildings can also benefit from this work to better understand the "human" or operation-related drivers of energy consumption. Such evaluation is often overlooked in the literature, contributing to the substantial differences observed between predicted and actual energy use levels. Finally, the application of the framework to a green campus located in the UAE is very relevant. Similar to other Arabian Gulf countries, the UAE is characterized by extreme weather conditions, high energy consumption levels per capita, rapid expansions of the building sector, and relatively limited research in the field mainly due to the lack of publically available and relevant sources of data.

2. Literature review

Early theories of human behavior formation are simplistic and linear, hypothesizing that an increase in people's knowledge about environmental issues automatically leads to increased environmental awareness or attitudes, which in turn increase pro-environmental behavior [32]. Later studies have contradicted these models by finding that positive pro-environmental attitudes do not necessarily lead to pro-environmental actions. For instance, the theory of Planned Behavior [33] argues that attitudes do not necessarily result in actions, but help develop behavioral intentions (i.e., planned behavior) that could eventually lead to actions. In parallel, the social identity theory [34] connects people's actions to their social identity, which is formed by their feeling of belonging, or non-belonging, to a group. Furthermore, Cialdini et al. [35] demonstrate how managing and communicating social norms can be very persuasive in altering existing behavior, supporting the theory of normative conduct. Finally, Stern [36] proposes a coherent theory of environment-related behavior (e.g., energy conservation actions in buildings), based on a comprehensive review of existing theories and models. Stern's theory identifies four types or categories of causal variables: (1) *Personal capabilities* (e.g., knowledge and skills to perform an action, sociodemographic variables); (2) *Attitudinal factors* (e.g., norms, values, and beliefs); (3) *Contextual factors* (e.g., difficulty of specific actions, institutional factors, physical environment constraints, policy or monetary incentives); and (4) *Habits and routine* (e.g., conditions to break existing behaviors). These four categories of variables are used as the basis for the survey development and the discussion of results; both presented later in the paper.

In parallel to developing theoretical models of human behavior, other research efforts aim to empirically assess drivers of occupancy actions in residential and commercial buildings [21,29–31,37,38]. Most studies typically start with a data collection effort, where information is gathered using a variety of tools and methods such as questionnaires, interviews, observations, sensors, Building Management Systems (BMS), or from existing