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Energy-related values and satisfaction levels of residential and office building occupants

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ABSTRACT

Improving occupant behavior is one of the best strategies to reduce building energy consumption. Values have major influence on a person's behavior. A better understanding of occupant values is, thus, critical to understand and improve energy use behavior. This paper presents the authors' work in (1) identifying the values of occupants that could be related to energy use behavior and energy consumption in residential and office buildings (e.g., thermal comfort, health, environmental protection), (2) discovering the importance levels of these values to residential and office building occupants, (3) discovering their current satisfaction levels with these values, and (4) determining the factors (e.g., occupant characteristics, level of occupant building control, building energy efficiency features, occupant behavior) that are associated with higher/lower importance and/or satisfaction levels. The discovery of importance and satisfaction levels was conducted using online surveys. A set of 618 residential and office building occupants in AZ, IL, and PA were surveyed using online questionnaires. The results show similarities and differences in importance and satisfaction levels across residential and office building occupants and across the three states. The results also show the factors that are associated with higher/lower importance and/or satisfaction levels. The outcome of this research could help advance the research and practice in the area of building energy efficiency by providing a better understanding of occupant values and satisfaction levels, both which impact energy use behavior and building energy consumption.

1. Introduction

In the U.S., the building sector represents 39% of the energy consumption and 38% of the CO_2 emissions [1]. The recent growth in energy demand comes at a time of increasing global concern over carbon emissions and resulting global climate change. The production and consumption of non-renewable energy, including oil and natural gas, pose adverse environmental impacts on the ecosystem in terms of air pollution and global warming. Improving building energy efficiency is one of the best strategies to reduce energy consumption [1]. Improving building energy efficiency is defined as the efforts to reduce energy consumption of buildings, while maintaining the living standards of occupants [1]. This can be achieved through improving building design and equipment efficiency and/or improving occupant energy use behavior.

Recent studies (e.g., [2–4]) emphasized the importance of occupant behavior as key means of improving building energy efficiency. Values have major influence on a person's behavior. "Values influence behavior because people emulate the conduct they hold valuable" [5]. In this context, a value is defined as anything that a building occupant believes is of worth, merit, utility, or importance (e.g., health, comfort, productivity). On the other hand, people spend the majority of their time in residential and commercial buildings, and therefore it is essential that while we aim to reduce building energy consumption that we also maintain the satisfaction levels of occupants with their values. It is, thus, critical that while we strive to improve the energy efficiency of buildings through the understanding of energy use behavior that we also understand the values (such as thermal comfort, indoor air quality, productivity) of building occupants, how these values may impact energy use behavior, and how we can improve energy efficiency without negatively impacting the satisfaction levels with these values.

Towards this goal, this paper aims to discover what occupants value in residential and office buildings – with focus on values related to energy use behavior and building energy consumption,

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the importances of these values to the occupants, and their current satisfaction levels with these values. The paper also compares importance and satisfaction levels across different types of occupants (residential and office), across different states (AZ, IL, and PA), and across different potential energy-related factors (PEFs) (e.g., occupant characteristics, primary building characteristics and energy efficiency features, level of occupant building control, occupant behavior).

2. State of the art and knowledge gaps

A body of research efforts has been undertaken towards enhancing building energy efficiency. Despite the importance of these efforts, two primary knowledge gaps are identified. First, there is a lack of empirical knowledge on discovering the values that are related to energy use behavior and energy consumption of residential and office building occupants. On one hand, a significant amount of existing research has examined energy efficiency in buildings and supported the importance of occupant behavior as key means of enhancing building energy efficiency. For example, Peschiera et al. [6] showed that occupant behavior plays an important role in energy consumption and that there is an energy-saving potential by only improving occupant behavior; Azar and Menassa [7] emphasized that occupancy behavioral parameters have a significant impact on energy consumption and developed an agent-based energy consumption forecasting model to account for different occupant behaviors; Petersen et al. [8] showed that supplying electricity consumption data to building occupants resulted in 32% reduction in energy consumption; and a simulation study by Klein et al. [9] showed that utilizing occupancy information, occupant preferences, and a meeting relocation agent resulted in 12% reduction in building energy consumption. These efforts provided important contributions to the field of occupant behavior-based energy efficiency. However, there is still a lack of studies on how the values (health, comfort, productivity, etc.) of occupants impact their occupant behavior and how to reduce energy consumption while maintaining the satisfaction levels with these values. On the other hand, there are number of studies (e.g., [10–13]) that focused on occupant comfort with indoor environmental quality (IEQ). For example, Lai and Yik [10] studied the importance of thermal comfort, air cleanliness, odor, and noise to high-rise building occupants in Hong Kong. These studies provide an important contribution towards understanding the values that affect occupant comfort, but they are not focused on studying the values to understand how they are related to energy use behavior and energy consumption.

Second, there is a lack of understanding of how the importance levels of values and the satisfaction levels with these values vary across different types of occupants, different states, and different PEFs. A number of research studies have conducted questionnaire surveys or instrumental measurements to understand how occupant satisfaction with some values [including thermal comfort, visual (lighting) comfort, and indoor air quality (IAQ)] varies across different PEFs. For example, Frontczak et al. [13] investigated the effects of 11 indoor environmental and building parameters on occupant satisfaction through post occupancy survey data collected by the Center for Built Environment (CBE). A literature survey by Frontczak and Wargocki [14] discovered occupant, building, and outdoor climate characteristics that affect the comfort of occupants in buildings. Despite the importance of these studies, these efforts did not analyze how satisfaction levels with values vary across different types of occupants and states and across a number of important PEFs such as energy efficiency building features and occupant behavior.

3. Research methodology

Two questionnaire surveys were conducted to solicit the input of a randomly selected set of residential and office building occupants in Arizona (AZ), Illinois (IL), and Pennsylvania (PA) on (1) the importance levels of occupant values and (2) the current satisfaction levels with these values. IL and PA were selected because the authors are currently conducting a set of energy utilization experiments in a number of residential and office buildings in these two states. AZ was additionally selected to capture the potential variability in responses as a result of a different climate, which provides an opportunity for investigating the impact of climate on occupant values and satisfaction levels with the values. According to the Köppen-Geiger climate classification [15], IL and PA have a humid continental (warm summer) climate (Dfa), whereas AZ has a dessert climate (Bwh). The research methodology was composed of five primary research tasks: (1) discovering potential energy-related occupant values and associated PEFs, (2) questionnaire design, (3) questionnaire validation, (4) respondent recruitment and survey implementation, and (5) survey results analysis.

3.1. Discovering potential energy-related occupant values and associated PEFs

In the context of building energy efficiency, a comprehensive literature review was conducted to identify all values that could be related to energy use behavior and energy consumption. As a result, seven main values were identified and classified into three categories: (1) values that may impact energy use behavior and energy consumption level: thermal comfort, visual comfort, and indoor air quality, (2) values that may be impacted by the set of values in the first category: health and personal productivity, and (3) values that may motivate enhanced energy use behavior towards reduced energy consumption: environmental protection and energy cost saving. Thermal comfort is “that condition of mind that expresses satisfaction with the thermal environment” [16]. Visual comfort is defined as “a subjective impression related to quantity, distribution and quality of light” [17]. Indoor air quality (IAQ) is “a term referring to the air quality within and around buildings and structures” [18]. Health is defined as “a state of complete physical, mental and social well-being” [19]. Personal productivity is defined as the efficiency of a person in conducting activities [20]. In an office context, activities include work activities like reading, writing, and computer work [21]. In a residential context, activities include household activities like housework, cooking, and yardcare, in addition to work activities if applicable [22]. Environmental protection is defined as “the prevention, reduction and elimination of pollution as well as any other degradation of the environment” [23]. Energy cost saving is defined as a reduction in the energy cost of a building. Values in the first and third categories are primary (mostly independent), while values in the second category are secondary (dependent on other values).

Subsequently, a comprehensive literature review was conducted to identify all PEFs that could be related to the seven values. For example, six primary factors affect thermal comfort: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity [16]. Among these factors, metabolic rate depends on a number of sub-factors such as activity level, age, gender, height, weight, and health conditions. The full list of the identified PEFs that were included in the questionnaire are shown in Section 4.5.

3.2. Questionnaire design

Two different questionnaires were used, one for residential and one for office building occupants. Both questionnaires were