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Evaluating the impact of extreme energy use behavior on occupancy interventions in commercial buildings

Elie Azar[a], Carol C. Menassa[b,*]

[a] Department of Engineering Systems and Management, Masdar Institute of Science and Technology, PO Box 54224, Abu Dhabi, United Arab Emirates
[b] Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI 48109, USA

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ABSTRACT

Occupancy interventions, which are typically used to diffuse energy conservation practices among commercial building occupants, are showing promising but un-sustained energy savings. One possible explanation to the observed results is the presence of extreme energy users in the buildings who can have an important influence on their moderate peers and revoke the benefits of occupancy interventions. While this 'extremism' in human behavior phenomenon has been extensively studied in various social science fields, it has yet to be applied on the study of energy conservation from occupancy interventions in commercial buildings. Using agent-based modeling and data from actual commercial buildings, this paper evaluates the influence of extreme energy users (1) on their peers and on the energy performance of commercial buildings and (2) on the effectiveness of commonly implemented occupancy interventions. Parametric variations and statistical analyses indicate that extremism can highly affect the effectiveness of traditional occupancy interventions. In parallel, a combination of methods has shown to empower moderate energy users, helping diffuse and maintain energy conservation practices even in the presence of extreme energy users. The demonstrated capability to test and optimize occupancy interventions is expected to support and boost their adoption in large-scale energy conservation initiatives.

1. Introduction

The commercial building sector accounts for a large portion of the energy consumed in most developed countries, and is oftentimes identified as the sector with the highest potential for large scale energy savings [1,2]. Recent energy conservation studies indicate that actions performed by commercial building occupants can have a significant impact on building energy use, and as a result, important energy savings can be achieved by encouraging and convincing them to adopt energy conservation practices [3–7]. Examples of such practices include but are not limited to turning equipment and lighting off when leaving a space, and adjusting thermostat set point temperatures to avoid excessive cooling or heating loads. As shown by Azar and Menassa [3,4], slight improvements in these behaviors can result in significant energy savings in the long run, confirming the potential energy savings benefits from improved occupancy energy use behaviors.

Diffusing energy conservation practices to improve occupancy energy use characteristics can typically be achieved through occupancy-focused intervention techniques, which can be divided in two main categories. The first includes *Discrete* energy interventions that occur at a specific point in time such as energy training and education [8,9], and green social marketing campaigns [10,11]. The second category includes *Continuous* social interactions and peer-pressure between occupants sharing a building or social environment (e.g., employees of a company) [12–14]. Social interactions can be induced through techniques such as comparative feedback, where occupants are continuously exposed to their energy consumption levels in addition to those of their peers. This has shown to create a certain level of social (peer) pressure on high energy users to reduce their consumption [15–17].

In practice, the application of occupancy interventions in commercial buildings is limited to few case studies with important design limitations and inconclusive results [15,16,18]. All of these studies were experimental in nature, where researchers applied occupancy interventions on actual buildings and monitored their resulting impact on building energy consumption. Such tasks consume significant time and resource, limiting the mentioned studies to small sample sizes and short evaluation periods. Consequently, the findings are hard to generalize and remain specific to the

* Corresponding author. Tel.: +1 734 764 7525.
E-mail addresses: eazar@masdar.ac.ae (E. Azar), menassa@umich.edu (C.C. Menassa).

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particular buildings that were studied. In addition, the obtained results were inconclusive as the energy saving practices promoted by interventions were rarely maintained over time and relapses to pre-intervention energy use levels are commonly observed. For instance, Murtagh et al. [15] tested feedback in an office building and showed that energy savings were only maintained for a period of two months. Similarly, Staats et al. [18] observed that periodical interventions were needed to maintain the energy savings obtained from an energy education intervention, as relapses were constantly observed.

In order to improve the effectiveness of interventions, researchers have been recently relying on computer simulation models to test and optimize occupancy interventions prior to their implementation in actual commercial buildings [4,19]. The use of simulation models, as opposed to experimental studies, helps avoid the resource-intensive and impractical process of testing occupancy interventions on a large number of actual buildings and monitoring their energy performance over a long period of time [20,21]. To date, the mentioned simulation studies have particularly focused on how social connections between commercial building occupants (e.g., employees of a company), which can be represented using social networks, impact the diffusion of energy conservation practices promoted by occupancy interventions [3,19]. Recommendations were then made on how to effectively use the knowledge about a particular building's social network setup to increase energy savings from occupancy interventions. While these studies successfully explain the role of social networks in the energy conservation process, they did not investigate how the individual characteristics of occupants (e.g., resistance to change and energy use behavior extremism) can highly affect how they respond, individually and as a group, to occupancy interventions.

The need to understand and account for occupancy characteristics is highlighted in several social science studies that discuss how people can have different levels of acceptance of new behaviors, ideas, or opinions [22–26]. People with extreme behaviors, referred to in literature as 'extremists', are typically harder to influence than people with moderate behaviors who are closer to the social norm. Furthermore, within a social group, extremists can have an important influence on their moderate peers and drive the behavior of the social group to an extreme. This extremism phenomenon has been observed in numerous fields, from human rights campaigns [24] to terrorism [26]. As a result, it is essential to account for the potential presence of extremists in any effort to promote particular behaviors within a social group, and in this particular case the adoption of energy conservation practices from occupancy interventions.

Therefore, the goal of this study is to evaluate the impact of extremism in the diffusion of energy conservation practices among social network groups in commercial buildings, in an effort to assist decision makers in tailoring occupancy interventions to the specific characteristics of building occupants; thus, resulting in more effective occupancy energy behavioral outcomes in buildings. This translates into three main questions that this study helps answer:

(1) What is the influence of extreme building energy users on other occupants and on the energy performance of commercial buildings?
(2) How does extremism impact the effectiveness of common interventions?
(3) How can interventions be tailored to reduce the number of extreme energy users in commercial buildings and maximize energy savings?

2. Background

In order to increase energy conservation practices among building occupants, it is essential to evaluate the root of the problem and investigate the factors that affect how people change and maintain behaviors, attitudes, and opinions. As discussed in Franks et al. [23], while human behavior can be shaped by individual reflections and cultural inheritances, they are oftentimes highly influenced by social context. Studies indicate that social interactions between two or more members of a community can lead to changes in opinions and potentially affect how various ideas, behaviors, or perceptions can spread across a social group [24,27,28]. Consequently, the diffusion of new behaviors (e.g., energy conservation practices) depends both on the characteristics of the social network where people interact (e.g., community, company, and building); as well as, the individual characteristics of the people interacting (e.g., their willingness and ability to change their behaviors or opinions). The following sub-sections discuss these characteristics.

2.1. Social networks

By definition, a social network is a theoretical paradigm that defines the relationships between individuals, groups or organizations, and the strength of their influence on each other based on the frequency of interaction and interdependence [29,30]. Researchers have developed simulation environments such as agent-based models to study the diffusion of ideas and behaviors in various fields, such as technology and innovation diffusion [27], epidemiology [31], urban growth [32], and decision making [28]. In a social network, individuals are represented by nodes and the channels of communication and influence between these individuals are seen as edges. This representation allows researchers to analyze patterns in the interconnection of individuals, study the characteristics of the network connecting them, and evaluate the influence they can have on each other over time [33,34]. Typical characteristics include but are not limited to social network size (i.e., number of people or agents), clustering (e.g., grouping of agents), and topology (i.e., structure and distribution of nodes and edges representing the relationship level and influence agents have on each other).

In recent years, social networks have been used to model the social interactions in residential [17,35] and commercial buildings [19,36], in an effort to assess how peer pressure and other intervention techniques affect building energy consumption. For example, Azar and Menassa [36] evaluated the influence of different social network characteristics on the effectiveness of interventions. Results indicate that in a commercial building, the number of sub-networks formed by independent social entities (in this case different companies in the building), and the level of interaction between these entities, highly affect energy conservation from occupancy interventions. In parallel, Anderson et al. [19] found that social network characteristics such as topology and structure can have a significant impact on the time required by building occupants to reach an agreement, or equilibrium, in their energy use behaviors following an occupancy intervention.

In summary, evaluating social networks in both residential and commercial buildings has shown to improve the understanding of the factors that influence the adoption of energy saving behaviors, leading to more effective occupancy interventions. While Azar and Menassa [36] and Anderson et al. [19] focused on social network characteristics, literature indicates that the potential presence of people with extreme opinions or behaviors can also significantly affect how new behaviors (e.g., energy conservation practices) are accepted and diffuse among the members of a social group [22,24]. That is, the results of the analysis are also highly dependent on the individual characteristics of the occupants in the building, which need further evaluation and understanding. Extremism in energy