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Synthesizing building physics with social psychology: An interdisciplinary framework for context and occupant behavior in office buildings

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ABSTRACT

This study introduces an interdisciplinary framework for investigating building-user interaction in office spaces. The framework is a synthesis of theories from building physics and social psychology including social cognitive theory, the theory of planned behavior, and the drivers-needs-actions-systems ontology for energy-related behaviors. The goal of the research framework is to investigate the effects of various behavioral adaptations and building controls (i.e., adjusting thermostats, operating windows, blinds and shades, and switching on/off artificial lights) to determine impacts on occupant comfort and energy-related operational costs in the office environment. This study attempts to expand state-of-the-art understanding of: (1) the environmental, personal, and behavioral drivers motivating occupants to interact with building control systems across four seasons, (2) how occupants' intention to share controls is influenced by social-psychological variables such as attitudes, subjective norms, and perceived behavioral control in group negotiation dynamic, (3) the perceived ease of usage and knowledge of building technologies, and (4) perceived satisfaction and productivity. To ground the validation of the theoretical framework in diverse office settings and contexts at the international scale, an online survey was designed to collect cross-country responses from office occupants among 14 universities and research centers within the United States, Europe, China, and Australia.

1. Introduction

In 2016, the building sector consumed more than one-third of the world's primary energy [1]. Reducing energy use in buildings remains a critical strategy to minimizing greenhouse gas (GHG) emissions and meeting energy policy and efficiency goals world wide. An international energy evaluation [1] confirmed that offices make up a significant segment of the commercial building sector, which, in turn, represents the fastest growing energy demand sector—with an average consumption increase rate of 1.6% per year from 2012 to 2040. Energy is consumed in office buildings for heating, ventilation, cooling, artificial lighting, and plug-in equipment [2]. However, energy use is strongly influenced by other factors as well, including the availability and efficiency of building control systems, their management, and their operation.

Today, people spend an average of 90% of their time in buildings [3]. Accordingly, energy is consumed in office buildings for maintaining comfortable and healthy environments for the occupants, and by occupants for operating computers and interacting with control systems and other technological equipment. Since the 1990s, companies have realized that building occupants are one of the largest budget items in office buildings [4]. Related costs of course include employment rates, but also include productivity and medical insurance covering working conditions (i.e., those related to health, safety, and comfort of employees) [5]. The average cost of providing health care can be up to 7.6% of a company's annual operating budget in the United States [6]. Increasing occupant's satisfaction with their office environment has become a way of improving productivity and reducing operational budget costs—thus increasing profitability for companies [7].

Occupant behavior research over the last decade primarily focused on the observation, understanding, and prediction of the behavioral phenomena in the office building sector [8,9]. Using information gained from the disciplines of building energy and social-psychology, research presented in this paper embraces a new interdisciplinary branch of occupant behavior research focusing on the link between occupant behavior, building controls, and energy-related consumption effects [8], driving innovations for building technology adoption in the commercial building sector.

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1.1. Needs for interdisciplinary studies

It seems timely to consider occupant behavior in buildings from an interdisciplinary perspective. Researchers now broadly recognize the contextual (rather than purely environmental) factors influencing the human-building interaction [10–17]. Explorations regarding the achievement of energy-efficient usage in the building sector are today established around the understanding of the socio-technical link between building occupants' behavior and the use of building technologies, energy services, and controls [9]. Abrahamse et al. [12] anticipated this interdisciplinary approach as a two-way exchange of knowledge from socio-technical disciplinary fields of sciences: *"sociologists can provide more insight into macro-level factors that shape […] energy use. Also, input from environmental scientists can be of valuable importance to further improve intervention studies. The environmental sciences can help translate energy-related behaviors […] into their environmental impact, e.g., in terms of CO2 emissions, and help select high-impact behaviors."*

A significant contribution towards the configuration of an interdisciplinary approach for understanding occupant behavior, comfort, and satisfaction impacting the achievement of high-performing buildings has been provided by researchers in the field of architecture [18] and social science [19]. Day and Gunderson [18] proposed a methodology blending disciplinary perspectives and research techniques stemming from interior design, building science, data science, and social science. The architects endorsed the hypothesis that occupants receiving effective training on how to use building technologies and energy systems were significantly more likely to be comfortable and satisfied with their office environment. By focusing on the highlight of social-psychological factors of energy concerns affecting employees' energy saving intentions within the workplace, Chen and Knight [19] contributed to the confirmation of the role of social scientific perspectives in energy research. These results are significant to the extent that social psychology theories, analytical methods, and insights can provide measurable improvement in promoting energy conservation, which is affected by both behavior and technology.

Advances in interdisciplinary research have emerged through the integration of multiple theories in the definition of frameworks organizing the human-building interaction issue. Supported by the vast amount of available energy consumption and human-related data, together with the advancements in big data analysis techniques, scholars [20] proposed an interdisciplinary research framework at the boundaries of energy and social sciences bounded with data information science. A conceptual framework for assessing energy use in the domestic sector was developed by Kowsari and Zerriffi [21]. Recently, Von Grabe [22,23] postulated a systematic framework for the energy-related human-building contextual factors aiming to a synergetic organization of this interaction phenomena in buildings. Similarly, Wolske et al. [24] introduced an integrated framework that combines variables from behavioral theories to explain consumers' interest in residential solar photovoltaic systems. Also based on a theoretical framework integrating multiple theories and disciplines, Li et al. [25] developed a survey instrument aiming to gather interdisciplinary knowledge on energy use behavior in buildings. Li's study provided survey data for statistical-based models of occupant behaviors, useful to provide insights into occupant energy saving behavior and characteristics as a function of occupant motivation, opportunity, and ability to interact with building technologies. Importantly, Li's study also provides useful suggestion on occupant interventions. Research from Allison [26], Axsen and Kurani [27], Ryghaug and Toftakerare [28], Sheller and Urry [29], and Sovacool [30] confirm that while disciplinary theories contribute important understandings of the behavioral phenomena, blending aspects of interdisciplinary theories can provide additional interpretations and insights. In this picture, further research integrating multiples theories, comprehensively describing the energy-relevant human-building interactions in office buildings based on the knowledge of interdisciplinary fields, will provide beneficial data.

1.2. Scope of work

The goal of this paper is to develop a new interdisciplinary framework, synthesized from building physics and social-psychological theories, to enable socio-technical knowledge exchange and co-learning on the human-building interaction phenomena. Based on this study, a questionnaire and associated measurements will provide data-driven information to ground the validation of the theoretical framework at the international scale. The questionnaire will enable interdisciplinary and cross-country data gathering. One of the objectives is to transform the knowledge discovered through large-scale survey data into behavioral-based energy efficiency solutions and insights, taking into consideration not only the energy metrics and physical properties from building physics, but also the contextual aspects of energy-related behaviors in the workspace. The paper is structured as follows.

- Section 2 introduces three theories and the ontology synthetized to explain energy use behaviors: the social cognitive theory (Section 2.1), The drivers-needs-actions-systems framework (DNAS) (Section 2.2), and the theory of planned behavior (TPB) (Section 2.3). The strengths of the proposed integrated framework compared to each individual existing theory are rationalized (Section 2.4).
- Section 3 illustrates the proposed research framework and the key research questions associated with four learning objectives: motivational drivers (Section 3.1), group behavior (Section 3.2), ease and knowledge of control (Section 3.3), and satisfaction and productivity (Section 3.4).
- Section 4 explains the survey design procedure, including selected description of measures (Section 4.1) and strategies for sampling and participant selection (Section 4.2), mitigation effects on the self-reported bias (Section 4.3), and translation guidelines (Section 4.4).
- Section 5 discusses benefits of (Section 5.1), advancements in (Section 5.2), and barriers to (Section 5.3) the proposed interdisciplinary research synthesizing building physics and social psychology.
- Section 6 provides a conclusive summary and highlights further research plans.

2. Integrated theoretical frameworks

Building on the emergent trend in energy and social sciences research, the goal of this study is to develop a data-driven research framework integrating multiple theories and interdisciplinary aspects. Together with a pool of researchers in the context of the International Energy Agency Annex 66 "Definition and Simulation of Occupant Behavior in Buildings" activities [31], the study explored and combined theories and insights from the technical and social dimensions of human-building interactions to support research in the fields of building and social sciences to better quantify the influence of occupant behaviors on building energy performance [8]. The proposed research framework is based on social cognitive theory (Section 2.1), the DNAS framework for energy-related behaviors (Section 2.2), and the theory of planned behavior (Section 2.3).

2.1. The social cognitive theory

The social cognitive theory (SCT), explained by Bandura [32], describes human behaviors as a dynamic interplay of environmental, personal, and behavioral factors (Fig. 1). According to SCT, people learn a certain behavior by observing others with the influences of these three factors (triadic reciprocal determinism). In other words, what people perceive (environmental physical and social factors, comfort, and control), believe (personal factors), and do (exercised past

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