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RESEARCH ARTICLE

Evaluating diverse patterns of occupant behavior regarding control-based activities in energy performance simulation

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Abstract
Simulation is recognized as an effective tool for building energy performance assessment during design or retrofit processes. Nevertheless, simulation models yield deviating outcomes from the actual building performance and a significant portion of this deviation originates from the dynamic nature of occupant behavior. Literature on occupant behavior indicates that occupant behavior is not integrated into building energy performance assessment procedures with appropriate resolution, instead they are accepted as assumed and fixed data sets that usually represent the presence of occupants. This study attempts to evaluate the effect of diverse patterns of occupant behavior on energy performance simulation for office buildings. Diverse levels of sensitivity of occupant behavior on control-based activities such as using lighting apparatus, adjusting thermostat settings, and presence in space are employed through three diverse occupant behavior patterns. These occupancy patterns are correlated with three identical office spaces simulated within a conceptual office building. EDSL Tas is used to run building energy performance simulations. Effects of occupant behavior patterns on simulation outcomes are compared for five sample winter and summer workdays, with respect to heating and cooling loads. Results present findings on how diversity of occupancy profiles influences the consumption outcomes.
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1. Introduction

Energy-efficiency of the built environment and slowing the adverse effects of climate change are of utmost importance for researchers and professionals involved in the production of built environment, since almost 40% of the total energy is consumed in the buildings (IEA, 2010). Reduction of the consumed energy in buildings through effective insulation strategies, glazing technologies, passive design considerations, and integration of renewable energy technologies are common measures (Diakaki et al., 2010; Hens et al., 2010) that are researched and employed to contribute the energy-efficiency of the built environment. Yet, abovementioned approaches are aggregated around the core of technological and scientific solutions, overlooking the fact that building occupants and their consumption related behavior are exceedingly influential on energy performance of buildings (Masoso and Grobler, 2010).

The multitude of research on building performance assessment demonstrated that simulation approaches are effective in evaluating building energy performance during building design or retrofit processes. Due to their dynamic capacities in modeling extensive sets of parameters that are influential on building energy performance, simulation models yield performance assessment outcomes that reproduce the real-world phenomena (Crawley et al., 2008). The set of parameters related to building performance assessment include (a) climate, (b) building characteristics (e.g. physical properties of building materials, orientation, area etc.), (c) building service systems (e.g. HVAC systems, domestic hot water, etc.), (d) building operation (e.g. schedules, equipment etc.), (e) indoor thermal and environmental quality (i.e. required thermal comfort and indoor air quality), and (f) occupant behavior (e.g. presence, control and activity patterns related to energy use, etc.) (Hong et al., 2016; Yu et al., 2011). Integrating the parameters (a) to (e) is a considerably straightforward process, once the specialists, who use the simulation tool, possess necessary knowledge, skills and precision. The simplicity lies in the means that the related data could be obtained quantitatively through audits, as-built drawings and measurements, moreover, the simulation software are mostly designed to facilitate such input. On the other hand, occupant behavior (f) depends on various factors influenced by income, energy prices, awareness on energy issues, gender, age, socio-cultural attitude, and so forth, and most importantly on the perception of indoor environmental conditions (Motuziene and Vilutiene, 2013). Such amplitude of subjective drivers that shape the behavior of building occupants makes it hard to quantify and ascertain occupant behavior for the building energy performance specialists. Thus, occupant behavior is commonly integrated in simulation environment as a fixed assumption that represents presence/absence in a space. The reasons behind such simplification in integration of occupant behavior could stem from a number of reasons: (i) monitoring occupancy requires installation of various measurement instruments, (ii) simulation users should be acquainted with the basic programming languages in order to intervene with the built-in occupancy interfaces to integrate the diversities in occupant behavior within the simulation software, since current simulation tools might have insufficiencies in full integration of occupant behavior (Virote and Neves-Silva, 2012), and (iii) measurable outdoor variables are commonly found more reliable than dynamic indoor variables and a correlation between outdoor variables and indoor variables are preferred for assessment rather than detailing occupant behavior (Gunay et al., 2013).

Aforementioned reasons are strongly related to uncertainties in building energy performance assessment, since diverse patterns of occupant behavior are not integrated into building energy performance assessment procedures with correct resolution and instead they are accepted as assumed and fixed data sets that represent the presence/absence of occupants. Given the fact that these assumptions are considered as one of the main reasons for the discrepancy between the predicted and actual energy performance of the buildings (de Wilde, 2014; Menezes et al., 2012), namely, *the building performance gap* (Motuziene and Vilutiene, 2013), occupant behavior is considered as a significant input that should be included in assessment procedures with approaches based on measurement and observation (Virote and Neves-Silva, 2012). In this regard, it is possible to assert that integrating occupant behavior in a rudimentary manner within the simulation models would contribute to the gap between the predicted and actual energy performance of buildings (Hong et al., 2015). To bridge this gap, it is essential to integrate diverse patterns of occupant behavior within the simulation environment with a resolution that represents the actual occupant behavior as effectively as possible.

The main objective of the present study is to put an emphasis on the significance of modeling occupant behavior and demonstrate the extent of influence of the occupant profiles on the assessment of building energy performance measures. Therefore, this study identifies effects of occupant behavior on building energy consumption through synthetic behavior sets that represent three diverse patterns of occupant activities within a hypothetical office building, modeled and simulated in EDSL Tas. In Literature Review section, an extensive review was carried out with a specific focus on assessment and modeling of occupant behavior with the aim to acquire information on the commonly investigated control-based activities and considerations related to modeling the occupant behavior. Methodology section introduces the approach of the study and Results and Discussion section elaborates on the study findings. In Conclusion section, a discussion on how occupant behavior modeling could contribute to the body of knowledge in building energy performance studies, is presented based on the outcomes of the present study.

2. Literature review

There exists a significant increase in studies dedicated to understanding the relationship between occupant behavior and building energy consumption in the last decade. Various approaches were studied to integrate the effect of building occupant behavior into building simulation software. Masoso and Grobler (2010) state that modeling occupant behavior is *"one of the weakest links in energy efficiency and*

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