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A critical review of observation studies, modeling, and simulation of adaptive occupant behaviors in offices

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ABSTRACT

Occupants' behaviors account for significant uncertainty in building energy use. A better understanding of occupant behaviors is needed in order to manage this uncertainty; as such many studies have been dedicated to this topic. The current paper reviewed the research on adaptive occupant behaviors by sorting it into three categories. The first group encompasses all observational studies. The second group includes modeling studies. The third group incorporates the simulation studies. The current paper presents the methodologies used in these studies, discusses the limitations associated with their application, and develops recommendations for future work. Generalized linear models – in particular, logistic regression models – were found to be appropriate for modeling occupant behavior. Reversal of adaptive behaviors (e.g. window closing) was modeled with deadband models or survival models. Occupant models were typically simulated as discrete-time Markov processes. It was concluded that with appropriate selection of building geometry and materials and occupant-predicting control strategies, impact of occupant behaviors on the building performance can be reduced.

1. Introduction

Building Performance Simulation (BPS) based design, despite its potential for significant improvements in energy use and indoor environment, has often been undermined by predictions that do not fully represent actual performance [1,2]. Some of these discrepancies can be attributed to deviations from standard weather data [3], modeling and simulation simplifications [4], occupancy profiles [5–7], unanticipated control behavior, and material/workmanship related uncertainties. However, the uncertainty introduced by occupant behaviors are undeniable [8,9].

Occupants adapt their environment and personal characteristics to achieve their comfort in ways that are convenient to them rather than being necessarily energy-conserving [2,10,11]. Environmental adjustments may involve decisions such as window/door opening, blind/shade positioning, light switch on/off, carpet/hardwood floor covering, fan on/off, and thermostat up/down. In a given building, occupants may or may not be given control over these actions, but it was reported that occupants' comfort perception is negatively affected if they have less control over their environment [8,12]. CIBSE [13] and ASHRAE [14] acknowledge this by including adaptive comfort models for naturally ventilated buildings. Occupants can also adapt their personal characteristics such as adjusting their typical beverage temperatures, location, posture, activity and clothing levels. These personal adaptive behaviors can be restricted with social factors such as workplace dress codes however, even in the most sealed and fully conditioned buildings there are some adaptive opportunities.

Adaptive actions, aside from their impact on perceived comfort, often have significant impacts on energy use. Therefore, building designers should foresee these occupant-use related impacts on energy consumption and incorporate them into design. However, building designers tend to make static assumptions about occupant behavior, whereas field studies have indicated that occupants may act in unexpected ways and respond to crises of discomfort [2,15]. For example, an occupant may add carpet or hardwood flooring on top of concrete in a passive solar house; failure to consider this action will lead to inaccurate BPS predictions [16]. A better understanding of occupant behaviors (aside from being a promising way to test buildings with expected occupant actions during the design stage) has been recently acknowledged as a promising way to operate buildings [16]. Clarke et al. [16], Thrun [17], Claridge and Abushakra [18], Guillemin and Molteni [19,20] and Dong et al. [21]

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have been pioneering this approach to retrieve occupancy-related information using inverse models which later can be utilized to create intelligent (i.e. learning, predicting, and adapting) control strategies.

The existing scientific literature on which these pioneering research efforts were based covers a broad range of methodologies to study adaptive occupant behaviors. However, existing review papers on occupant behaviors give high resolution insights into particular adaptive behaviors such as only manual control of windows [22,23], window shading devices [24,25] or lighting [20,26] with an emphasis on the observational methodologies and their limitations. In this paper, a comprehensive, yet broad, approach was taken to cover common findings and limitations of the occupant behavior research in general with an equal emphasis on the observational, modeling, and simulation methodologies.

The current paper reviewed the research on adaptive occupant behaviors in offices by sorting it into three categories as shown in Fig. 1. These categories were formed to represent the logical flow of research approach for any phenomena: observe → model → simulate. This will help revealing the research needed from each category. The first group encompasses all observational studies. In these studies, researchers observed a system (e.g. naturally ventilated office building) for a period of time (e.g. heating season) in order to develop a correlation between the observed state (e.g. operable window or window shades) and the monitored variables (e.g. indoor temperature). The second group includes modeling studies. In these studies, occupant behavior models were predicted by assuming an idealized probability distribution (e.g. binomial) via a regression analysis (e.g. logistic) to reveal the predictor variables that drive an adaptive behavior. The third group incorporates the simulation studies. In these studies, occupant behavior models were simulated (e.g. discrete-time Markov Chains) with the building energy models to predict the energy impacts of occupants' behaviors for adapting building design and control. The current paper presents the methodologies used in these studies, discusses the limitations associated with their application, and develops recommendations for future work. Due to substantial contextual differences, occupant behaviors in residential buildings, although they account for about the same amount of energy use [27], were not included in this paper. These contextual differences can be explained with the responsibility of energy bills, need for privacy, social factors, type of activities/task, et cetera. The long-term objective of this research project is to develop building design and operation strategies which better account for occupants' behaviors, habits, and preferences.

2. System observation

To assess the adaptive actions of occupants, researchers have observed a system to be able to correlate a state (e.g. window position) with a set of variables (e.g. indoor air temperature). The validity of extending the conclusions of these observations to another context may be restricted to the characteristics of the observed building envelope and operation [28]. Moreover, techniques employed to collect information about the adaptive behaviors (e.g. time-lapse photography, sensors) and the monitored physical (e.g. indoor/outdoor thermal and non-thermal) and non-physical (e.g. privacy, view to outside) variables constitute limitations for the future models proposed based on these observations. This section identifies the factors that may affect the generality of

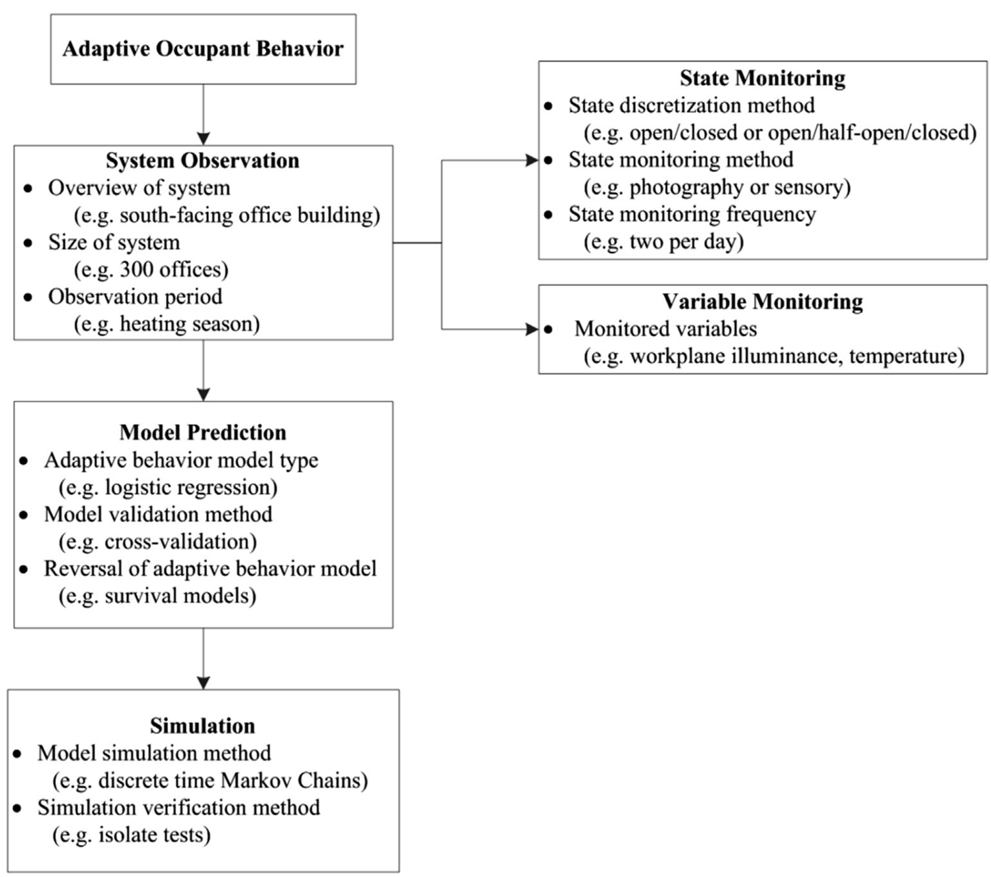

Fig. 1. Research and modeling approach on adaptive occupant behavior.