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Simulating multiple occupant behaviors in buildings: An agent-based modeling approach

Yoon Soo Lee [a,*], Ali M. Malkawi [b]

[a] Department of Architecture, School of Design, University of Pennsylvania, 401 Furness Building, 220 South 34th Street, Philadelphia, PA 19104, United States

[b] Graduate School of Design, Harvard University, 48 Quincy Gund Hall, Cambridge, MA 02138, United States

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ABSTRACT

A new simulation methodology using agent-based modeling is presented to simulate multiple, occupant behaviors in a commercial building. The purpose of the agent-based modeling is to mimic a real-world occupant: an autonomous agent that interacts with both its environment and other agents, and makes behavior decisions based on the level of its thermal comfort. First, individual agent behaviors are simulated; second, the results are aggregated to explain the behavioral phenomena of the building as a whole. Using simulation coupling, the behavior impact on the thermal conditions and, energy use can be scrutinized. A simple simulation experiment was conducted to see (1) how an agent considers five behaviors (adjust clothing level, adjust activity level, window use, blind use, and space heater/personal fan use behaviors) to achieve its comfort goal, and (2) how an agent adapts to the dynamic thermal changes in the space to optimize both comfort and energy savings.

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1. Introduction

Growing out of efforts to increase the prediction accuracy of building energy simulation programs, the process of modeling building occupant behavior and its impact on energy use has gained an increasing attention in recent simulation research. Hence, it is important to have a good prediction of the various behaviors, along with how they impact the overall building energy performance.

The objective of the paper is to present a simulation method using an agent-based modeling (ABM) approach that tries to mimic real-world occupant behaviors in a commercial building while also accounting for the behavior influence on both the thermal conditions and energy use in the building. The main advantage of an ABM approach is that it addresses the primary drawback of current simulation programs (on modeling occupant behaviors), which are generally limited in both uncertainty prediction and dynamically responding to those uncertainties [1]. By accounting for occupant behaviors and behavior feedback, the ultimate goal is to bridge the gap between the simulated and actual energy consumption results.

2. Agent-based modeling overview

Occupant behavior has been reflected in existing simulation practices as oversimplified, predetermined inputs. Occupants are presented as fixed metabolic heat generators [2], and behaviors are reduced to fixed schedules (occupancy, light use, equipment use, etc.) based on historical data [3], or as a discrete 'stimulus–behavior' relationship [4]. Moreover, these inputs are a collective average of the whole building that merely represents the dynamic behaviors observed in a real workplace; thus, the simulation results fall short of correctly predicting the internal loads that are indicative of the energy performance of buildings. By contrast, the ABM mindset is fundamentally different from that of existing simulation practices, as it takes into account the aggregate behaviors that emerge from the interactions of numerous autonomous agents (occupants) [5]. The following summarizes the merits of ABM implementation in behavior research:

- ABM has capabilities to address the uncertainties of the real world (using techniques such as Bayesian network, fuzzy logic, and rough sets) [6].
- An agent in ABM can act and think like humans, by operating under autonomous control and by perceiving its environment and adapting to changes in order to achieve a certain goal [7].
- In making behavior decisions, ABM outperforms a simple reactive 'if-then' rule (which is basically how existing simulation

* Corresponding author.
E-mail address: yoonslee@design.upenn.edu (Y.S. Lee).

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programs characterize occupant behaviors) by allowing agents to learn and change behaviors in response to their experiences [8].
- Even at the simplest level, if an ABM is created that consists of agents and relationship between them, there could be valuable findings about the system as a whole [9].

The ABM in the paper is primarily responsible for making behavior decisions and linking building energy simulator (via simulation coupling) to calculate energy use and changing thermal conditions as a result of the behaviors, as shown in Fig. 1.

3. Methodology (Fig. 1)

3.1. Human behavior model

The human behavior model encompasses the three processes that are essential in initiating the behavior research: define behaviors, identify behavior triggers, and measure/quantify behaviors. The ABM in the paper is focused on behaviors that affect the occupant thermal comfort (which typically ranks as the highest identified source of occupant dissatisfaction in a leading post-occupancy comfort survey [10]) such as window use, blind use, and space heater or personal fan use. The behaviors are not only closely related to the thermal comfort, but are part of the building system, with implications on building energy use once changes in the behaviors are implemented. Behaviors are dictated by thermal comfort, and are closely correlated with a specific environmental parameter (usually climate data) or behavior triggers.

It is important to understand the trigger mechanism for occupant behaviors because there needs to be a quantitative metric to represent incremental behavior changes and to assess the occupant comfort level. On that note, the paper determines the comfort level by adopting Fanger's PMV model [11]. Table 1 is an example of a behavior list and its connection to the trigger mechanism (also PMV parameter). Also, the table lists the initial behavior values associated with specific behaviors/PMV parameters that are used in the experiment. The control values in Table 1 refer to the range of the behavior values applied, such as minimum, maximum, and other increment changes incurred from behaviors.

As an essential process in making behavior predictions, our tactic for measuring and quantifying occupant behaviors is rooted in the idea that 'human behavior follows reasonably and often spontaneously from the information or beliefs people possess about the behavior under consideration' [12]. Based on this assumption, the beliefs associated with occupant behaviors can be categorized as the following (adopted from the reasoned action model) [12]:

- Behavioral beliefs: Beliefs about the positive or negative consequences occupants might experience if they perform the behavior (outcome expectancy).
- Control beliefs: Beliefs about personal and environmental factors that can help or impede occupants' attempts to carry out the behavior (accessibility/adjustability).
- Normative beliefs: Occupants form beliefs that important individuals or groups in their lives would approve or disapprove of their performing the behavior as well as beliefs that these referents themselves perform or do not perform the behavior in question (perceived norm).

3.2. Cost function

A cost function is a mathematical equation that an agent (in the ABM) calculates to make behavior decisions. The ABM in the paper consists of goal-based agents, which can be defined as agents who 'keep track of the world state as well as a set of goals they are trying to achieve, and choose an action that will eventually lead to the achievement of their goals' [7]. The cost function helps an agent to make the optimal behavior decisions to achieve its goal, which is the agent comfort level, with an ability to accommodate different

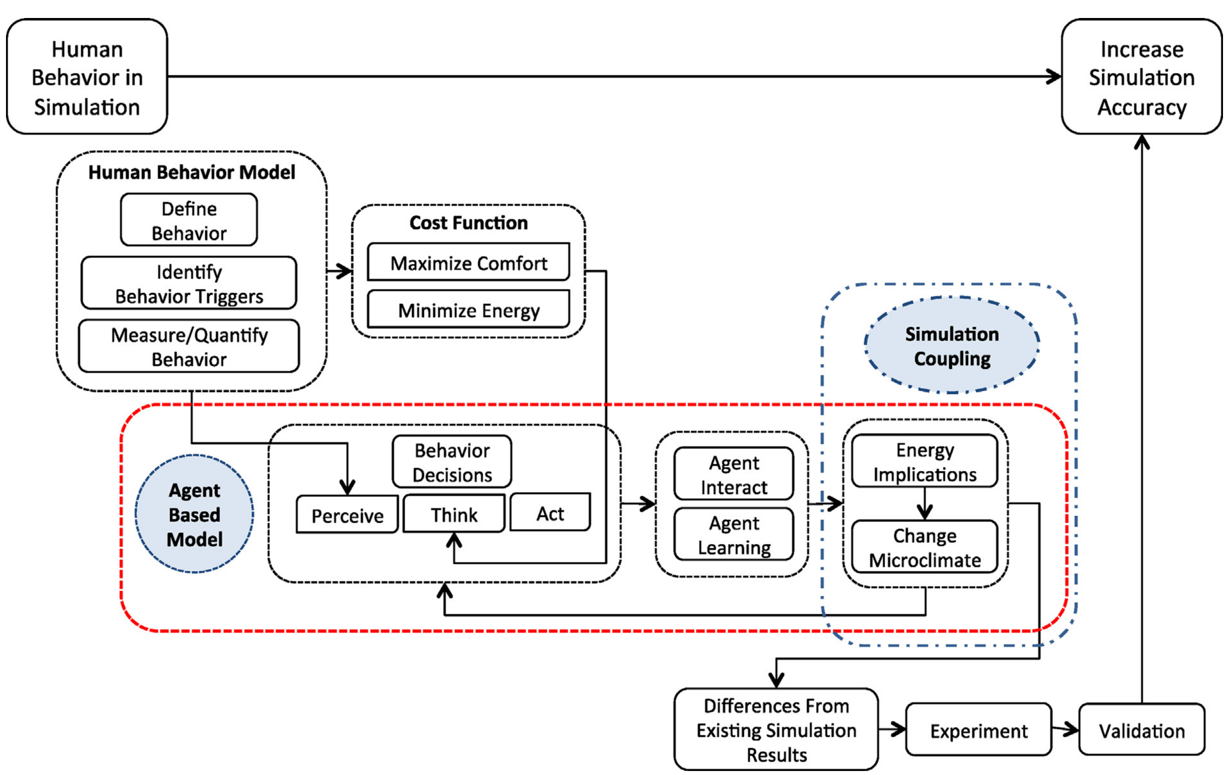

Fig. 1. Overview of ABM embedded simulation process.

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