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Different Occupant Modeling Approaches for Building Energy Prediction

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Abstract

Building simulation tools have been developed to represent physical phenomena, but discrepancies between actual and modeled phenomena still persist. Various sources of the gap have been identified such as physical uncertainties, limitations of tools, subjective assumptions, simplification of the model, etc. One source of these discrepancies, which is non-negligible, is the non-static behavior of building occupants. Two approaches have recently emerged for occupant modeling: **stochastic approach** and **agent approach**. The two approaches account for what has not been considered in the deterministic approach. Particularly, this paper introduces a new concept, **random walk approach**. This paper explores three approaches with experimental evidences and literature review. The paper reports that the occupant modeling must be carefully selected based on the characteristics of occupancy pattern.

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Keywords: Occupant behavior; Markov Chain; Agent; Random Walk

1. Introduction

As buildings continue to use a significant portion of the energy consumed, it is important to address the energy efficiency of buildings through the whole building life cycle [1]. Building energy performance simulation (BEPS) tools, which can be used to assess building performance, have been developed to accurately represent physical phenomena, but discrepancies between actual and modeled energy use still persist [2]. Various sources of the gap have been identified, such as physical uncertainties, limitations of tools, subjective assumptions, simplification of the model, etc.

Another source of the aforementioned discrepancies, which has been recognized as significant, is the non-static behavior of building occupants [2]. However, so far we are not fully capable of describing the occupants' behavior and its impact on building energy consumption. In addition, it is still difficult to make a mathematical model of human beings either in a statistical manner or in an analytical manner. The traditional method to account for building occupants in BEPS is to use hourly schedule [3], so called a deterministic approach. Recently, there are three emerging approaches as follows: **stochastic approach, agent approach, and random walk approach**.

This study aims (1) to explore the approaches by literature reviews, (2) to introduce a new approach so called random walk approach, (3) and to report the insights learned from these approaches.

2. Stochastic Approach

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There have been significant efforts to develop the probabilistic model of occupants to be integrated into BEPS tools [4-9]. Newsham et al. [4] developed a stochastic model, Lightswitch-2002, to predict the lighting profiles for an office, and the Reinhart [5] proposed a model in the same context of Newsham's model to predict the lighting energy performance of manually and automatically controlled electric lighting and blind systems. Page et al. [6] proposed a generalized stochastic model for the occupant presence with the Markov Chains' transition probabilities. The model produces a time series of the state of occupant presence using the profile of the parameter of mobility, and a period of long absence. Feng et al. [7] developed a software module to simulate the occupancy based on the Wang's Markov chain concept [8].

A common feature in the aforementioned stochastic or Markov chain studies is that the model is statistically described by conditional probabilities or transition probabilities derived from the measured data. Thus, it is very obvious that the stochastic model is beneficially applicable when occupant's presence or behavior is of a resembling stochastic characteristics (e.g. occupant presence in K-12 school buildings). The other concern with stochastic prediction is that the model is usually generated in a collective manner (e.g. occupant presence in whole residential apartment buildings). Such collective model is not always applicable to individual household's situation. What follows is an example for such case [10].

Fig. 1 shows the comparison between (1) a measured value, (2) simulated prediction of Markov chain, and (3) an average value of 10 households' measurements. The simulated value is similar to the measured value, but the measured average value, which can be regarded as the collective prediction, is significantly different from the others ((1), (2)). This signifies the limitation of the stochastic model that the collective prediction is not always reliable and that an individual household's model has to be made for better prediction.

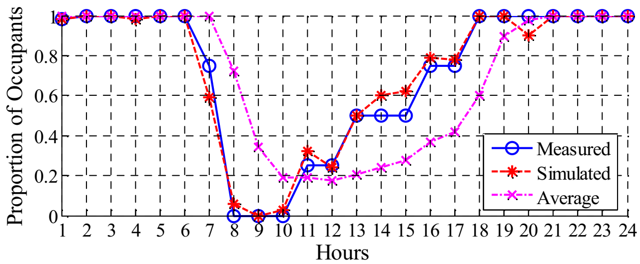

Fig. 1. Stochastic simulation results [10]

3. Agent Approach

An agent approach aims to describe the interactions based on the occupants' perception, desire, intention, etc. The agent focuses on what an occupant perceives and does under a certain situation. In other words, the agent approach tries to simulate autonomous occupants. Fujii and Tanimoto [11] introduced the agent model which is a computational model of a cognitive process that couples perception and action. Lee and Malkawi [12] showed how the agent adapts to the thermal changes in the space to optimize the multi objective, comfort and energy savings.

One of interesting features of agent approach is that it reflects socio-economic and psychological interactions between occupants under the decision-making process. Robinson et al. [13] proposed a framework for a multi-agent simulation system that considers occupants' presence, activity, behavior, comfort and investments. Kim et al [14] developed the multi-agent simulation combined with movement algorithm using Markov Chain.

Fig. 2 [14] shows a comparison of agent simulation with three deterministic (or conventional) simulation results during a day. The three deterministic simulation cases (#1, #2, #3) were conducted for randomly selected three households out of 30 households [10]. The deterministic simulation cases used measured hourly occupancy presence and a constant room temperature of 26.00C when occupants are present. However, the deterministic simulation cases do not reflect occupants' cognition, perception, desire, intention and interaction, while the agent simulation does. The agent approach reflects occupants' responses (turn on/off air conditioner, opening/closing windows). As shown in Fig. 2, there is a significant gap between the conventional approaches and the agent approach. However, the reliability of the agent simulation lies in how accurately we can describe occupants' sensation, perception, desire, intention, interaction, etc. Considering that any human being is not identical to one another, the agent approach might be a long winding road.

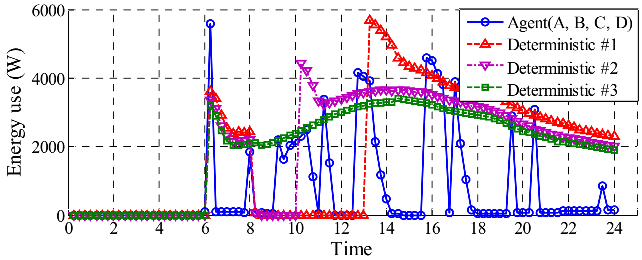

Fig. 2. Agent vs. deterministic simulation results [14]

4. Random Walk Approach

Mahdavi et al. [15] reported that different office zones shows significant differences in their occupancy patterns even if the zones are in a same building. Motivated by Mahdavi et al. [15], a random walk approach was introduced by the authors. The random walk process is a sequence of random variables [16]. The random walk is a mathematical formalization of a path that consists of a succession of random steps as follows [17]:

$$x_{k+1} = x_k + w_k \quad (1)$$

where x_k is a state of the kth time-step, x_{k+1} is a state of the (k+1)th time-step, and w_k is a random variable. The random variable can be regarded as a white noise added to a time-series. White noise draws its name from white light, although light that appears white generally does not have a flat spectral power density over the visible band. The white noise means a sequence of serially uncorrelated random variables [18].

The time-series data can be converted into a frequency domain with Fourier transform, which consists of 2π-periodic functions. w_k can also be expressed as a combination of cosine and sine waves and then analyzed with regard to the periodicity. The Normalized Cumulated Periodogram (NCP) is commonly used for identifying the periodicity of a given time-series in a frequency domain [19]. If any time-series data is uniformly distributed over the entire frequency range, w_k follows the random walk.

A series of experiments were conducted in two universities' laboratories and study rooms to collect occupancy pattern. The experiment was conducted at a sampling time of 10 minutes.

Fig. 3 shows the result of NCP analysis. The blue line denoting w_k is located between the 95% confidence limit (two red dotted lines). This means that the spectral density of w_k is evenly distributed over the entire frequency range as the white noise is, signifying that the occupant presence follows the random walk. Inferring from the fact that the occupant presence follows a random sequence, w_k is unpredictable.

This result is contradictory to aforementioned two well-known approaches (stochastic Markov chain, agent), both of which aim to predict occupant's presence and behavior. Be noted that this 'random walk' case study is based on university labs, which are quite different from process-driven buildings such as residential apartments, K-12 schools, and hospitals.

Based on the observation on the aforementioned three approaches, it can be inferred that there is no universally applicable occupant prediction model but the modeling approach must be carefully selected based on the occupancy characteristics.

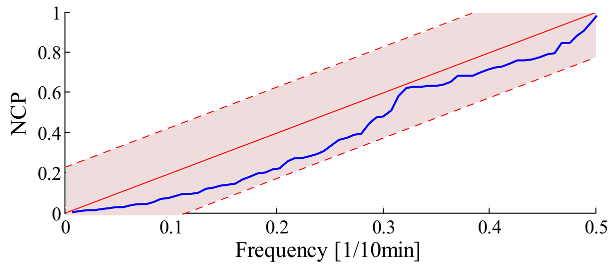

Fig. 3. NCP of the difference between x_k and x_{k+1} (w_k)

5. Conclusions

This paper explores three approaches: stochastic, agent, and random walk. The stochastic approach usually employs the Markov chain, but it is applicable only if occupancy pattern follows the transition probability. In the agent approach, occupant's sensation, perception, desire, inference, intention, and interaction are reflected. There is a non-negligible difference between the deterministic vs. stochastic approach or the deterministic vs. agent approach.

The third approach presents a new concept, randomness of occupancy pattern. In contrast to the aforementioned two approaches, the random walk approach views occupancy pattern in a different way that occupancy pattern is unpredictable in certain cases.

Based on the studies presented in this paper, we have to confess that our understanding on occupant presence and behavior is too shallow to accurately simulate occupant behavior and its impact on building performance. In near future, more effort and research have to be invested on occupant modeling and behavior for better building performance simulation and prediction.

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