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Integrating probabilistic methods for describing occupant presence with building energy simulation models

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ABSTRACT

This paper presents a method for developing a probabilistic-based occupancy model that focuses on occupants' long vacancy activities (greater than 1 week) and other potential building underutilization that is further integrated with a building energy simulation model. The combined model is then applied toward an existing Leadership in Energy and Environmental Design (LEED) certified military dormitory and later compared with corresponding values from the energy model's original prediction as well as actual building energy data. The occupancy model simulates annual building occupancy rates comprised of weekly values based on the frequency, duration, and seasonality of occupants' long vacancy activities. The energy model uses the simulated occupancy rates to yield the building's predicted range of energy performance. Applying the combined model to the existing LEED building resulted in an improved, predicted Energy Use Intensity (EUI) mean value of 612 MJ/m^2 as compared to the original model and actual EUI values of 691 and 590, respectively. While the model also demonstrated its utility in describing the change in predicted performance over a range of probabilities associated with certain long vacancy activities, efforts to incorporate other occupant behavior-related aspects such occupant schedules and thermal set points could further improve modeling efforts.

1. Introduction

Building energy modeling remains a key element in the design of energy efficient and sustainable buildings. The United States (U.S.) Department of Energy's (DoE) Office of Energy Efficiency and Renewable Energy cites nearly 400 building energy simulation software tools available for use in simulating various building design alternatives' impact on energy consumption [1]. Buildings consume a significant amount of energy as compared to other sectors, such as transportation and industrial. According to the DoE, the residential and commercial building sector accounted for approximately 41% of the nation's total energy consumption in 2010 [2]. As buildings continue to use a significant portion of the total energy consumed, building energy models will continue to play an intricate role in the design of new buildings and renovation of existing ones for both the private and public building sectors.

The literature contains numerous studies that evaluate the effectiveness of energy modeling efforts by comparing predicted to actual energy consumption, particularly buildings certified through the Leadership in Energy and Environmental Design (LEED) program [3–9]. Turner and Frankel's [3] large study of 121 LEED buildings cited that from a programmatic standpoint, the energy models predict building energy consumption rather well. However, they also concluded that significant variance existed between predicted and actual energy consumption values among individual buildings and that further research was necessary to further explain these sources of model error.

Sources for building energy model error can normally be attributed to one of four different areas: differences between the energy model parameter values and the as-built building, its mechanical systems, or presumed activities within designated spaces within the building not accounted for in the model; building systems operating at suboptimal performance levels, perhaps due to insufficient commissioning or maintenance activities; differences in climate conditions affecting building performance; and occupant influence. Torcellini's [9] study of six high-performance buildings revealed inadequate building controls to enable efficient integration of building systems, less than expected savings from daylighting and photovoltaic (PV) systems, higher than expected plug loads, over estimating the building's effective insulation values, and an overly optimistic estimation of occupant acceptance of building systems as actual sources of model error.

The latter of these actual sources of model error fall under the broader category of occupant influence. As building energy models

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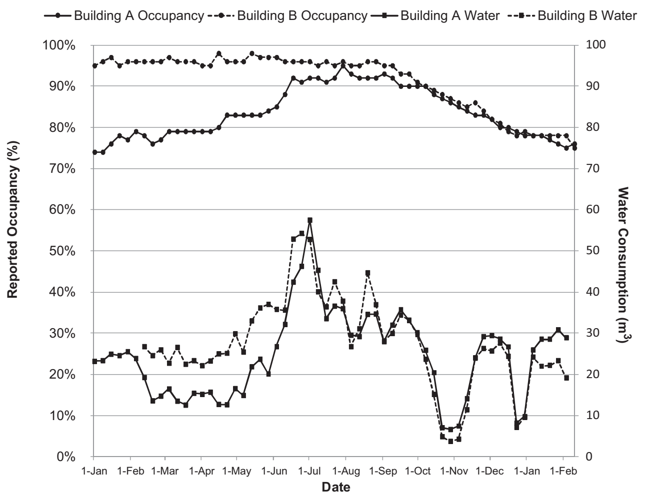

Fig. 1. Reported daily occupancy rates and average weekly building water consumption.

become more sophisticated in predicting energy consumption, future models will need to incorporate the vast variation that lie within building occupant influence. Occupant influence on building performance can be further divided into occupant behavior and presence. Most energy modeling efforts describe occupant behavior and presence through predetermined occupant schedules and assumed plug load factors that deterministically describe occupant influence in the building's energy consumption. For example, building energy models typically use weekday and weekend schedules to model occupant presence throughout the week. However, while these model assumptions may suffice under certain circumstances, they do not adequately describe the range of variation that can be observed among building occupants. They do not account for variation within individual work schedules, energy consumption related behavior, or periods of intermediate and long vacancy. Past research studies have tried various methods for describing occupant behavior and to a lesser extent, occupant presence, and will be described in greater detail in the literature review section.

Fig. 1 illustrates the reported, actual occupancy for two, identically-constructed, and co-located LEED-certified military dormitory buildings and their associated water usage. The primary vertical axis represents the building's daily reported occupancy as reported by the military installation's housing management office. The secondary vertical axis represents the building's daily water intake in cubic meters (m^3) which is used as an indirect measure of the building's actual occupancy within the building. The illustration serves two purposes. First, it illustrates that unlike the respective building energy model's assumption of fully-utilized dorm rooms throughout the year, the number of unassigned rooms varies not only with time, but also among buildings. Second, the noticeable spikes and troughs in building water consumption illustrate that the reported occupancy data does not account for tenants' long vacancies, but do in fact occur. The increase in water consumption observed in both buildings from May through September may partly be explained by the building's usage of additional water for outdoor irrigation purposes. But it does not account for other occurrences, such as the larger troughs observed in November and December, and Building A's noticeable decrease from February to May. A similar graph illustrating energy consumption and reported occupancy was constructed in a previous paper [10]. The buildings' water data used in this study was used to improve our understanding of the buildings' actual occupancy by detecting large and sudden changes in the buildings' actual occupancy. While the building energy model assumed a consistently fully-occupied building, Fig. 1 clearly shows significant differences exist. Further research is necessary to integrate building occupant presence and more specifically, long periods of vacancy, in order to modeling efforts associated with building energy consumption.

The purpose of this study is to propose a method that accounts for the potential variance in occupant presence, specifically long vacancies, through probabilistic methods that are in turn integrated with a building energy model. For demonstrative and validation purposes, this method is applied toward the aforementioned military dormitory building and compared these results with the original building energy model's prediction and actual energy consumption results.

2. Literature review

Integrating user impact with building performance through occupants' related behavior and presence patterns are important elements in any whole building energy simulation analysis. Occupants influence building energy consumption through a variety of activities such as emitting heat and water vapor through mere presence, making changes to the building's indoor environment such as opening/closing window shades and adjusting thermostat controls, and engaging in work and leisure-related tasks conducted within the building. Degelman [11] noted that the building's operational characteristics, implicitly implying occupant behavior, can have an even greater impact on building energy performance than the building's thermal envelope. However, much less has been done on modeling building occupant behavior as compared to building systems. The American Society of Civil Engineers (ASCE) Visualization, Information Modeling and Simulation (VIMS) technical committee states that accurately modeling building occupant behavior is a challenge that demands attention [12].

Integrating behavior models with whole building energy models largely began with incorporating behavior models with energy models associated with indoor artificial lighting. Hunt [13] began this area of research by translating detailed observations of how people used indoor lighting under varying circumstances into a prediction model for the likely use of manually-operated lighting systems. Unfortunately, many building energy models typically address user presence and behavior through static and rigid methods such as occupant profiles and consumption factors. The occupant profiles generally consist of 24 hourly values representing the percentage of an assumed peak load. Building energy models may also use separate schedules for weekdays, weekends, and holidays to account for the assumed differences in usage based on building type during these time periods. Page et al. [14] listed multiple shortcomings of this approach that included over simplifying the variety of occupancy patterns among building occupants during weekdays or weekends and excluding atypical behaviors such as intense presence or long periods of vacancy, all of which can be accounted for when observing actual energy data. This agrees with Degelman [11] who noted that energy models tend to better align with reality when building operations are more constant and routine (e.g. when the occupant exhibits less control over indoor environmental conditions). Kwok and Lee [15] further illustrated this shortcoming in their study of relating occupant behavior to building energy consumption. Their study consisted of evaluating a large office building comprised of numerous multi-national firms that utilized the building during various sets of business hours.

Bourgeois et al. [16] addressed these shortcomings by developing a behavior model that accounted for the variety and frequency of occupant responses to adjusting indoor lighting levels. He integrated a sub-hourly occupancy-based control (SHOCC) model with the Lightswitch2002 behavior model, developed by the contributions from Newsham et al. [17] and Reinhart [18], into the whole