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Promoting Energy Efficiency of HVAC Operation in Large Office Spaces with a Wi-Fi Probe enabled Markov Time Window Occupancy Detection Approach

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Abstract

In recent years, demand-based control in HVAC systems have achieved a great amount energy saving by providing precise services in according to actual demand. As the premise of determining actual demand, occupancy information has a significant impact on building heating, cooling and ventilation in building control and energy auditing. In this paper, a Wi-Fi probe based occupancy detection method is applied to detect the occupancy in typical office buildings. Given the Wi-Fi coverage and smart devices are widely used in modern buildings, Wi-Fi probe requires no initial investment and could scan the Internet connection request and response of occupants. Previous studies suggest time-series and stochastic characteristics of occupancy information, this research proposed a Time-Window based Markov Chain (TWMC) model to detect occupancy. An on-site experiment was conducted in this study to validate the proposed method. The results report an accuracy of over 80% (x-accuracy when x equals 4). Compared to actual occupancy profile, the proposed model shows over 88% of supply air amount reduction in energy simulation with an absolute deviation less than 20%. By integrating the proposed TWMC model based on Wi-Fi probe and demand-based control system, the energy consumption of HVAC system could be significantly reduced.

Keywords: Wi-Fi probe; occupancy; Markov approach; energy efficiency; demand-based control;

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1. Introduction

HVAC systems serve as a significant role in maintaining building indoor environment and providing related services, such as lighting, heating, cooling, and ventilation. As the major energy consumer in commercial buildings, HVAC systems consume more than 40% of energy consumption in commercial building [1]. One of the most widely adopted energy saving strategy is to improve the efficiency in HVAC control [2,3]. Occupancy as the premise of HVAC control often integrated with other indoor environment parameters, such as temperature, humidity and Carbon Dioxide (CO2) concentration [4,5]. Tradition control modes operates the system with preset parameters and likely result in energy inefficiency caused by over-cooling or over-heating. Therefore, the role of accurate occupancy information has risen quickly in recent years, given it is closely associated with many building energy systems' operation, such as lighting, heating, ventilation, air-condition system [6]. Thereby, many research effect has been invested to excavate the solution of accurate occupancy information. When the occupancy information is unavailable, the facility managers adopt the standard occupancy schedules that recommended by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) standard 90.1-2007 [7]. However, due the various design and occupancy pattern, the actual occupancy schedules could dramatical different from the standard schedules. In Gunay and O'Brien's study, an difference as high as 40% can be observed between the actual occupancy and the standard occupancy schedules recommended in the ASHRAE [8].

Therefore, many researchers utilized CO2-based detection systems [5] and Radio Frequency Identification (RFID) [9] to portrait occupancy profiles in typical office rooms. However, the CO2-based method inevitably was limited to its sensitiveness to environment and time delay while the RFID solution also constraints to it high cost. Another alternative technology is Wi-Fi probe, which utilizing Wi-Fi requests and responses between clients and Wi-Fi signals and the device hardware addresses to detect the unique identity of occupants. Several studies have demonstrated that the Wi-Fi connections and disconnections could be utilized as indicators of building occupancy [10] and energy load variation [11]. However, previous studies require the occupants' mobile devices to be connected with the target access points (AP). The new generation of Wi-Fi probe detection dose not require such connection and generate redundant data that difficult to differentiate occupants from wireless devices. This proposed research aims to develop a new occupancy detection algorithm that can be implemented in the actual HVAC operation in commercial buildings with large continuous spaces. Also, the proposed Time-Window based Markov Chain (TWMC) model was validated in a test office space.

2. Methodology

Many exiting studies suggests when modeling building occupant, two data characteristics should be concerned: 1) the time series characteristic: since occupancy changes over time, its changes can be modeled as the sequences of stochastic process at equally spaced time intervals; 2) the statistic characteristics: occupancy evolves regularly and could be learned from historical data. Therefore, considering these stochastic characters, a time-window based Markov chain is proposed to utilize previous time series occupancy status to predict its current occupancy schedule. Markov chain modeling is a classical method to mimic stochastic processes through analyzing the transitions from data status. In a Markov chain model, two important input parameters should be derived to construct the system, including the initial status and transfer probabilities. This study modeled the occupancy as two Markov status, either "in" or "out". When the unique hardware address (UUID) of a client's mobile device was detected by the Wi-Fi probe, the client is set as "in", otherwise, as "out". Many conventional stochastic model penalize the probability of current status, for example, when the status is "out", the next iteration the probability of "in" will be increased. In the proposed model, there is not such discount in probability and the status are modeled as multiple devices. To do so, the Markov chain was applied with a moving time window and screening all possible UUID in the time window. It assumes that if the UUID of one client has been detected in the current time window, it would be still detected possibly in the next time window. Figure 1 shows an illustration of time-window based Markov chain model. Since there are two initial occupancy statuses: in / out, it could define that P_{i-i} denotes the probability that one occupant whose status is "in" at current time would be still "in" in the next time and P_{o-i} denotes the probability that one occupant whose status is "out" at current time would be "in" at the next time. Then we could calculate the probability in equation (1).