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Detecting occupancy behaviour of buildings through environment monitoring sensing

Binta Fatima Yahaya [1, *], Allan Joseph Usman [2, 3] and Joy Nanlop Uwa [4]

[1] *Department of Architecture, Kano University of Science and Technology, Wudil, Nigeria.*
[2] *Department of Architectural Technology, Federal Polytechnic Nasarawa, Nasarawa State, Nigeria.*
[3] *Department of Architecture, Abia State University, Uturu, Abia State, Nigeria.*
[4] *Department of Architecture, Cyprus International University (CIU), Nicosia, Cyprus.*

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Abstract

The goal of this research is to produce a realistic occupancy forecast as well as an ideal occupancy-based controller for increasing the performance of Heating Ventilation and Air-Conditioning [HVAC] systems. Reliable occupancy prediction is a critical enabler for demand-based HVAC control since it ensures that the HVAC system is not running unnecessarily while a room or zone is empty. We present simple yet successful occupancy prediction methods, as well as an approach for automatically setting temperature set-points, in this work. We present three alternative occupancy prediction algorithms based on historical occupancy measurements. The proposed approach uses historical occupancy profile and environmental room data to establish an occupancy identity strategy that can provide a stochastic model based on uncertain basis functions as an alternative. According to the findings, the proposed occupancy prediction algorithms could reach an accuracy of approximately 85% reliable prediction with few negative predictions.

Keywords: Occupancy based; Performance predictions; Historical HVAC; Algorithms alternative approach based control; Building comfort.

1. Introduction

The construction industry accounts for a considerable portion of worldwide energy usage. This percentage varies by country, but it reaches around 40% throughout Europe [1]. The significance of occupant behavior in building energy performance has been a topic of great interest in the research world [2]. As indicated in Figure. 1, the number of publications on this issue has increased by around 230 percent in the last ten years and by 30 percent in the last few years. In general, the research of occupant behavior in buildings aims to solve at least the energy consumption problem.

* Corresponding author: Binta Fatima Yahaya
Department of Architecture, Kano University of Science and Technology, Wudil, Nigeria.

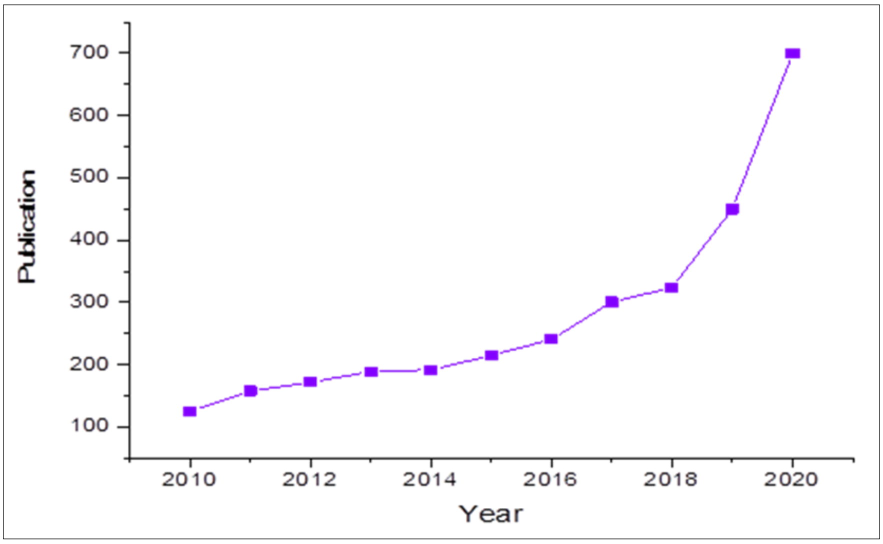

Figure 1 Number of indoor occupancy detection related research for a decade

2. Related Work

According to [4], the primary activities targeted by scientific research in residential structures are the functioning of windows and the management of air conditioning systems. The major inhabitant behaviors associated with vapor generation in a home were investigated from a different angle [5]. For gathering occupant behavior data, several methods are available, including in-situ surveys (monitoring), focus groups, and laboratory investigations [6]. But they are non-intrusive, the first techniques are the most accurate, but the others move away from the framework of regular building functioning and tend to distort the actual processes of everyday occupant behaviors. Many researchers, on the other hand, conducted investigations only utilizing surveys, aiming to reduce probable discrepancies by employing large sample sizes.

1569 questionnaires were utilized by [7] to analyze the behaviors of inhabitants that have an impact on the indoor environment of homes. [8] evaluated time-dependent occupant behaviors using 7949 questionnaires. The study's goal was to develop a statistical foundation model. In general, the researchers point out that lengthy surveys have a high rate of non-negligible mistakes [9]. Surveys, on the other hand, can be a useful tool when used in conjunction with monitoring initiatives [1, 2]. As a result, mixed methods research might be a useful tool for measuring occupant behavior and gaining qualitative occupant viewpoints [10]. Mixed methods research is widely used and is being used in occupant behavior studies [11, 12, 13].

In terms of the observation operation, sensors exist that enable real knowledge of regular occupant actions, as well as others that use the collected parameters to infer occupant behaviors [14]. Sensors that detect occupant activities directly can be employed alone [15] or in conjunction with modeling and simulation [16]. In-situ monitoring campaigns, on the other hand, are difficult tasks that necessitate a high level of expertise to optimize researcher decisions at various levels [17], including sensor types [16], sensor technologies [18], ideal placements [19], observing promotional duration and data collection time step [20]. Occupancy detection research has received considerable interest from many academics [21]. Based on occupancy, this study field focuses on increasing energy efficiency, thermal comfort, and indoor air quality [22, 23]. Occupancy knowledge, on the other hand, is difficult to come by since a big amount of data that may be utilized as ground truth is not always accessible, and alternative learning techniques are in high demand [24]. Despite a wide range of possible applications, building occupancy estimation remains a time-consuming, error-prone, and costly procedure [25]. [26] provided a comprehensive literature analysis for real-time monitoring systems and modeling in office buildings. Several occupant behavior models have been developed for occupancy modeling [27]. Furthermore, similar occupancy models have been combined with movable windows, blinds, and lights [13]. Using Markov-chain algorithms [28] or machine learning techniques [29], occupancy information has lately been used in Home Energy Management Systems (HEMS).

As previously stated, unreliable occupancy data is crucial in designing a demand-driven HVAC control plan. Short-term occupancy forecast for single rooms is difficult due to the stochastic nature of the occupation. Previous occupant model studies have utilized binary data (i.e., presence and absence) [30], exact discrete values (i.e., the number of occupants) [24], or normal distribution ranges (i.e., the number of occupants) [25] to represent various levels of occupant behavior detail. Based on the application context, each of these simulations accomplished a decent trade between model accuracy and intricacy. Demand-driven control may employ precise occupancy estimates to regulate real-time HVAC usage, lowering energy consumption and preserving interior thermal comfort conditions [31] [32]. According to [32] having a strong design that is less susceptible to occupant fluctuation can result in a 75 percent energy reduction. Using real-time occupancy data has also resulted in 42 percent energy efficiency when combined with design control techniques [33]. A typical HVAC management system's main goal is to keep the temperature and indoor air quality within a comfortable range while using as little energy as possible. The current standard for HVAC management relies on the selection of predetermined dead-band values, which necessitates a substantial degree of time-consuming adjustment. Indeed, with the increasing complexity of modern HVAC systems, this adjustment has grown more difficult, especially when it comes to the unpredictable features of occupancy [34].

Another option is to employ the well-known model predictive control (MPC) method, which considers whether an occupancy projection (as shown in Figure 1). MPC reduces energy usage at each sample period by refining a preparation for future HVAC operation based on meteorological and occupancy forecasts over a future time horizon [35]. As studies in [36] reveal, MPC has been widely used in building temperature control systems and has proven substantial energy efficiency.

3. Proposed Work

Most of the previous studies need an off-line training phase including a substantial quantity of gathered data. However, the purpose of this work is to present an alternate online approach for predicting short-term occupancy. By using a non-fixed thermostat set-point for the HVAC controller, the presented occupancy-based control framework seeks to reduce overall HVAC energy consumption while maintaining a comfortable interior atmosphere in buildings. We recall one effective approach [31] for properly allocating temperature set-points based on real-time predictions of building occupancy information.

In this work, we make three contributions: To begin, we create a utility function that works in tandem with a temperature set method to capture the trade-off between occupant comfort and energy usage. Second, we provide three alternative occupancy estimate techniques for quick stochastic modeling of short-term exposures. Finally, we evaluate and confirm the suggested approaches' power capabilities. Energy consumption is compared in detail using several occupancy estimation techniques as well as without any occupancy information. Only a few implementations of occupancy models in building modeling have been documented [31]. To the best of the authors' knowledge, there are few guidelines or analyses for occupancy-based HVAC control approaches that use projected occupancy information. This study connects the world of dependable stochastic occupancy modeling with an energy-efficient building model.

It is a follow-up to the prior work of [37], in which they developed a more sophisticated prediction system. The concept of Uncertain basis has been introduced. In this work, we offer a unique quantified analysis of actual energy savings using a demand-based HVAC management method. Finally, an additional explanation is offered to better show how the suggested demand-based management method may save energy.

3.1. Indoor Thermal Model

The standard one-dimensional resistance-capacitance (RC) model used throughout the MPC design is described in this section. The model is built on a thermodynamics consistent model that incorporates room temperature, the inside surface temperature, and facade core temperature changes. This building thermal model has been used to simulate multifamily housing structures in hundreds of studies [32, 36, 37]. It is characterized as follows:

$$\mathrm{var.}\Delta X=(X_{t+1}-X_{et+1})-(X_t-X_{et}) \quad (1)$$

$$\mathrm{var.}\Delta X=((X_t-X_{et})/X_t) \quad (2)$$

Where

X_t is represented by the temperature, moisture density, or CO2 level which correlates to the inside model parameters at time t.

X_{et} is represented by the discrepancy between the interior and outside temperatures or the interior and exterior moisture pressures which correlates to the outside values of the independent variable at time t.

The data processing phase follows, within which data extraction is carried out using the behavior detection method in equations (1) and (2). It is the method's most delicate and difficult stage. An acceptable error of just a one-time step (10 minutes) was proposed as a criterion for defining what constitutes a successfully identified activity. As a result, an action detected by the suggested technique is only considered a "true positive" if it occurs within 10 minutes of an activity validated by the occupant's regular diaries or sensors for that effect. Because occupant activities produce fluctuations in the relevant data over many time steps, a refinement criterion must be developed. This criterion prohibits the technique from identifying the same activity many times as if it were multiple actions occurring in a row. After employing the refining criterion, the accuracy of the prediction index must be recalculated in the form of the A index (see equation 3). The model prediction results on the historical data collected are presented in the table. The results of the prediction are analyzed to determine the reliability of the models' incorrect predictions.

Accuracy=(TTP/TP) X 100 (3)

where

TTP represents the total true prediction correctly identified and TP represent the total true prediction

Table 1 Proposed Occupancy Prediction Model Results

Training Set Score	Testing Set Score	Cross-Validation	Total Prediction	True Prediction	Negative Prediction	Confident Level
0.441482	1.5789	-0.77255	17	17	0	0.928259
-0.81178	-1.27055	-0.77255	12	12	0	0.8528
-0.26125	-0.20372	1.001942	9	9	0	0.928259
1.315848	2.352166	1.001942	28	22	6	0.85285
0.723222	1.110835	1.445564	5	5	0	0.828259
-0.53004	-0.19071	-0.77255	3	3	0	0.928259
1.544155	0.025868	2.018078	91	64	27	0.8528
1.413	2.262522	1.086869	22	21	1	0.928259
1.058396	-0.19071	0.930003	32	28	4	0.928259
-1.11295	-1.05294	-0.77255	94	65	29	0.8528
0.468198	1.615853	-0.77255	13	13	0	0.928259
2.252391	0.408737	1.129833	29	25	4	0.8528
0.34433	1.151072	1.188183	114	85	29	0.928259
-0.1764	0.091767	1.032316	59	56	3	0.928259
-0.22887	-0.07165	1.041908	76	74	2	0.8528
-0.71463	-0.16061	-0.77255	76	74	2	0.928259
Total			674	573	101	

The model prediction performance can be determined by calculating the true prediction and negative prediction using the following prediction formula.

For true occupancy prediction the model achieved the following:

Accuracy=(573/674) X 100

Accuracy=85%

The false-negative prediction can be calculated using the following:

Accuracy=(101/674) X 100

Accuracy=15%

4. Conclusion

In residential structures, occupant behavior is critical to their hygrothermal efficiency. Understanding occupant behaviors, on the other hand, is a difficult process. An environmental data control method that employs temperature, relative humidity, and/or CO_2 concentration sensors was used to create a technique to identify occupant daily routines (i.e. opening windows, showering, cooking, and heating). The technique was founded on the idea that occupant behaviors impact the environmental data being monitored, leading to serious data statistical analysis values. The approach may be integrated into existing data time series, giving it a unique quality and significantly broadening its application range. From current registers, the technique may extract new and useful data. The following findings were reached after using this approach for a case study:

- The technique may be used to detect gable vents.
- It can be used with reduced, convenient, moderate, and simple-to-install sensors.
- It is predicated on the idea that an efficient variable can be utilized as a trigger for an actual action to occur.

Compliance with ethical standards

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Disclosure of conflict of interest

This manuscript has no conflict of interest among the authors

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Author's short biography

	**Arc. Binta Fatima Yahaya** is currently a lecturer at the Kano University of Science and Technology, Wudil since 2001 till date. She is a member of Nigeria Institute of Architects and a member of the Association of Architectural Educators of Nigeria, and Community service and University Responsibilities: She is a recipient of many awards including the 2019 World Women Day Award, by Her Excellency, the Wife of Kano State Governor, for Outstanding Contribution to the profession of Architecture in Kano State.
	**Arc. Allan Joseph Usman (MNIA)** Is a Senior Lecturer and was the Head of the Department, Department of Architectural Technology, Federal Polytechnic, Nasarawa, 2019, January 2019 to May 2019 currently a doctoral candidate at the Imo state university, with a Ph.D. (In View) in Architecture. He is a member of the Nigeria Institute of Architects
	**Joy Nanlop Uwa i**s a doctoral candidate at the Cyprus International University (CIU) her area of interest borders on researches in sustainability, place-making, and optimizing space management & resources in the practice of architecture and the built environment in general. Over nine (9) years she has served in the Physical Planning and Development department of the National Commission for Colleges of Education (NCCE) Abuja as an Architect and Supervisor that ensures maintenance of standards for buildings and construction projects of the Commission and Colleges.