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Vision-Based Occupant Tracking Application For Smart Glass Window Façade Embedded with Thermal Imaging Sensor to control HVAC ventilation

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Abstrack- Today, Heating, Ventilation, and Air Condition (HVAC) equipment account for an average of 60% of total traditional building energy consumption. A high percentage of this consumption was avoidable through efficient control to avoid ventilation of vacant space as well as operating automatic and continues adjusting ventilation rate proportional to the number of occupancies equipment presently in space. Recent research focuses on implementing various strategies to leverage the concept of the Internet of Things (IoT) by transforming traditional home to smart home, which can monitor meteorological data and occupied areas by turning HVAC equipment ON at a specified ventilation rate. These researches have attained an overall average of 45% accuracy and 30% energy saving potential. The existing strategies suffer from false human occupancy detection and estimation in order to accordingly set ventilation rate to serve occupancies proportionally. This research aimed to improve human occupancy detection and introduce HVAC fuzzy controller by estimating the occupancies number and set ventilation rate according to their requirement. The study uses thermal camera approach to collect occupancy information and methodological data as input to controller to operate HVAC equipment. The experimental analysis shows the proposed controller have achieved significant energy saving and acceptable comfort level.

Keywords -*HVAC, tracking, occupant, smart, window*

I. Introduction

Smart home energy management system (SHEMS) is one of the advancements of the Internet of Things (IoT) technology that emerged in the global information industry, equipped with IoT products and Zigbee technology aimed to transform the traditional building into an energy-aware environment to minimize excess energy consumption. Studies show Heating, Ventilation, and Air-condition(HVAC) systems are essential to improve occupants' lifestyles and maintain a healthy living environment [1-4].

Today HVAC system accounts for an average of 60% of total building energy consumption, and its demand forecasted to increase in upcoming years[5]. A recent investigation [6, 7]reveals a large portion of the energy consumed by the HVAC system is actually avoidable, usually caused as a result of poor HVAC operation control practice including heating/cooling vacant space and overheating/cooling of occupied space.

Reliable human occupancy detection and estimation is one of the logical approaches to avoid ventilation of vacant and over ventilation of the occupied space, which in turn saves a significant amount of energy and maintain acceptable indoor air quality. Research on occupancy detection and estimation to manage HVAC equipment has gained more popularity in recent years targeting both commercial and residential buildings to reduce unnecessary energy consumption. A recent investigation shows the current algorithms and technologies have promised an average of 25% energy saving potential compared to the traditional approach [8]. However, poor accuracy in human occupancy detection and estimation is among the common challenges heavily suffered by the current proposals. Therefore, building technologies are still seeking accurate and reliable indoor occupants counting to improve the building performance in various applications, which include HVAC indoor ventilation control for energy management.

This study proposed an occupant counting using non-contact temperature thermal imaging measurement technology, which can provide remote monitoring of the thermal distributions of occupants to efficiently applied to control indoor ventilation of occupants without compromising their thermal comfort.
The rest of the paper has four main sections. Section 2 performed a literature review. Section 3 describes a computer vision analysis. Section 4 experimental setup. Section 5 experimental discussion and the last section concludes the paper

II. LITERATURE REVIEW

Studies in [9-11] presented a fixed schedule to control HVAC operation in an office environment. Experimental result analysis demonstrates the accuracy of the proposed approach heavily relied on the occupant's behavior patterns on fixed daily activities. This practice might produce poor results when occupants skip certain office activities or in a residential building where occupancy behavior or activities are not governed by the tight schedule.

A real-time occupancy detection and estimation data processing approach using camera-based image processing was proposed in and [12]. These approaches use background extraction using a computer vision library template to perform pixels analysis and uses vector support machine algorithms for collective occupancy counting, which will then be used to control HVAC ventilation. The proposed approaches suffered false alarm when occupancy overlap occurred in the period, which introduces comfort dissatisfaction and excess energy consumption.

The recent proposal uses Passive Infrared (PIR), [13] [14] [15]and Carbon Dioxide (CO_2) sensors to control HVAC ventilation based on collective occupancies number in an indoor environment. one of the challenges faced by both PIR and CO_2 lack of additional information which is likely to cause comfort dissatisfaction and false alarm in the presence of any stationary objects [12].

In [16] [12] a video surveillance application was proposed to perform adaptive crowd counting analysis to overcome the challenge of occupancy overlapping in previous studies and [17]. The proposed approach employed collaborative Gaussian models (GP) with different kernels designed for occupant counting. The experimental results analysis indicated that the level of accuracy of the method adopted was poor due to the presence of image noise. The technique did not take into account the fact that in every image, there exist sets of noise that needs to be filtered for better pixel estimation.

A study in [18]proposed a modified prevailing method for face detection previously used in [12]. The proposed approach, however, was tested in different scenarios to achieve the proposed goal. However, the method failed in certain instances, especially if the occupant's face is not well detected. Examples are in a crowded place; not all faces ate directly facing the camera. So, for this method to be accurate, all faces must face the camera.

In a software application was designed that counts [19] [20]occupant using an identifier and the software connected via USB. This technic performed poorly because the visual analysis was done using a background identification technique. Rather than run a proper image processing algorithm from stages to stages, an identifier was used to perform the counting. The issue of osculation and poor lightening was taking into account in [21], [22]. The author attempts to overcome the challenge by adjusting the indoor lighting illumination level, which will facilitate background image extraction by minimizing the complexity of scenes with multiple occupants overlapped. The experimental validation was performed on two five-minute video sequences captured at a public event with a moderate density of pedestrians and heavy occlusions. However, poor performance was observed when deployed on a live video stream.

A study in [23] proposed an occupancy classification algorithm to differentiate between human and non-human occupants to avoid false alarm caused by pets or stationary objects in the area of interest. The experimental result simulation shows significant energy saving on the HVAC system. The study described turnstiles and mat-type foot switches occupancy detection using the obstructive occupant counting procedure proposed in [24]. Turnstiles had some issues like high cost, low flexibility, and could obstruct the passageway [25]. In a situation of a high flow of traffic of occupants, a lot of time would be consumed, as stated by [26]. Moreover, there are limitations to undercounting possibilities. Also, non-obstructive systems like infrared beams or thermal (heat) sensors do not block the doorways; hence they can suffer from undercounting issues as well [26]. A vision-based counting system, one of the non-obstructive systems, can be said to be an alternative system compared to the other occupant counting methods. Also, vision-based occupant counting systems have the advantage of higher accuracy, inexpensiveness, and non-intrusiveness [27]. Since Vision-based occupant counting offers an alternative to these other methods. The first and common problem of all vision systems is to separate occupants from a background scene (determine the foreground and the background). In [28] an indoor occupancy counting was proposed using a PIR sensor to observe occupants movement in the area of interest to control HVAC ventilation. The counter was installed in the door entrance to count the occupants as they passed through. The authors claimed to have addressed occupancies overlapping problems that frequently occurred in a camera-based approach when groups of occupants pass through the camera's field of view.

Occupant presence was determined using an occupant tracking approach in [29]. Their system uses continuous tracking and detection to handle occupant occlusion. Template-based tracking is able to drop detection of the occupant as they become occluded, eliminating false positives in tracking. Using multiple cameras improves the resolution of the occlusion problem. But the problem is the need to have a good calibration of two cameras (when 3D reconstruction is used).

Analysis of related literature reveals that existing methods are based on skin detection, which provides inaccurate count, the method
involves complex algorithms and difficult to compute the faces, and all these methods of occupant counting involve a lot of hardware components.

This paper, therefore, presents an AI-based thermal occupant counting application for smart window façade using a low cost thermal, visual camera. The occupant counting application will use an AI-based image-processing algorithm that would take into account facial and body detection with less hardware and would be able to distinguish between occupants and objects and count accurately.

III. COMPUTER VISION VIDEO ANALYTICS

Video analytics, or intelligent video analytics, is software that is used to monitor and process video streams or images in real-time. While tracking the videos or pictures, the software identifies attributes, events, or patterns of specific behavior via video or image analysis of monitored environments. Video analysis software also generates automatic alerts and can facilitate forensic analysis of any data identifying trends, patterns, and incidents. The software enables its users to analyses, organize, and share any insight gained from the data to make smarter, better decisions. Some of the common areas of Application of video analytic are widespread, including monitoring vehicle patterns or violations of traffic laws, or occupant counting. The data received from either of these applications can then be sorted by time and date or over an extended period to create a trend analysis.

Video analytics comes with many benefits in security for public safety and smart building applications. It is being proposed and used to enhance these two sectors with comprehensive intelligence, security, and investigative capabilities. Therefore, the developed AI-based thermal occupant counting analytic software would be used to estimate the number of persons in the building at any particular time. This Application will run the AI-based image processing algorithm that will automatically determine the number of occupants and objects in a thermal video stream. Once the number of objects is determined, the objects per unit area or the density can also be estimated. The method would involve counting based on the size of objects, the color of objects, applying edge detection techniques, face detection, and body detection algorithm.

IV. OCCUPANCY ESTIMATION

Occupant counting software is an application used in calculating the number of an occupant in thermal video stream or images. Since computing, the number of objects is an integral part of image processing. Knowing the number of objects present in an image by using the expression in Eq 1, the information gotten can then be useful for further analysis in a wide range of applications. Like occupant tracking, disease control, thermal comfort, health monitoring, to mention just a few. This Application presents a simple method for automatically determining the number of objects in a thermal image. Once the number of objects is determined, the objects per unit area or the density can also be estimated. The method would involve counting based on the area of objects, the color of objects, applying edge detection techniques.

$$\textbf{OBJECTS PER UNIT AREA} = \frac{\textbf{NO OF OBJECTS}}{\textbf{TOTAL SIZE OF IMAGE}} \qquad \textbf{(Eq 1)}$$

The goal of occupant counting is to estimate the number of an occupant or the density of crowds in a monitored environment. However, detecting or calculating the density of crowds is always a challenging task due to some of the issues stated earlier, such as partial occlusions, low-quality images, clutter backgrounds, and so on. Two primary techniques would be used to count occupants in the thermal image. The first technique would be to count occupants based on face detection. Face detection is the process in which possible human faces are detected from a thermal image. Once the number of faces is detected, the density can be calculated, and rectangular boxes would be used to map the faces in the thermal image, as seen in figure 1(a and b) below.

Figure 1(a): multiple occupancy detection

Figure 1(b): Face and Body Detection

The second technique used in determining the number of an occupant in a thermal image is by possible body detection. Some thermal photos might not have clear possible head faces of an occupant in it. But with the help of the human figure body detection technique, the occupant counter application can calculate the number of persons in the thermal image as seen in figure 1(a and b)

Similarly, Figure 2 shows the image processing processes carried out when the thermal occupant counting application is running.

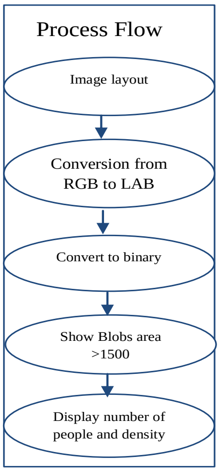

Figure 2: the flow of occupant Counting

4.1 Thermal Imaging Processing

All objects emit heat by three means: Conduction, convection, and radiation. Conduction transfers heat through solid objects. Convection transfers heat through fluids like air and water. Radiation transfers heat through electromagnetic radiation. Objects continuously radiate heat with a certain wavelength. Therefore, thermal imaging converts thermal radiation into a digital signal and is converted into a visible image.

Figure 3: thermal occupant counting stages

- Figure 3 shows the stages involved in the thermal occupant counting application. The thermal feed is converted from thermal view to lab Brightness equalization is done, and. The equalized image is converted to binary. The blobs in the thermal feed are opened when the area of the blob is greater than 1500. The number of occupant and density are displayed. Also, facial skin temperature features and gender differences were estimated using eq 2 as seen in [30]

$$\bar{\mu} = \frac{1}{n}\sum_{k=1}^{n} \mu_k, \quad SD(\bar{\mu}) = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n} (\mu_k - \bar{\mu})^2}$$ **(Eq 2)**

V. FUZZY INFERENCE SYSTEM

Fuzzy Inference System (FIS) is the concept that allows decisions to be made based on a possible number of options rather than "Ýes" or "No" option. Usually, the fuzzy decision approach differs from classical binary decision with the concept of "IF…THEN" rules alongside with "OR" or "AND" connector to draw a logical conclusion. These rules are made of linguistic prediction prescribing how FIS should decide on output based on inputs.
For instance

if (a given input1 belongs to set of membership function1) and/or (a given input2 belongs to set of membership function2) and/or then (the output decisio$_n$ belongs to set of output membership functio$_n$).

This is statement can be represented as

if the indoor temperature is high and the occupancy number is high, then the indoor ventilation rate should be very fast.

Or

if the occupancy body height is high and occupancy body width is high, then the occupancy is human.

5.1 Input and output membership for the proposed fuzzy HVAC controller

The input memberships of the proposed controller are ambient temperature Figure 4, and occupancy number Figure 5.

The controller reads indoor ambient from temperature sensors installed and the occupancy number captured by the thermal camera as variable inputs parameter.

The output value of the proposed controller in Figure 6 is the HAVAC setpoints value that can be adjusted to control the ventilation rate of the HVAC system depending on indoor temperature conditions and occupancy numbers.

These inputs and output values are called crisp mathematical values. These values are then converted by the fuzzifier module into fuzzy sets for generating fuzzy rules presented in Table 1. The fuzzy rules definitions are done by developer and expert, and it varies depending on the problem on the ground. The proposed controller consists of 30 fuzzy rules. If the user occupancy is low and the temperature is the setpoints are reduced accordingly to reduce energy consumption and make sure the occupancy comfort is not compromised.

The output of the controller is the temperature set point ventilation in Figure 7 to maintained satisfactory indoor air quality. The output temperature set point is controlled by fuzzy rules in Figure 6.

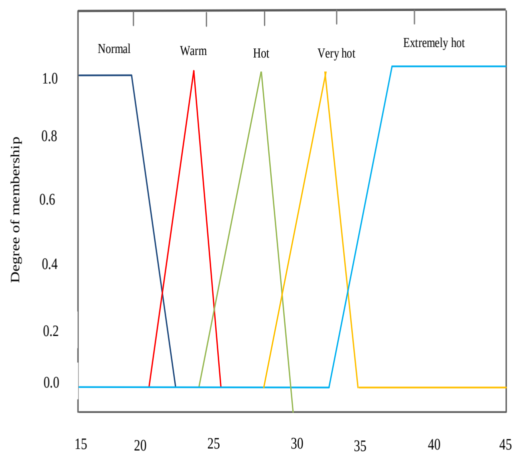

Figure 4 inputs membership functions for ambient temperature for the proposed DCV fuzzy controller

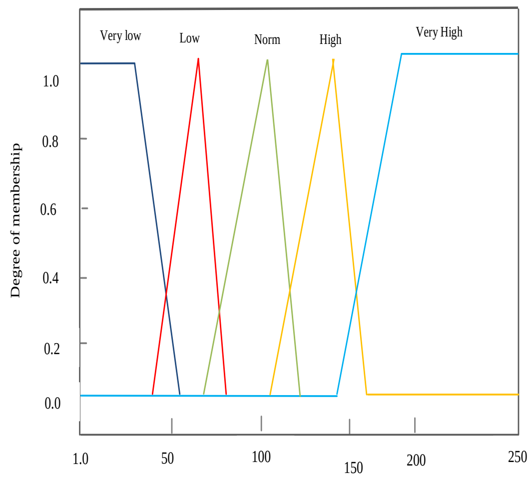

Figure5 input membership occupancies number for the proposed DCV fuzzy controller

Table 1 fuzzy rules for the fuzzy controller

Temperature	Occupancy	Setpoints
Normal	Very low	Extremely slow
Normal	low	Extremely slow
Normal	Normal	Extremely slow
Normal	high	Slow
Normal	Very high	High
Normal	Extremely high	High
Warm	Very low	Slow
Warm	low	Slow
Warm	Normal	Slow
Warm	high	Fast
Warm	Very high	Fast
Warm	Extremely high	Fast
Hot	Very low	Fast
Hot	low	Fast
Hot	Normal	Fast
Hot	high	Very fast
Hot	Very high	Very fast
Hot	Extremely high	Entirely fast
Very hot	Very low	Fast
Very hot	low	Fast
Very hot	Normal	Fast

Very hot	high	Entirely fast
Very hot	Very high	Entirely fast
Very hot	Extremely high	Entirely fast
Extremely hot	Very low	Very fast
Extremely hot	low	Very fast
Extremely hot	Normal	Very fast
Extremely hot	high	Entirely fast
Extremely hot	Very high	Entirely fast
Extremely hot	Extremely high	Entirely fast

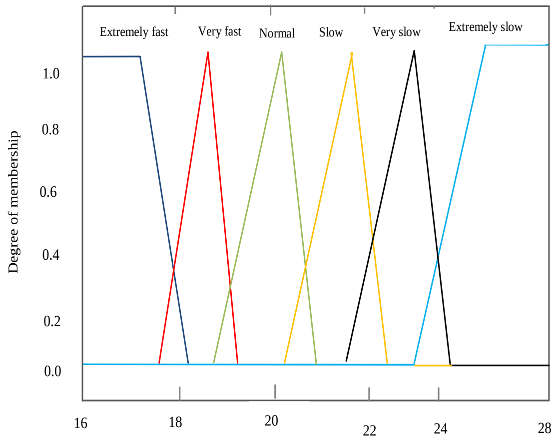

Figure 6 output membership ventilation rate setpoints for the proposed DCV fuzzy controller

6.0 Experimental Setup

As can be seen in the experimental setting(see Figure 7), a test was done by connecting a single thermal camera to the thermal occupancy counting application. The thermal camera was embedded into the glass window, as in Figure 7.

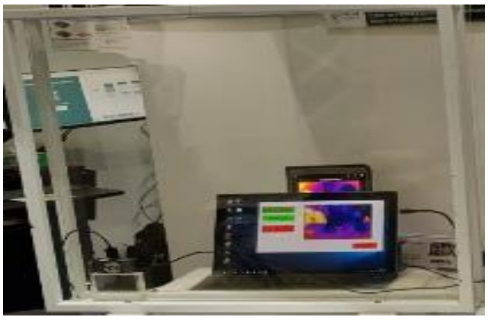

Figure 7: Experimental settings

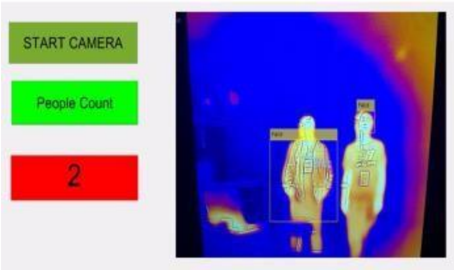

Figure 8: Smart Glass window with vision-based thermal Occupant Counting app Embedded with a thermal camera

Figure 8 shows every individual that passed through the thermal camera coverage area was detected and counted, and their body temperature was recorded. Also, the camera has a maximum coverage range of 30 meters.

After testing the countability and precision of the counting application, the glass window was installed on a climate chamber for environmental indoor and outdoor monitoring to evaluate the occupant's comfort level. The goal here was to be able to automatically estimate the comfort level based on the counting output to control the air-conditioning. The ventilation rate for operating HVAC equipment is recommended based on indoor temperature and occupancy counted.

The proposed approach was simulated using five LEDs actuators representing the ventilation rate based on ambient temperature and occupancy number within the indoor environment(see Figure 9).

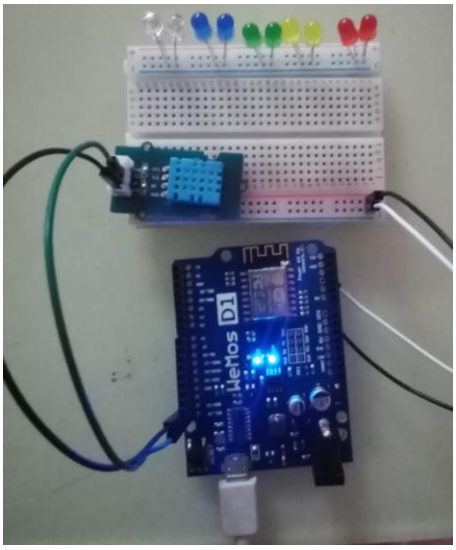

Figure 9 Five different LEDs representing HVAC ventilation rate

For instance,
(if the ambient temperature low and the indoor occupancy are low, then the HVAC ventilation rate should be very slow) -represent Red LED in

(if the ambient temperature low and the indoor occupancy are very high, then the HVAC ventilation rate should be slow) –represent the yellow LED

(if the ambient temperature high and the indoor occupancy are very high, then the HVAC ventilation rate should be normal) –represent the green LED

(if the ambient temperature is extremely high and the indoor occupancy are high, then the HVAC ventilation rate should be fast) –represent the blue LED

(if the ambient temperature is extremely high and the indoor occupancy are extremely high, then the HVAC ventilation rate should be very fast) –represent white LED

Result evaluation and discussion

This study proposes a fuzzy controller that monitors meteorological and occupancy data to automated indoor ventilation control to balance energy saving and occupancy thermal comfort satisfaction. A previous study in [21] does not account for occupant numbers for recommending the setpoint temperature for indoor ventilation, which leads to excess energy consumption and comfort dissatisfaction when there is more or less occupancy as expected in the room.

To demonstrate the study contribution, two prototype ware developed prototype. The first is a replica of the study proposed in [21], and the second is our proposal, which takes both metrological data and occupancy information as input to the controller, unlike the prototype that uses only metrological data. The main goal of this study is to reduce excess energy consumption through DCV that automatically and continuously monitor and manage indoor ventilation rate when temperature and occupancies increase or decrease within the space. The study compared the energy consumption of existing and proposed approaches with regard to HVAC ventilation cycle time for a period of 1hrs 30 minutes for each session, see Figures 10 and 11.

The goal is to attain the desired comfort temperature based on the condition of outdoor temperature and indoor occupancies without interaction with HVAC thermostats. Figures 10 and 11 show the HVAC compressor was in an active state when the indoor temperature was 37^0C until it reaches 16^0C for the existing system and 22^0C for the proposed method.

This indicates the proposed system starts ventilating the indoor room at a normal ventilation rate until it reaches the desired temperature and turned the compressor OFF as soon as it reached 22^0C, which is considered as an acceptable level of thermal comfort [22]

The proposed system takes 1 hr 15 minutes to cool down indoor space occupied by 40 occupancies from 37^0C to 22C and 25 minutes to cool down the same space occupied by 8 occupancies of the same temperature. While the existing system, on the other hand, took only half of the time took by the new system to cool down the same indoor space occupied by the same occupancies from 37^0C to 16^0C.

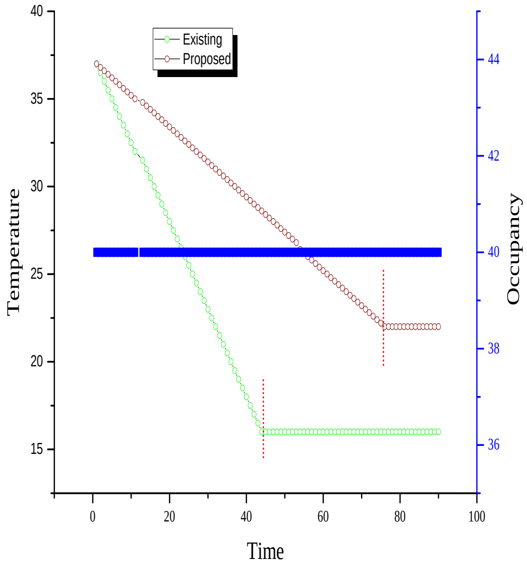

Figure 10 HVAC cycle time result on Existing and proposed study on 40 occupancies on 37^0C indoor temperature

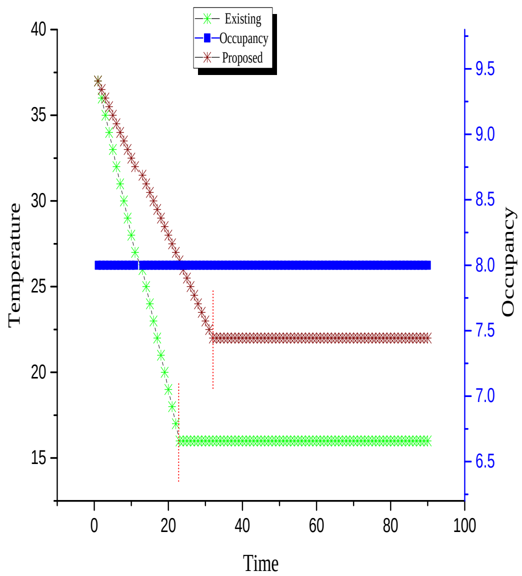

Figure 11 HVAC cycle time result on Existing and proposed study on 8 occupancies on 37^0C indoor temperature

HVAC equipment consumes energy every time its compression is active, and the existing system appeared to be faster than the proposed method with a shorter cycle time. However, the proposed system makes manage HVAC equipment to operate at a low ventilation rate as possible to cool down indoor space, which is always economical and energy-efficient compared to the existing approach operating at a higher ventilation rate.

Similarly, HVAC equipment operating for a longer period gradually to change the indoor space temperature provides a gradual increase in the thermal comfort level, which also help to maintain the desired comfort low, thereby reducing the sudden comfort level variations leading frequent compressor OFF/ON, which in turn reduces the life span of HVAC equipment and comfort dissatisfaction level.

Conclusion

Indoor ventilation is essential to primary a healthy environment and improves occupancy productivity. Studies show the traditional approach to operate and manage indoor ventilation activities is inefficient and not economical. Recent studies proposed different strategies to control and maintain HVAC equipment to ensure economic and energy-efficient ventilation activities without disturbing thermal comfort satisfaction of the occupancy. However, the existing strategy relies on outdoor metrological data to control to adjust the HVAC ventilation rate to change the indoor temperature at desired comfort without accounting for the number of occupancies presently in the space.

To address the challenge, the study conducted an empirical study on 283 participants to determine the acceptable comfort level temperature setpoint, and 85% of the participants found 22^0C as the perfect desired setpoint temperature to ensure thermal comfort satisfaction. Thus, the study uses IoT devices to collect metrological data and occupancies information that helps to predict the number of occupancies with the indoor space.

The study proposed two fuzzy inference controllers. The first control uses thermal camera sensors to analyze the occupancy body dimension to differentiate human and non-human occupancy. The second controller takes both metrological data and occupancy numbers from respected sensors to recommend the feasible ventilation rate to change the indoor temperature to desire to comport in a viable and efficient manner. The experimental analysis shows the proposed system reliable and achieved high occupancy prediction accuracy. Similarly, the proposed system promises high energy saving potential, as well as ensuring occupancy thermal comfort satisfaction efficiently in comparison with the existing approach.

Future work

There are several applications of occupancy counting technologies, ranging from counting occupants in a mall or an office building to the counting of pedestrians and even counting of the vehicle as well. The future study includes the possibility of connecting occupants using 20 multiplex thermal cameras from a single P.C. station, indoor surveillance, and lighting control applications.

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