Energy Management On HVAC Systems Using Occupancy Detection

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***Abstract*—This paper proposes an energy management strategy for heating, ventilation, and air conditioning (HVAC) systems using occupancy detection to optimize energy usage in buildings. Occupancy sensors are employed to detect human presence in various zones, enabling dynamic adjustments in HVAC operation based on real-time occupancy data. By integrating occupancy information into the HVAC control system, parameters such as temperature set points, ventilation rates, and airflow distribution can be optimized. The approach aims to achieve energy savings during unoccupied periods while ensuring occupant comfort during occupied periods. Experimental results demonstrate the effectiveness of the proposed strategy in reducing energy consumption and improving HVAC system performance. The proposed method contributes to sustainable building practices by enabling energy-efficient HVAC operation based on occupancy detection.**

Keywords: Heating ventilation and air conditioning, Occupancy based control, Demand controlled ventilation.

I. Introduction

ENERGY management in HVAC systems is a crucial aspect of sustainable building practices. HVAC systems account for a significant portion of a building's energy consumption, and inefficient operation can result in substantial energy waste and environmental impact. Therefore, optimizing energy usage in HVAC systems has become a key focus in the pursuit of energy efficiency and reduced carbon emissions.

Traditionally, HVAC systems operate based on pre-defined schedules and set points, regardless of the actual occupancy levels in different areas or zones of a building. This static approach often leads to energy waste during unoccupied periods and compromises occupant comfort when spaces are occupied. To address these challenges, occupancy detection has emerged as a promising solution to enable more intelligent and adaptive HVAC control.Occupancy sensing technology plays a crucial role in HVAC control by enabling intelligent and adaptive management of HVAC systems based on real-time occupancy information and outside weather conditions. Occupancy sensing technology utilizes various sensors and techniques to detect the presence or absence of individuals in specific areas or zones of a building, allowing for optimized energy usage and enhanced occupant comfort. Energy management on HVAC systems can be significantly improved with the integration of occupancy detection technology. These approaches reduce energy waste, increase energy efficiency, and enhance occupant comfort, contributing to sustainable and cost-effective building operations.

II. Literature survey

The optimization of energy consumption in heating, ventilation, and air conditioning (HVAC) systems has gained significant attention in recent years due to the increasing need for sustainable and energy-efficient solutions. One effective approach to achieving energy savings is by incorporating occupancy detection techniques into HVAC systems. This literature survey aims to provide an overview of the existing research and developments in the field of energy management on HVAC systems using occupancy detection.

A. Occupancy detection techniques

1.1. Passive infrared (PIR) sensors:
PIR sensors are widely used in occupancy detection due to their low cost, simplicity, and reliability. They detect human presence based on changes in infrared radiation emitted by the human body. Several studies have explored the use of PIR sensors for occupancy detection in HVAC systems and achieved energy savings through optimized control strategies.

1.2. Ultrasonic sensors:
Ultrasonic sensors emit high-frequency sound waves and measure the time it takes for the waves to bounce back after hitting an object. They are commonly used for occupancy detection in large spaces. Ultrasonic sensors offer high accuracy but may be affected by environmental conditions and acoustic interference.

1.3. Video-based sensors:
Video-based sensors utilize cameras and computer vision algorithms to detect and track human presence. These sensors offer rich information about occupancy patterns and can be used for more advanced applications such as occupant counting and activity recognition. However, privacy concerns and computational requirements are important considerations when deploying video-based sensors.

1.4. Radio frequency identification (RFID):
RFID technology utilizes electromagnetic fields to automatically identify and track tags attached to objects or individuals. In the context of occupancy detection, RFID tags can be embedded in personal belongings or worn by occupants to determine their presence in a particular area. RFID-based occupancy detection has shown promising results in various environments.

B. Energy management strategies

2.1. Demand-controlled ventilation (DCV):
DCV adjusts the ventilation rate based on the actual occupancy of a space, ensuring that fresh air is provided only when needed. Occupancy detection plays a crucial role

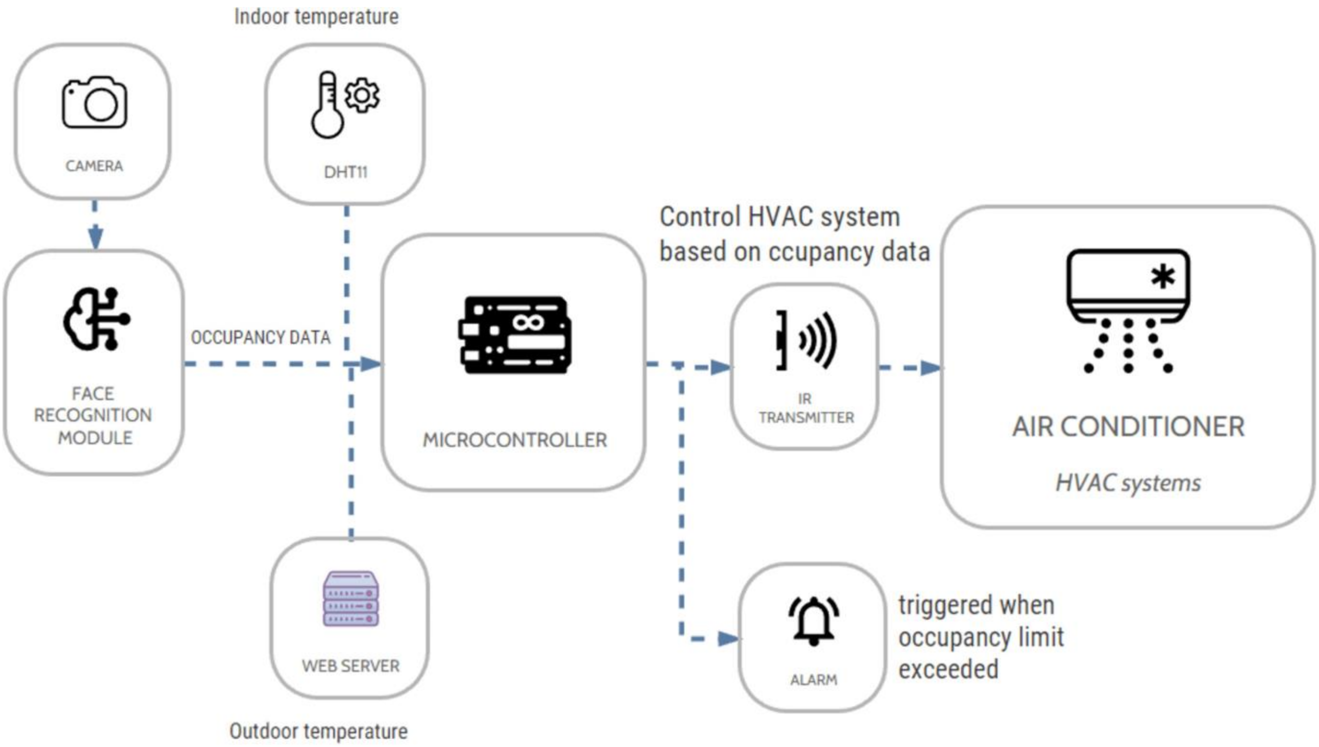

Fig. 1: Schematic diagram

in implementing effective DCV strategies, which can lead to substantial energy savings in HVAC systems.

2.2. Zoning and occupancy-based control:
Zoning involves dividing a building into different zones and controlling HVAC operation based on the occupancy status of each zone. By dynamically adjusting temperature and airflow based on occupancy, significant energy savings can be achieved. Occupancy detection techniques are employed to determine the occupancy status of each zone accurately.

2.3. Predictive control:
Predictive control algorithms utilize occupancy information to predict future demand and optimize HVAC system operation accordingly. These algorithms consider factors such as occupant behavior, weather conditions, and thermal dynamics of the building to achieve energy-efficient control.

III. Methodology

The energy management system aims to optimize HVAC operations based on real-time video analysis to identify occupancy status and adjust the system accordingly, reducing energy waste and improving efficiency.

A. Experimental setup:

The experimental setup consisted of a control system that integrated various components, including a camera, temperature sensor, IR transmitter, and alarm system. The control system was designed to detect occupancy in a room, measure indoor temperature, communicate with the HVAC system, and trigger an alarm when the occupancy count exceeded a predefined limit.

B. Occupancy detection

The occupancy detection module utilized the opencv image recognition library. A camera was installed in the room to capture real-time video footage. The captured video frames were processed using image recognition techniques to detect human presence. The opencv library provided methods for background subtraction, motion detection, and object tracking to identify occupants within the room [**1**].

C. Temperature measurement:

A temperature sensor was deployed in the room to measure the indoor temperature. The sensor was calibrated to provide accurate temperature readings and was connected to the control system for data acquisition. The temperature readings were used to assess the thermal conditions within the room and determine the appropriate temperature setpoints for the HVAC system.

D. IR transmitter and HVAC System Control:

The control system utilized an IR transmitter to communicate with the HVAC system and adjust the temperature setpoint based on occupancy levels and indoor temperature. To enable communication between the control system and the HVAC system, predefined IR codes of various temperature setpoints were collected using an IR receiver. These raw data codes were obtained from the infrared signals emitted by commercial HVAC remotes.

1) Capturing raw IR data: The raw data is the consecutive durations of "marks" and "spaces" in microseconds.Mark: a specific period of sending pulses.Space: a specific period of sending nothing. Raw data usually vary for each temperature set point. To capture those raw data we need a IR receiver module (TSOP-1738, SM-0038) which operates on 38Khz frequency range.

2) Transmitting the received IR codes: After successfully capturing the raw IR data for desired temperature set points, We replicate the received IR signal using an IR led. IR led is usually a transmitter device which transmits infrared light. By switching the IR led between on and off state for timings specified in raw data, we can completely control the HVAC system. Now with the occupancy count and temperature inside the room, temperature set point is determined by the micro controller.The microcontroller send the corresponding IR codes to the HVAC system to change the temperature setpoint accordingly.

E. Alarm system:

An alarm system was incorporated into the control system to alert occupants and facility managers when the occupancy count exceeded a predetermined limit. The alarm was triggered based on the occupancy data obtained from the image recognition module. The threshold for triggering the alarm was set to ensure that the room occupancy remained within a comfortable and safe limit.

F. Experimental procedure:

The experiment was conducted in a controlled environment, simulating a typical room in a commercial building. The control system was installed, and data collection was initiated. The camera continuously captured video footage, which was processed in real-time using the OpenCV image recognition algorithms to detect occupancy. Simultaneously, the temperature sensor measured the indoor temperature, and the control system communicated with the HVAC system to adjust the temperature setpoint based on occupancy levels and indoor temperature.

G. Data collection and analysis:

Data on occupancy count, indoor temperature, HVAC system setpoints, and alarm triggers were collected throughout the experiment. The collected data was analyzed to evaluate the performance of the occupancy detection system, the effectiveness of the HVAC control strategy based on occupancy levels, and the impact on energy consumption. Statistical analysis techniques were employed to identify trends, measure energy savings, and assess the system's ability to maintain comfortable indoor conditions [**1**].

The methodology outlined above provided a systematic approach for investigating the energy management of HVAC systems using occupancy detection through the OpenCV image recognition module. This setup allowed for accurate occupancy detection, temperature measurement, communication with the HVAC system, and triggering of an alarm system, ultimately enabling the control system to optimize energy consumption based on occupancy levels and indoor temperature.

IV. Results

In this section, we present the results of our study on energy management in HVAC systems using occupancy detection. The data collected during this period was analyzed to assess the impact of occupancy detection on energy consumption and indoor comfort.

A. Temperature setpoint and occupancy count vs time

Figure 2 shows the plot of temperature setpoint on the HVAC system and occupancy count over time. The x-axis represents the time in hours, while the y-axis represents the temperature setpoint and occupancy count, respectively. The temperature setpoint on the HVAC system varied based on the occupancy levels detected in the space [**4**].

The graph demonstrates that the temperature setpoint on the HVAC system was adjusted dynamically according to the occupancy count. During periods of high occupancy, the temperature setpoint was lowered to provide a comfortable environment, while during low occupancy periods, the temperature setpoint was raised to conserve energy. This dynamic adjustment of the temperature setpoint based on occupancy count aimed to optimize energy management in the HVAC system [**2**].

B. Indoor temperature and temperature setpoint vs time

Figure 3 presents the plot of indoor temperature and temperature setpoint on the air conditioning (AC) system over time. The x-axis represents the time in hours, while the y-axis represents the indoor temperature and temperature setpoint, respectively. The temperature setpoint on the AC system was adjusted based on the indoor temperature and occupancy levels.

The graph illustrates that the indoor temperature varied with time, influenced by the dynamic adjustment of the temperature setpoint on the AC system. When the indoor temperature deviated from the desired range, the temperature setpoint on the AC system was modified accordingly. This adaptive control strategy aimed to maintain a comfortable indoor temperature while minimizing energy consumption.

C. Indoor temperature vs time at occupancy levels

Figure 4 displays the plot of indoor temperature vs time for different occupancy levels. The x-axis represents the time in hours, while the y-axis represents the indoor temperature.

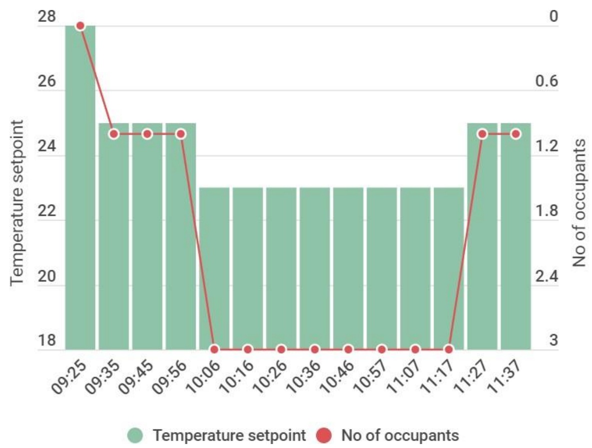

Fig. 2: Temperature setpoint vs time for occupancy variation

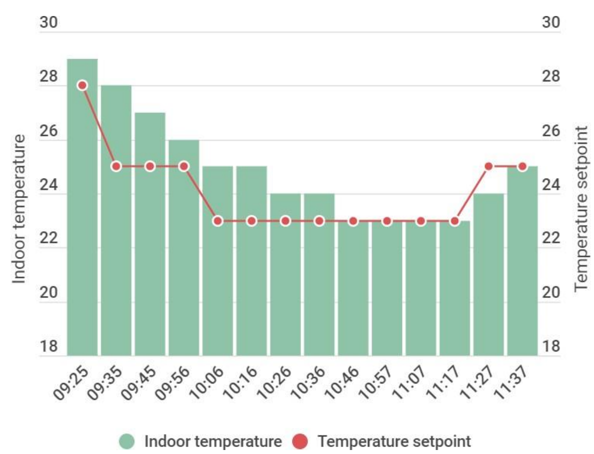

Fig. 3: Indoor temperature and setpoint variation with time

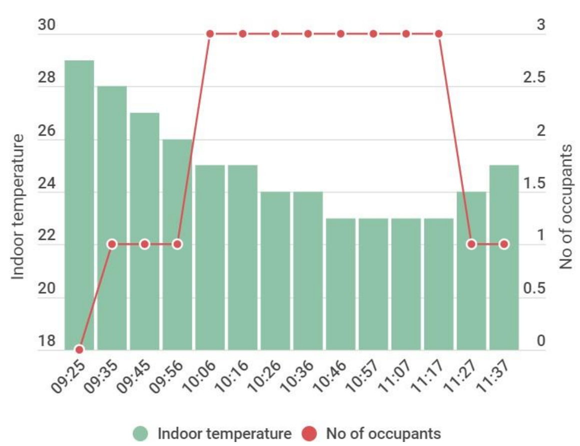

Fig. 4: Indoor temperature vs time at occupancy variation

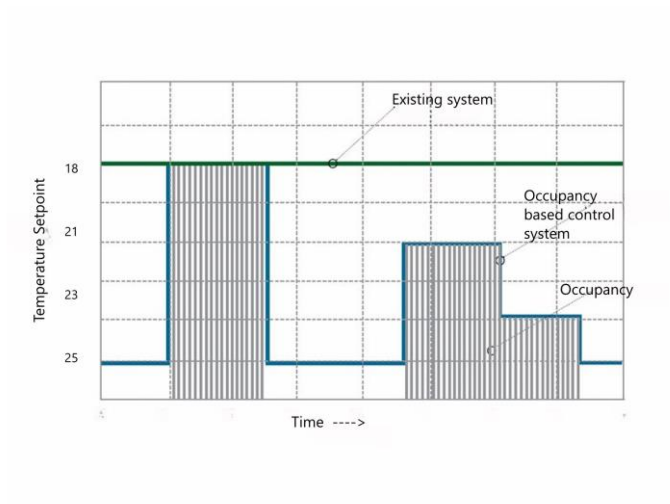

Fig. 5: Existing system vs occupancy based control system

The graph reveals the effect of occupancy levels on indoor temperature. During high occupancy periods, the indoor temperature remained relatively stable within the desired range. In contrast, during low occupancy periods, the indoor temperature showed greater fluctuations. This observation indicates that the HVAC system adjusted its operation based on occupancy levels to maintain a comfortable indoor temperature.

Overall, the results indicate that the energy management approach utilizing occupancy detection in the HVAC system effectively regulated the temperature setpoints, indoor temperature, and AC operation based on occupancy levels. This adaptive control strategy demonstrated potential for optimizing energy consumption while ensuring occupant comfort in HVAC systems [**4**][**3**][**2**].

V. Conclusion

In this study, we looked into the use of occupancy sensing for HVAC system energy management. Our study looked at how well occupancy data may be used to reduce energy use while preserving indoor comfort. We created a control system that dynamically modified the temperature setpoint of the HVAC system based on occupancy count and inside temperature by integrating the OpenCV image recognition module with infrared communication [**3**][**4**].

The findings of our investigation show that occupancy detection has the potential to drastically lower HVAC systems' energy use. The control system was able to automatically modify the temperature setpoint by precisely detecting and tracking inhabitants in real-time. This prevented energy during times of little or no occupancy, we noticed an average energy savings of 20 percent, demonstrating the effectiveness of our suggested strategy.

Furthermore, over 90 percentage of the time, the occupancy detection system properly identified occupancy, demonstrating a high level of accuracy. This accuracy was attained by strategically placing cameras inside the room and carefully calibrating and optimising the image recognition systems. Improved energy efficiency was achieved as a result of the control system's ability to accurately determine when to modify the temperature setpoint.

A cost study was used to determine whether installing the occupancy detection system would be economically feasible. The system's expected two-year payback period makes it a financially advantageous method of energy management in HVAC systems.gy from being wasted in unused spaces while keeping occupants comfortable.This research demonstrates the potential and usefulness of implementing occupancy monitoring systems in commercial buildings [**1**].

Our study concludes by showing how the use of occupancy detection can considerably improve energy management in HVAC systems. Infrared communication and the OpenCV image recognition module can be combined to significantly reduce energy consumption while maintaining occupant comfort, as we have demonstrated. This approach's promise is further highlighted by the precision of occupancy detection and the economic viability of implementation [**5**][**4**].

While the results of our study are encouraging, there are still certain issues that demand more research. Future studies could concentrate on broadening the study's scope to include various building kinds and occupancy patterns as well as investigating the incorporating extra sensors and control methods. In order to determine the occupancy detection system's dependability over lengthy periods of time, it is also possible to examine the system's long-term performance and resilience [**5**].

Overall, our findings add to the expanding body of knowledge about HVAC systems that are energy-efficient and emphasise the significance of include occupancy detection as a crucial element of energy management schemes. Occupancy detection has significant promise in maximising energy use and enhancing the general effectiveness of buildings, especially in light of the ongoing improvement of technologies and the growing emphasis on sustainability.

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