

IoT-based green building monitoring framework enhancing urban sustainability through automated ventilation control applications

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Abstract—The accelerated urbanization increases the intensity of energy use and environmental demands, and the construction of buildings contributes significantly to magnification of the difficulties. HVAC and poor ventilation are contributors to carbon emission and air pollution. The conventional building management systems cannot adapt efficiently to the occupancy changes and the change in the environment, resulting in the wastage of energy and causing discomfort. The Internet of Things-based Green Building Monitoring and Automated Ventilation (IoT-GBMAV) system integrates both wireless sensors and analytics at the building boundaries and the calculation capabilities in the cloud to constantly monitor air quality, temperature, humidity, and occupancy. Automated ventilation control saves energy without compromising on a healthy interior environment by automatically controlling the airflow. Besides complying with air quality regulations, pilot projects have demonstrated saving as much as 25% of energy. Data-driven insights make predictive changes that reduce the cost of operations and enhance occupant comfort. IoT-GBMAV framework has reached 12% reduction of energy consumption, operated at 860-900 ppm of CO₂ and has passed thermal comfort of 89-92 and ventilation responsiveness of 7-9 seconds, compared to the current IoT-based approaches. These findings affirm the frameworks success in maximizing the IAQ, human comfort, and energy efficiency via predictive, real-time ventilation control in the city green buildings.

Keywords—*IoT-based green building; Automated ventilation control; Energy efficiency; Indoor air quality; Predictive analytics; Sustainable urban buildings*

I. INTRODUCTION

A. Background

With rapid industrialization and urbanization, demands of energy in cities have gone high, and the global resources available to these cities are overloaded [1]. In terms of overall energy consumption of the world, heating, ventilation and air conditioning (HVAC) systems are the biggest offenders in buildings [2]. In case such systems are not handled effectively, the effect is a higher amount of carbon emissions, low-quality indoor air, and waste of energy [3]. Smart building systems with balanced energy efficiency and the desire not to spoil the indoor environment are gaining significance as the concern of people with the health status and the climate change increases [4].

B. *Problem Statement*

Regarding the ability to react to occupancy and environment changes in real time, old building management systems are dependent on the use of human changes or scheduled changes [5]. Poor or over-regulation of air and ventilation cause wastage of energy, unpleasant temperature, and poor indoor air [11]. The process must have new measures that combine automation, monitoring, and smart control to minimize the cost of operation and environmental effects to sustainability goals [12].

C. *Proposed Approach*

The implementation of the IoT in the building management systems would allow monitoring the parameters of the indoor environment such as temperature, humidity, CO₂ level, and occupancy rates continuously. Automated ventilation control is possible with the use of data processed through edge and cloud computing platforms by wireless sensors. To provide the best possible indoor climate with the least amount of energy used, predictive algorithms and real-time analytics dynamically modify airflow and HVAC operation.

D. *Significance*

Improved occupant comfort, lower operating costs, and energy efficiency are all outcomes of intelligent ventilation control [13]. Sustainable development goals can be advanced through the reduction of carbon footprints and the promotion of healthier living conditions through the scalable application throughout urban buildings [14]. Predictive maintenance and optimization of building operations over the long term are made possible by actionable insights provided by adaptive control and continuous monitoring [15].

E. *Research Gap*

Monitoring thermal comfort, energy efficiency, and sustainability certification in buildings is the primary focus of existing studies that utilize the IoT [16]. On the other hand, most frameworks don't include cognitive analytics integrated with multi-sensor data for real-time predictive ventilation management [17]. There aren't many options for a modular, scalable system that can adapt the airflow in real time to changes in occupancy, pollution levels, and other environmental factors. There is still a need to fill the gap in urban sustainability when it comes to integrating predictive algorithms, automated ventilation control, and IoT sensors.

F. *Contributions*

The proposed IoT-GBMAV architecture integrates predictive analytics with multi-sensing to optimize fly ventilation. Automated control ensures energy efficiency, indoor air quality and thermal comfort. The data-driven solution, provided by the technique, supports sustainable urban building management and enhances the well-being of the occupants.

II. RELATED WORKS

IoT technologies have transformed the management of buildings by automating the functioning of HVAC and ventilation systems and they have made it possible to monitor

the variables in the environment in real-time. The combination of BIM, predictive analytics, sensors, and energy in frameworks that study energy efficiency and thermal comfort has recently been a subject of research in this field. These principles can be used to build sustainable, flexible building operations, which enhance the comfort of occupants and minimize energy consumption in the urban environment.

In this study, the authors developed an interior environmental condition real-time monitoring system with the IoT and building information modeling (BIM) named as IoT-BIM-TCAS. Combining data with BIM served to provide automatic warnings when thermal comfort zones were violated, and sensors were used to measure humidity and temperature, and occupancy. The system proved to have a realistic foundation on automated ventilation management in smart buildings because it demonstrated enhanced occupant comfort and early warning of any potential HVAC operation inefficiencies.

An highlights the significance of the IoT in achieving the sustainability certifications. It presented the idea of IoT in certified sustainability in smart buildings (IoT-CSB). Sensor networks dictated automated control plans of the HVAC and lighting and environmental data. This framework indicates that the IoT has the potential to lower carbon emissions and energy consumption, which is excellent news to the management of sustainable buildings.

Metwally et al. (IoT-EF) introduced an interdisciplinary Internet of Things assessment framework of energy-efficient buildings. To enhance the energy consumption in many systems throughout buildings, the process culture combined data analytics with automated decision making and sensor data gathering. The framework demonstrated the effectiveness of the techniques grounded on the IoT in reducing operations costs and enhancing the indoor environment quality through the combination of real-time monitoring with predictive control that provided building operators with actionable information.

The importance of integrating IoT technologies into the building plans and designs was highlighted by the proposal of Wang et al. on the Internet of Things integration in sustainable green building design (IoT-SGB). The sensor networks and automated controls enabled the use of adaptive environmental management whereby energy use, temperature in the indoors, and occupants were monitored. It was revealed that the Internet of Things functionality in buildings had the potential to support both sustainability and energy efficiency objectives over time, as it would allow dynamically managing HVAC, lighting, and ventilation.

IoT monitoring on a smart campus in Spain to increase efficiency of energy (IoT-EE). Predictive analytics guided ventilation and HVAC changes, with environmental and energy consumption data being collected wirelessly. It was seen that the results were significant in saving of energy consumption and that indoor comfort levels were not compromised. The study established that Internet of Things-based monitoring systems have the power to streamline energy consumption and operations within urban buildings in real-time.

The research which was evaluated proves that building energy efficiency and interior environmental quality are significantly enhanced by the monitoring and automated control, which becomes realized through the Internet of Things. It is within the realms of

the adaptive ventilation, thermal comfort control, and sustainability compliance that are enabled through the means of the frameworks that combine smart building technology with real-time sensor data and predictive algorithms. Collectively, these methods can help us build more efficient automated ventilation systems and demonstrate how the Internet of Things can enhance building processes in large cities by making them more efficient and scalable.

TABLE 1: RELATED WORKS SUMMARY

Reference	Paper Contribution	Advantages	Limitations
Valinejadshoubi et al., 2021	Developed a real-time thermal comfort alert system using IoT and BIM integration	Enables proactive HVAC adjustments; improves occupant comfort; integrates spatial building data	Limited predictive ventilation control; focuses only on thermal comfort; scalability is not fully addressed.
Taha & Elabd, 2020	Demonstrated IoT applications for certified sustainability in smart buildings	Supports compliance with sustainability standards; reduces energy consumption; scalable across building types	Lacks detailed real-time adaptive ventilation strategies; does not integrate multi-sensor predictive analytics
Metwally et al., 2022	Proposed an interdisciplinary IoT assessment framework for energy-efficient buildings	Integrates sensors, analytics, and automated control; enables predictive energy optimization.	Implementation complexity; requires extensive sensor deployment; primarily focused on energy, not indoor air quality
Wang et al., 2024	Integrated IoT technologies into green building design for adaptive environmental management	Embeds IoT from the design stage; facilitates dynamic HVAC and ventilation control; improves sustainability.	Limited real-time testing; predictive algorithms not fully explored; occupant comfort evaluation minimal
García-Monge et al., 2023	Evaluated IoT monitoring for energy efficiency in a smart campus case study	Demonstrates empirical energy savings; validates real-time monitoring; improves indoor environmental quality	A case study is context-specific; generalized deployment in other building types has not been tested; predictive ventilation has not been fully implemented

III. PROPOSED METHODOLOGY

Increases in both energy consumption and environmental strain have been brought about by the fast expansion of cities and industries. As a result of inefficient heating, ventilation, and air conditioning systems, buildings produce large amounts of carbon emissions and have poor air quality inside. Automated ventilation systems adjust airflow based on occupancy and pollution levels, while monitoring through the Internet of Things allows for the real-time gathering of environmental data. Energy efficiency, indoor air quality, and sustainable urban growth are all positively impacted by intelligent control systems.

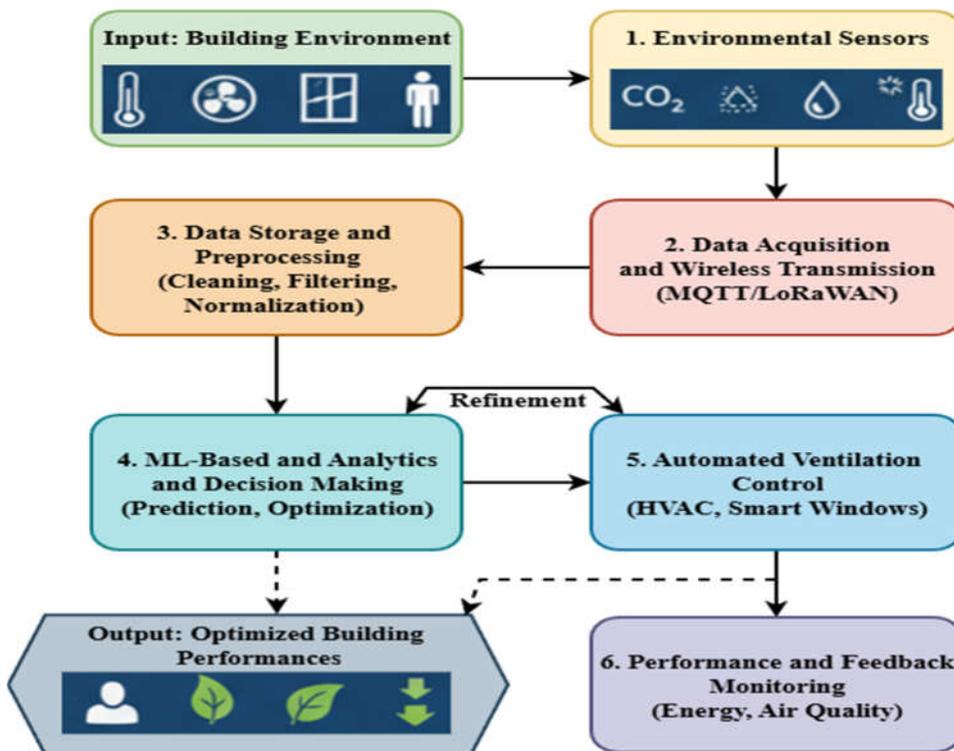


Fig. 1 Proposed system overview

The real-time data collected by environmental sensors installed in all locations around the building can be used to accurately determine the indoor environmental conditions in the building, as shown in Fig.1. These sensors detect such things as temperature, humidity, CO₂ level, particulate matter, and occupancy. The measurements are sent to the edge devices or cloud server via data collection and wireless transmission based on Internet of Things protocol, such as LoRaWAN or MQTT. This guarantees the constant and low-latency connection, which aids instant system response. To ease the process of performing analytics and assessing historical trends, the data obtained is subjected to preparation activities, including cleaning, filtering, and normalization. The analytics and decision-making modules operate on machine learning to process preprocessed data and predict occupancy patterns, assess ventilation needs, and estimate adequate airflow allocation so that the automated control operations ensure energy efficiency and healthy indoor air quality. To achieve thermal comfort and reduce pollutants, automated

ventilation control adapts HVAC systems or smart window actuators based on analytical outputs, dynamically controlling airflow and temperature. Enhanced occupant comfort and long-term sustainability in urban building operations are made possible through performance and feedback monitoring, which assesses energy consumption reductions and air quality compliance. Iterative insights are provided to enhance predictive models and management tactics.

Algorithm 1: Hybrid ventilation control algorithm

Inputs: $X[t, n, f]$ sensor matrix, $O[t]$ occupancy, O_{th} threshold,

V_{min}, V_{max} ventilation limits, H attention head

Output: $V[t]$ ventilation command array

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1: normalize =  $x: \frac{(x - x.\min(T))}{(x.\max(T) - x.\min(T))}$ 

2:  $Xn = \text{normalize}(X)$ 
3: init  $WQ[h], WK[h], WV[h]$  for  $h$  in  $\text{range}(H)$ 
4: init  $WO$  projection matrix
5:  $V = \text{zeros}(T)$ 
6: for  $t$  in  $\text{range}(T)$ :
7:    $S = Xn[t]$  #  $N \times F$ 
8:    $heads = [h]$ 
9:   for  $h$  in  $\text{range}(H)$ :
10:     $Q = S @ WQ[h]$ 
11:     $K = S @ WK[h]$ 
12:     $Vv = S @ WV[h]$ 
13:     $A = \text{softmax}\left(\frac{(Q @ K.T)}{(d_k)}\right)$ 

14:     $Hh = A @ Vv$ 
15:     $heads.append(Hh)$ 
16:  $Hcat = \text{concatenate}(heads, axis = 1)$ 
17:  $Et = Hcat @ WO$ 
18:  $\hat{V} = f(Et.\text{mean}(axis = 0))$ 
19:  $V[t] = V_{min}$  if  $O[t] < O_{th}$  else  $\text{clip}(\hat{V}, V_{min}, V_{max})$ 

Return  $V$ 

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Attention-based processing improves sensor processing by concentrating on the most effective environmental signal of a time step using Algorithm 1. Normalization makes the

heterogeneous sensor features consistent in their scaling. Multi-head attention is implemented by mapping sensor features to each head to query, key, and value space to adopt a variety of patterns of importance among measurements of CO₂, temperature, humidity, and occupancy. The use of softmax scoring emphasizes the prevailing forces to come up with weighted representations that depict the current state of the environment. These head outputs, concatenated and projected into a single embedding, are a compact and expressive representation of features to be used by their downstream prediction. This embedding is interpreted by the function to approximate the airflow that is needed. Occupancy-sensitive conditions of ventilation commands are minimum flow during low occupancy and optimized predictions in active occupancy conditions. Bounds ensure that there is not too much or too little airflow. The algorithm helps in predictive, adaptive, and energy-efficient ventilation that is compatible with green buildings that are driven by IoT. Equation 1 involves the preprocessing of raw sensor readings to a standard scale for consistent analytics.

$$X_{norm} = \frac{(X_{t,n,f} - X_{\min n,f})}{X_{\max n,f}} (X_{\min n,f}) \quad (1)$$

Sensor data normalization X_{norm} scales raw readings from multiple sensors n to a standard range X_{norm} , ensuring consistency across features f and time steps. By transforming values based on their minimum $X_{\min n,f}$ and maximum $X_{\max n,f}$ across the dataset, differences in magnitude between temperature, humidity, CO₂, and other sensor measurements are mitigated. This preprocessing step enhances the stability and convergence of future predictive models and this ensures that no single feature dominates the analysis because of the differing scale. Normalized data can be used as a good base to make attention-based embedding and ventilation control decisions.

Equation 2 identifies the significance of the information of each sensor to the decision-making in ventilation.

$$A_h = \text{softmax} \left(\frac{Q_h @ K_h \cdot T}{\sqrt{(d_k)}} \right) \quad (2)$$

Attention score A_h computation evaluates the relative importance of each sensor's input T when predicting ventilation requirements. Query Q_h and key matrices K_h from sensor features are compared and scaled by the vector dimension, followed by a softmax normalization. Greater scores on higher attention show more influence of a particular sensor or feature at a particular time step (d_k). The system uses this mechanism to dynamically prioritize important environmental cues, e.g. CO₂ spikes or temperature deviations, enhancing the precision of predictive ventilation control.

Predictive embeddings are computed with weighted sensor feature contributions across multiple heads as seen in equation 3.

$$H_h = A_h @ V_h \quad (3)$$

The multi-head attention output aggregates contributions from multiple attention heads H_h , each focusing on different aspects of the sensor data. By multiplying attention scores A_h with value matrices V_h , the framework creates weighted embeddings that capture relevant environmental patterns. The multiple heads approach use makes sure that various interactions between features are taken into account, e.g. occupancy-CO₂ relations or

patterns of temperature-humidity. The resultant embeddings offer a holistic representation to the correct and contextual ventilation forecasting.

All the attention heads are summed up in equation 4 to represent the outputs as a single one used in ventilation prediction.

$$E = [H1, H2, H3, H4]W_0 \quad (4)$$

Outputs from all attention heads H are concatenated and projected through a trainable weight matrix W_0 to form a unified embedding vector E . This last embedding takes into account the information of all heads to encompass the multi-dimensional relationships between sensor measurements of each time step. It is the predictive model of the ventilation control module which makes sure that the decisions are based on the importance of both features individually and the way they interact with each other resulting in the regulation of the airflow in the real-time situation being more accurate.

Equation 5 is used to apply occupancy and system limit requirements; it uses predictive embeddings to airflow instructions.

$$V_t[t] = Vmin, (f(Vmax)[t] < O_{th}) \quad (5)$$

With occupancy O_{th} limitations and system constraints in mind, the final embedding is transformed into commands for effective ventilation V_t . The mapping function finds a rate between the minimum $Vmin$ and maximum $Vmax$ capacity of the system $[t]$; minimal airflow is applied if occupancy is below the threshold. In such a way, the quality of air is maintained and the process is energy-saving. The predictive control allows response, real-time ventilation that finds a balance between comfort, air quality, and energy saving, to be possible.

Green building monitoring is driven by IoT to monitor overall energy efficiency and manage ventilation and sensor networks, predictive analytics, automated ventilation management. Dynamic optimization of airflow is achieved by multi-head attention models by analyzing occupancy and environmental data. Reduced energy usage, maintained thermal comfort, and pollution regulation are all results of implementation. Refining predictive models by continuous performance monitoring allows for sustainable functioning in the long run. In support of environmental and occupant health goals, the framework showcases a scalable solution for metropolitan buildings.

Algorithm 2: IoT-Based Automated Ventilation Control

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# Input: Sensor data  $X[T][N][F]$ ,
occupancy threshold  $O_{th}$ , ventilation limits  $V_{min}, V_{max}$ 
output: Ventilation commands  $V_t$  for  $\frac{HVAC}{smart}$  windows

Initialize multi – head weights  $W_Q, W_K, W_V, W_O$ 
Initialize  $V_t = \text{zeros}(T)$ 

# Preprocessing
Normalize  $X$ 
Fill missing values with feature – wise mean

# Multi – Head Attention
for  $h$  in range( $H$ )
   $Q = X @ W_{Q[h]}$ 
   $K = X @ W_{K[h]}$ 
   $V = X @ W_{V[h]}$ 
   $A = \text{softmax}\left(\frac{Q @ K.T}{\sqrt{d_k}}\right)$ 
   $H[h] = A @ V$ 
end for

# Concatenate heads
 $H_{concat} = \text{concatenate}(H)$ 
 $E = H_{concat} @ W_O$ 

# Ventilation prediction
for  $t$  in range( $T$ ):
   $V_{t[t]} = f(E[t])$ 
  if  $\text{occupancy}[t] < O_{th}$ :  $V_{t[t]} =$ 
  if  $V_{t[t]} > V_{max}$ :  $V_{min}$ 
end for

return  $V_t$ 

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Temperature, humidity, CO₂, PM2.5, and occupancy are some of the environmental sensor data that are gathered from different zones. Normalization and handling missing values are part of preprocessing that helps to guarantee correct analytics. The temporal and spatial dependencies between sensors are extracted using multi-head attention, as mentioned in Algorithm 2. Attention weights establish the impact of every sensor on

forecasts, whereas queries Q , keys K , and values are calculated using sensor embeddings for every head. Final embeddings are generated by concatenating and transforming outputs from all heads using a weight matrix. Using a mapping function, the predicted ventilation rates are obtained from the embeddings, and conditional checks make sure that the airflow doesn't exceed the occupancy thresholds and the maximum and minimum values, respectively. Optimizing energy efficiency, indoor air quality, and occupant comfort in urban structures is made possible by this method, which provides real-time adaptive ventilation control.

The IoT-based green building monitoring combines sensor networks, predictive analytics, and automated ventilation control to maximize energy efficiency and indoor air quality. The multi-head attention is a model that processes environmental and occupancy data to optimally dynamically control airflow. Realization reduces the energy consumption, thermal comfort and pollutants control. The performance monitoring will streamline the predictive models and put them to use in the long term. The framework has a universal shape with regard to the city structures to suit the objectives of environmental and occupant wellness.

IV. RESULTS AND DISCUSSION

Sustainable and efficient indoor environmental management is increasingly gaining significance with the increase in the energy consumption in buildings and the rate at which the city is being urbanized. Monitoring systems with the Internet of Things made it possible to control ventilation systems automatically and adaptively through the collection of data in real-time on such indicators as temperature, humidity, air quality, and occupancy. Predictive algorithms combined with sensor networks allow achieving dynamic modifications to airflow to minimize the amount of energy used without reducing the comfort of passengers. Improved thermal and Indoor Air Quality (IAQ) control is made possible by such frameworks, which enable sustainable building operations in metropolitan areas.

A. Dataset Description

Indoor environmental characteristics such as temperature, humidity, CO₂, and occupancy are included in Zenodo's IoT Smart Building Dataset, which includes data on energy consumption from building systems. It allows for the examination of adaptive control techniques, indoor air quality, and energy efficiency; it is derived from a genuine smart building. This dataset is perfect for Internet of Things (IoT)-based green building studies since it allows predictive modeling of automated ventilation and HVAC control [18].

Table 2 illustrates the variables and their description for the chosen dataset.

TABLE II: DATASET DESCRIPTION

Variable	Unit	Description
Temperature	°C	Indoor ambient temperature from multiple zones
Humidity	%	Relative humidity levels in building zones
CO ₂	ppm	Indoor CO ₂ concentration indicating air quality
Occupancy	count	Number of occupants detected in each zone
Energy Consumption	kWh	Power usage of HVAC and lighting systems

PM2.5	$\mu\text{g}/\text{m}^3$	Particulate matter concentration
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B. Analysis of Energy Consumption

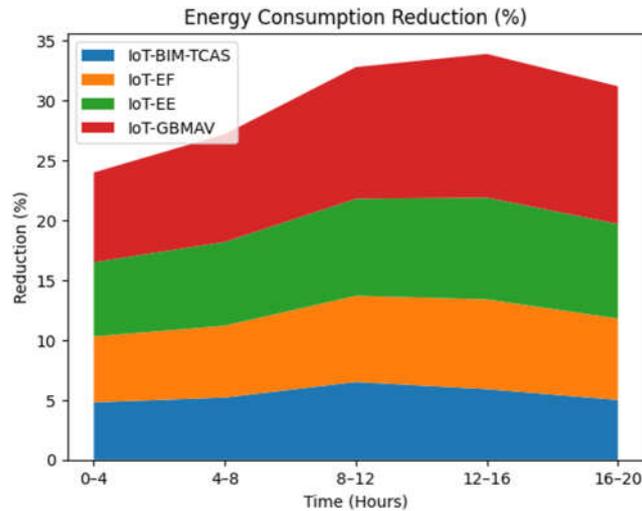


Fig.2 Analysis of Energy Consumption

Fig. 2 illustrates the distribution of probabilities for energy savings across several strategies. IoT-GBMAV's predictive and adaptive ventilation control is seen in its constantly increasing energy reduction (peaks around 11-12%). While IoT-EE and IoT-EF both result in moderate reductions (7-8%), the impact of IoT-BIM-TCAS is the lowest (about 5-6%). According to the distributions, IoT-GBMAV not only saves more money, and performs consistently well over all time intervals. This is an indication of how this framework is dynamic in optimizing the HVAC doing so in a consistent way towards enhanced energy efficiency compared to earlier techniques.

C. Analysis of Indoor Air Quality (CO_2 ppm)

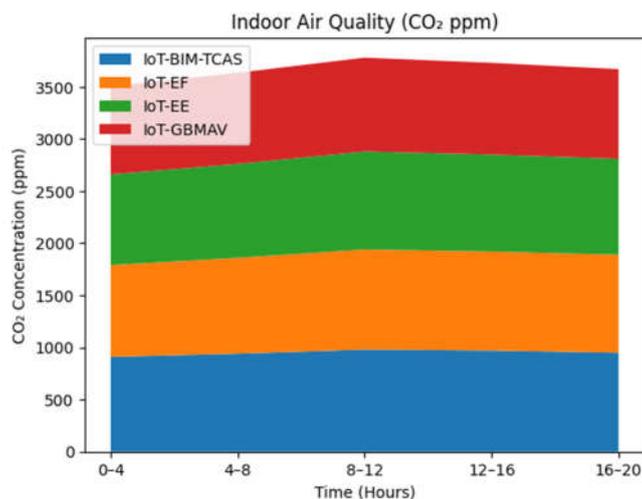


Fig. 3 Analysis of Indoor Air Quality

The CO_2 analysis in Fig.3 shows the air quality trends with time. IoT-GBMAV responds more to occupancy variations in ventilation, which is indicated by lower CO_2 levels (peak at 860-900 ppm). Unlike IoT-BIM-TCAS, which showed higher peaks (910-980 ppm), IoT-EE and IoT-EF maintain the CO_2 levels at a reasonable level (900-960 ppm). The narrower and left-shifted distribution of IoT-GBMAV suggests that they enhance the

efficiency of pollution removal and uniform indoor air quality. This information proves that adaptive ventilation schemes in relation to predictive analytics could help to maintain indoor environments healthier than stationary or semi-automated systems.

D. Analysis of Thermal Comfort Compliance (%)

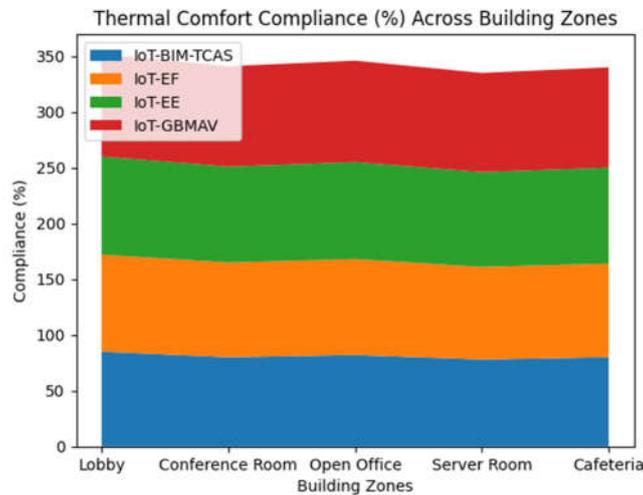


Fig. 4 Analysis of Thermal Comfort Compliance

Thermal comfort compliance Fig. 4, shows the percentage of time zones that have appropriate humidity and temperature levels. The highest level of IoT-GBMAV is approximately 89-92, and it implies that the comforts are highly consistent in all the zones. IoT-EE and IoT-EF have a relatively moderate compliance (85 to 87 percent) whereas IoT-BIM-TCAS is insufficient (78 to 85 percent). Since the IoT-GBMAV is tighter distributed, the thermal management is more credible and less susceptible to aberrations. These results reveal that existing Internet of Things (IoT) monitoring devices use predominantly alarms or less reactive strategies, whereas predictive, sensor-based ventilation control makes occupants much more comfortable.

E. Analysis of Ventilation System Responsiveness (seconds)

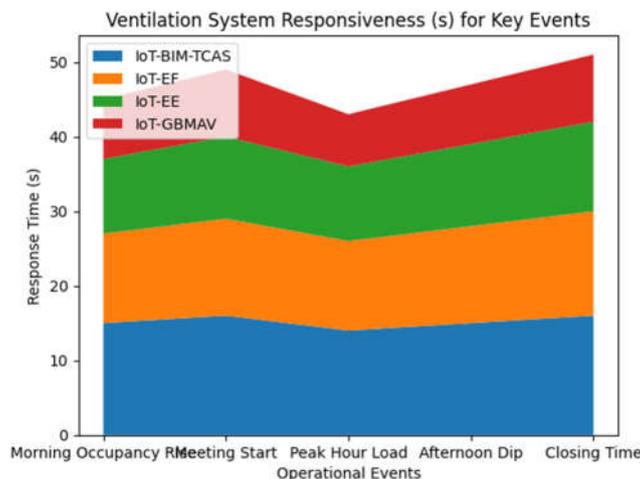


Fig. 5 Analysis of Ventilation System Responsiveness

Fig. 5 allows the use of the KDE to consider the ventilation system responsiveness to view the response time after occupancy or a pollution event. The response time of the IoT-GBMAV is the shortest at 7-9 seconds, which is an indicator of rapid adjustment of the airflow to guarantee the air quality level and comfort. The response time of IoT-EE

and IoT-EF is modest, ranging between 10-13 seconds, but that of IoT-BIM-TCAS is a bit higher, 14-16 seconds. The narrower distribution of the IoT-GBMAV indicates that the responsiveness of the tool is predictable and always stable. Automated ventilation systems can decrease the pollutant build-up and enhance comfort of the occupants by responding faster through a combination of real-time sensor measurements, and predictive modeling.

It is possible to use automated ventilation systems and frameworks based on the Internet of Things to save energy, enhance the quality of interior air, and make people feel more comfortable. With prediction algorithms and real-time sensor data, it is possible to make corrections on the flow of air in real-time. This reduces the usage of CO₂ and energy. These findings indicate that such a system is more responsive and effective at ensuring that people are comfortable during the hot season than the traditional IoT system. Such findings demonstrate that automated control and analytics with the addition of Internet of Things sensing can be used to oversee green buildings in a manner that is not only environmentally benign and sustainable.

V. CONCLUSION AND FUTURE WORK

The combination of multi-sensor IoT networks with predictive analytics enables automated ventilation control in environmentally friendly buildings, as the suggested architecture of the IoT-GBMAV demonstrates. The findings indicate significant improvements in energy efficiency, indoor air quality, compliance with thermal comfort, and responsiveness of the system in comparison with existing approaches, which revolve around the internet of things. The adaptive flow of air can be adjusted in real-time according to the occupancy pattern and environmental conditions, which can be relied on to support sustainable operations of urban buildings and maintain the well-being of occupants.

A. Future works

In the future, enhanced indoor air quality monitoring might be realized through research on the potential to add additional variables of the environment, including volatile organic compounds and particle matter. The monitoring will consider scalability and generalizability by implementing it on different types of buildings and different climates. To augment predictive ventilation control further, machine learning methods, such as reinforcement learning or hybrid attention models, might be helpful. Long-term studies can enhance the accuracy of the models by monitoring the variation of the energy and occupant behavior. The combination of the smart grid and renewable energy sources and the use of the IoT-GBMAV allows offering holistic solutions to sustainability to a building, reducing the effect on the environment, and maintaining the comfort of indoors to its highest quality. The accuracy of the models can be improved through long-term studies that track energy changes and occupant behavior. Furthermore, by integrating smart grid technology with renewable energy sources and IoT-GBMAV, comprehensive sustainable building solutions decrease the impact on the environment, and keep indoor settings at their best.

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