Analyzing the Impact of Occupancy Patterns on Indoor Air Quality in University Classrooms Using a Real-Time Monitoring System

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***Abstract*—Indoor air quality (IAQ) in universities is of concern because it directly affects students' health and performance. This study presents an IoT-based system for real-time monitoring of IAQ in university classrooms. The system uses MQ-7 and MQ-135 sensors to monitor CO and CO2 pollution parameters. The data is then processed by the ESP32 microcontroller, displayed on the LCD screen, and responded to immediately in the mobile application. The system's real-time monitoring capabilities, data display, and alert mechanism provide valuable insights to improve the classroom environment. The sensors used in the system achieved an accuracy of 97.17% for five people and 93.96% for ten people's scenarios. This study investigates the relationship between human behavior, classroom activities, and occupancy impacts the IAQ. The results show a strong positive correlation between occupancy rates and CO2 levels, indicating the importance of ventilation in densely populated classrooms. The correlation coefficient between the number of students and the CO2 levels is 0.982. This coefficient is remarkably close to 1, indicating a strong positive correlation. In other words, as the number of students in the classroom increases, the CO2 levels also increase significantly. The high correlation coefficient suggests a direct relationship between the number of students and the CO2 levels. This IoT-based system will facilitate a data-driven approach to improving indoor environmental conditions, supporting healthier and more effective learning environments in educational institutions.**

Keywords*—*Indoor air quality; monitoring; pollution; IoT

I. Introduction

Indoor air quality is a concern for researchers, especially regarding health. Human activities much more cause air pollution. Industrial gases and vehicle emissions in urban areas are the primary sources of pollutants. Indoor air pollution is a significant health problem because indoor pollutant levels can be 10 to 100 times higher than outdoors [1]. The many sources of hazardous pollutants indoors are risk factors for human health. Common indoor pollutants include particulates, volatile organic compounds, chemical gases, heavy metals, and biological contaminants. The negative impacts of this air pollution are hazardous to human health. This includes the risk of stroke, lung cancer, heart disease, asthma, eye irritation, nasal irritation, and various other diseases [2]. This air pollution has a similar impact to smoking tobacco. From several studies, it is now known that sources of emissions from building materials, furniture, and consumer goods, as well as from the combustion process, are sources of hazardous pollutants in indoor air [3]. Children and women are much more vulnerable because they spend more time indoors. Indoor air quality, especially in cooking areas, can be a source of incomplete combustion. This condition releases toxic gases such as carbon monoxide. Therefore, mitigation is significant to improve indoor air quality. Improving indoor air quality requires various adjustment processes. Avoiding cigarette smoke, using proper ventilation, and choosing low-emission building materials improve indoor air quality [4]. Indoor air pollution in many developing countries has a higher risk than in developed countries. This is mainly due to the combustion of fuels widely used in developing countries. This pollution, therefore, poses significant health risks. Thus, this condition requires more serious mitigation to improve public health in the region [5].

Indoor air quality problems also occur on campuses or colleges. Research on indoor air quality on campus reveals high levels of air pollution. Indoor environmental conditions, such as schools, can have higher levels of pollutants than outdoors. Classrooms and laboratories in various campus environments have poor air quality. The concentration of carbon dioxide (CO2) in classrooms, libraries, and student cafeterias can exceed the standard of 1000 ppm, according from research results conducted by [6], [7]. The increase in carbon dioxide concentration was also followed by high levels of total volatile organic compounds (TVOC) in several locations. Various initiatives are needed to increase campus community awareness of indoor air quality. Monitoring of air quality parameters such as CO and CO2 can be done to raise environmental awareness in educational institutions [8].

The classroom with high pollution will ultimately affect students' health in the long term [9]. Indoor air quality (IAQ) significantly affects university students' satisfaction, study engagement, and cognitive performance. The study found that variations in CO2 levels and other IAQ parameters correlated with students' engagement and memory performance. Poor IAQ conditions can lead to dissatisfaction and reduced cognitive function, ultimately impacting academic performance

[10]. Research by [11] shows the impact of indoor microbial activity on human health. Ventilation systems and clean living habits can reduce indoor pollution levels. The campus building zone or location significantly impacts indoor air quality in campus buildings. Studies [12] and [13] concluded that campus building zones located in places with high pollutant sources can potentially affect the health and performance of occupants.

Other studies, such as those conducted by [14], evaluated indoor air quality in laboratories and classrooms at the Coimbra Health School. The results found that several indoor pollutants exceeded the limits. Students spend a lot of time indoors at school, so their exposure to air pollutants will be affected. However, other studies have also revealed that students and other people are significant sources of indoor pollution in university classrooms. Devices such as computers do not contribute significantly as pollutants [15]. Occupants in schoolrooms affect indoor air quality through respiratory and skin emissions [16]. Considering the above conditions, monitoring and action are needed to improve air quality on campus. Further studies reveal poor indoor air quality in higher education buildings in the UK. Air quality, especially in larger rooms with high occupancy, can be worse, which affects student comfort and performance. Ultimately, the potential health implications of poor indoor air quality can occur in students. Students can experience health conditions such as cough, throat irritation, headaches, eye irritation, and respiratory problems [17], [18]. Ultimately, the study emphasizes the importance of maintaining good IAQ for overall productivity improvement [19], [20].

The above findings underline the need for indoor air quality monitoring. Mitigation measures can be carried out through continuous monitoring and adequate ventilation. Carrying out a monitoring process is expected to ensure healthy indoor air quality conditions for students and staff on university campuses. Monitoring parameters such as temperature, relative humidity, CO, CO2, and PM2.5 levels at various locations on campus needs to be carried out. This monitoring can help management identify campus areas with poor air quality. Knowing the air quality conditions at each location can be used to implement pollution control measures to improve indoor air quality [21]. Monitoring indoor air quality can be done using sensor technology and the internet. Continuous air quality monitoring in university classrooms can be carried out by installing monitoring devices. This policy can create a healthier indoor air quality environment for students, staff, and visitors. The work in [22] implemented a real-time indoor air quality monitoring system in campus classrooms. This study used Internet of Things (IoT)-based technology and Wireless Sensor Networks to detect pollutants such as CO2, dust, temperature, and humidity. Similar work by [23] presents an IoT system for real-time indoor air quality monitoring in a university environment. This system focuses on CO2, CO, and particulate matter pollutants. However, the relationship between room occupancy patterns and air quality is not studied. According to the condition mentioned earlier, conducting further research on indoor air quality is very important.

This research analyzes the relationship between the influence of human behavior, activities, and occupancy patterns on indoor air quality conditions. Furthermore, the results of this research can be used to develop policies to improve university indoor air quality. Excellent or healthy indoor air quality conditions will correlate to enhancing students' health and academic achievement. This research develops an Internet of Things (IoT)-based system for real-time monitoring of indoor environments within university classrooms. The primary objective is to observe and analyze indoor air quality parameters, including carbon monoxide (CO) and carbon dioxide (CO2) levels. These two air quality parameters are chosen since this parameter has a close relation with human occupancy and activities. The designed monitoring system will integrate multiple sensors to monitor air quality metrics. The notification of environmental conditions exceeding the safe limitation will trigger the alarm and be sent by internet to the mobile application. The data collected from monitoring air quality parameters is stored in the database. This research also investigates the relationship between human behavior, classroom activities, and occupancy patterns with indoor air quality. The results show how different factors, such as classroom size, activity intensity, and occupancy, affect indoor air quality parameters. The findings from this research are expected to contribute to policies. Therefore, classroom environments can be optimized for better air quality and occupant comfort. This IoT-based monitoring system provides a data-driven approach to improve indoor environmental conditions. Good indoor air quality can support healthier and more efficient learning environments in educational institutions. This paper is divided into several sections namely, introduction, literature and research framework, methodology, results and discussion and finally a conclusion.

II. Literature and Research Framework

A. *Indoor Air Quality (IAQ)*

Indoor air quality standards are set to ensure indoor air quality is free from harmful gases or particles above the threshold. Based on research, indoor pollutant levels can be higher than outdoor pollutants. This will certainly affect the health and satisfaction of occupants. Indoor air quality (IAQ) standards and limits are necessary to maintain human health in buildings. This is because long-term exposure to pollutants above the limit can have adverse effects on humans. However, consistent national and regional IAQ standard values have not yet been agreed upon. This lack of regulation has led to uneven IAQ assessments across countries [24], [25]. The World Health Organization (WHO) has established health-based guideline values for several indoor air pollutants. However, these values have not been universally adopted as legally binding standards across countries. This could be due to the complexity and global variability in IAQ regulations. Efforts are underway to develop comprehensive, science-based IAQ guidelines. A study by [26] The research highlights the limitations of indoor environmental quality standards. It also highlights gaps in the evidence supporting thermal, visual, and air quality requirements and urges critical assessment for better standards.

The standards for a healthy room include a temperature range of 18°C-28°C and humidity levels of 40%-60%. This is stated in the Decree of the Minister of Health of the Republic of Indonesia Number 1405/Menkes/SK/XI/2002, addressing the Office and Industrial Work Environment Health requirements. The average concentration of carbon dioxide indoors is between 250 - 400 parts per million. The concentration of carbon dioxide between 2,000 - 5,000 ppm may affect human health in ways such as headaches, drowsiness, stagnant air, poor focus, an elevated heart rate, and minor nausea [27]. The impact of air quality on human health is also studied by research in [28], [29]. The thresholds for several air quality parameter are presented in Table I.

TABLE I. CRITERIA FOR CHEMICAL POLLUTANT THRESHOLDS

No#	Parameters	Unit	Requirements
1	Sulfur dioxide (SO2)	ppm	0,1 in 24 hour
2	Nitrogen dioxide (NO2)	ppm	0,04 in 24-hour
3	Carbon monoxide (CO)	ppm	9 in 8 hours
4	Carbon dioxide (CO2)	ppm	1000 in 8 hour
5	Lead (Pb)	mg/m3	1,5 in 15 minutes
6	Formaldehyde (HCHO)	ppm	0,1 in 30 minutes
7	Volatile organic compound (VOC)	(VOC)	3 in 8 hours
8	Environmental Tobacco Smoke (ETS)	mg/m3	35 in 24-hour

B. Monitoring Systems

An indoor air quality monitoring system is needed to evaluate and improve air quality within indoor environments. These systems assess air pollutants' conditions, including gases and particulate matter. The monitoring system is used to ensure a healthy and safe indoor environment. Typically, monitoring systems comprise several vital components. Pollutant sensors, data storage, and processing units are implemented into one system. These sensors detect and measure the concentration of air pollutants present. After measurement, the data is processed through a processing unit for storage in the database. Calibration integrates these monitoring systems to effectively and accurately detect pollutants. This brings in the need for calibration of the monitoring devices [30]. Calibration is the most essential step in maintaining the accuracy of sensor readings. The calibration step ensures that data collected for indoor air quality parameters reflects the environmental conditions. Recently, indoor air quality monitoring systems have become so advanced that their capabilities have increased manifold in several prospects [31]. The modern architecture of these monitoring systems integrates wide-area networks, servers, and client devices. This architecture provides extensive and real-time indoor air quality data monitoring and analysis. Such networked architecture allows for the gathering and aggregating data from many sensors and geographic locations. Comprehensive data gives a general view of indoor air conditions. Integrating sensors for such gases as CO and CO2 makes an advanced system able to provide exact and detailed measurements. Real-time air quality monitoring notifies us about changes in air quality in time. Therefore, these results allow immediate corrective actions. Advanced monitoring systems will be able to supply more detailed and accurate data in a timely way to support effective management and control of indoor air quality parameters. Thus, they will contribute toward healthier and more comfortable indoor environments in the long run [32].

III. METHOD

Fig. 1 depicts the proposed design architecture for the IAQ monitoring system in university classrooms. This system consists of three parts: an input block, a processing block, and an output block. The input block utilizes the MQ7 sensor to detect carbon monoxide (CO) and the MQ135 sensor to detect carbon dioxide (CO2). These sensors monitor the air quality parameters in the classroom in real time. The collected data is then transferred to the microcontroller for processing in the processing block. In the processing part, the data is handled by the ESP32, which acts as a microprocessor. The processed data determines the commands to be executed in the output block. A 5V power supply powers the ESP32.

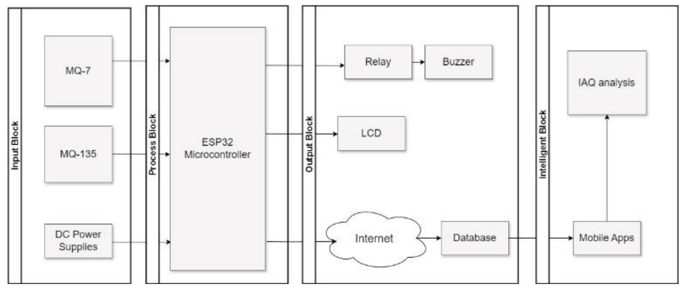

Fig. 1. Proposed system design.

The commands received in the output block trigger appropriate actions based on the processed data. The analysis data is displayed on a 16x2 LCD screen in the enclosure. The system monitors real-time gas levels on the LCD screen and mobile apps. The buzzer is activated when CO and CO2 levels exceed 250 ppm and 1000 ppm, respectively. The buzzer will stop operating when the gas level falls below these limits. This condition indicates that the air quality has returned to a safe level. Data on each sensor's air quality parameters will be stored in a centralized database. This ensures that data can be efficiently accessed and used for various purposes. A summary used by the system's embedded mobile application enables real-time visibility of air quality meters. Users can see their current carbon monoxide, carbon dioxide levels, or any components of interest on their smartphone application. This application offers an easy way to improve air quality comfortably. Besides real-time monitoring, this mobile application can issue warnings when CO2 or CO levels exceed any predetermined limit. These warnings ensure immediate interference to keep the air quality within safety boundaries. The information provided by the application's system contributes to quicker reactions in dangerous situations.

Two different test scenarios were used to gather detailed information. In the first scenario, there were five students in the classroom. In this experiment, CO and CO2 concentrations were recorded at five separate measurements to ensure the accuracy and reliability of the data. This scenario provides the first understanding of how low occupancy rates affect indoor air quality. In the second scenario, there were ten students in the same classroom. Measurements were repeated five times under these conditions to assess the effect of increased

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occupancy on CO and CO2 concentrations. This scenario illustrates the impact of occupancy rates on air quality, particularly regarding CO2 levels.

That is why this monitoring system enhances proficiency in managing indoor air quality. Indoor air quality data was collected and used as a dataset. This enhances, in general, the capability to analyze more and adds value to the monitoring system. The system puts forth a proactive approach toward air quality management. The system is holistic indoor air quality monitoring, highly technological, collecting data, monitoring it in real-time, warning per system deployed, and analysis. This system immediately provides feedback and uses advanced technology to furnish valuable insights and predictions.

IV. Results and Discussions

A. Hardware Implementation

The primary component that sense the air quality parameter include MQ-7 and MQ-135 sensors. Other components are an ESP32 microcontroller, LCD, buzzer, LED indicator, mobile application, and power supply. In this work, an ESP32 microcontroller was chosen due to several GPIO pin arrays for multi-function operations and WiFi connectivity. These modules provide both speed and internet support for system operations and communications. MQ7 and MQ-135 sensors measure CO and CO2, respectively. LCDs instantly read these sensors in real-time to give direct access to the current air quality status. Also, a buzzer is attached to the device as an audible warning system to inform the user if the levels of gases exceed the usually pre-set safety limits. A feature like this would enable the system to monitor the gas level remotely using the mobile application. The setting updates the user with real-time information and contextual air quality status. Thus, users can respond immediately if there is any potential air quality problem inside the classroom. The hardware wiring implementation of the device is shown in Fig. 2, which shows the configuration and integration of these components throughout the system design.

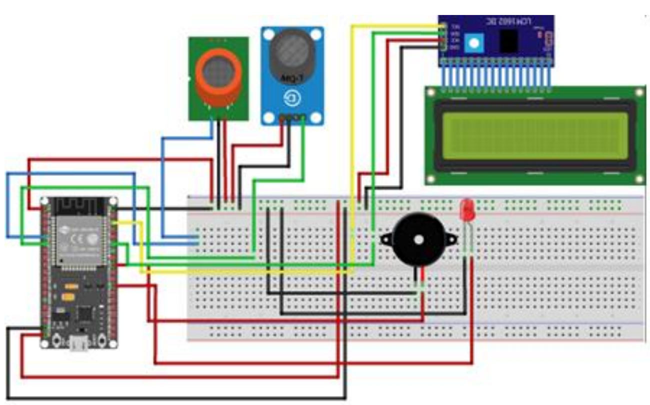

Fig. 2. Hardware wiring implementation.

Fig. 3 depicts the monitoring box implementation. The monitoring system being developed in this study consists of a 9 cm x 15 cm x 10 cm box. The indoor health monitoring system is designed to measure carbon monoxide (CO) with the MQ-7 sensor and carbon dioxide (CO2) concentration with the MQ-135 sensor. This system is integrated with an internet connection and allows real-time data transfer to mobile application users. The Internet and mobile applications enable users to monitor air quality and remotely receive alerts on dangerous levels.

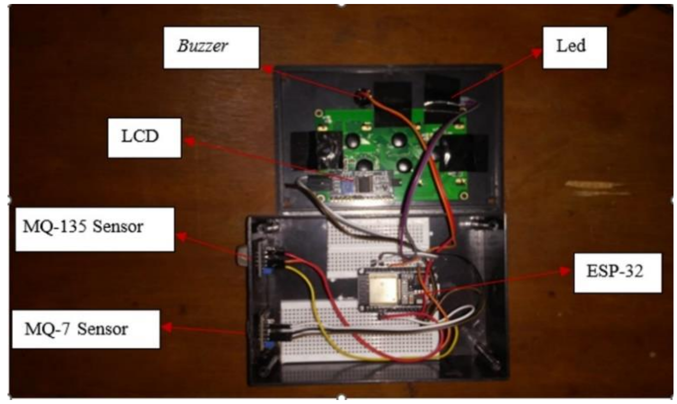

Fig. 3. IAQ hardware implementation.

B. Calibration Process

Once the entire device is assembled, all components are tested and calibrated to produce more accurate results. The method used is linear regression, a statistical technique for comparing sensor outputs with linear characteristics against standard values. In this case, calibration will be performed for the MQ-135 and MQ-7 sensor system readings. The reference instruments are the AZ7752 Instrument and Portable Gas Leak Detector BH-90E. These two devices were chosen as calibrators since they have more accurate results than the low-cost sensors used in this monitoring box. The data resulting from the system calibration are presented in Tables II and III.

TABLE II. MQ-135 Sensors Measurement Process

No.	Calibrator	MQ-135	% error	% accuracy
1	202	203.2	0.59	99.41
2	203	203.2	0.098	99.9
3	204	203.95	0.024	99.98
4	204	204.46	0.22	99.78
5	204	205.3	0.63	99.37
6	204	211.2	3.52	96.48
Average	203.5	205.22	0.847	99.15

TABLE III. MQ-7 Sensors Measurement Process

No.	Calibrator	MQ-7	% error	% accuracy
1	218	216	0.91	99,09
2	218	219	0.45	99.55
3	209	194	7,17	92.83
4	207	193	6.76	93.24
5	208	195	6.25	93.75
6	210	197	6.19	93.81
Average	211.6	202.3	4.62	95.37

The next process is performed using linear regression with Eq. (1). The Y represents the value obtained from the reference instruments Az 7752 and BH-90E as calibrators, and the X denotes the design device sensors' output value.

$$Y = a + bX \quad (1)$$

Fig. 4 and Fig. 5 show the correlation calculation between the readings from the designed device and the reference instrument or calibrators using the linear regression equation.

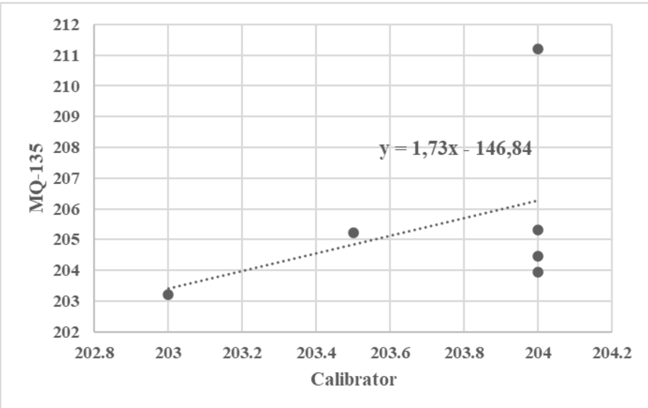

Fig. 4. MQ-135 linear regression graph.

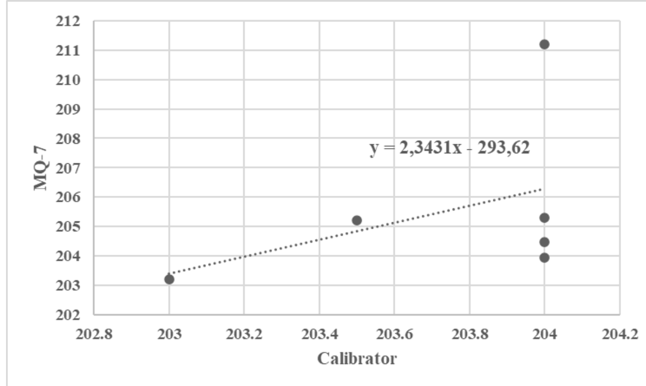

Fig. 5. MQ-7 Linear regression graph.

The linear regression results for the MQ-135 sensor are represented by the equation y = 1.73x – 146.84, and for the MQ-7 sensor, y = 2.3431x – 293.62. These regression equations provide calibration adjustments to enhance the accuracy of the raw sensor readings. By implementing these equations into the source code, the sensors' measurements can be corrected in real-time. This setting allows the system to compensate for any inaccuracies inherent in low-cost sensors. Consequently, the monitoring box that relies on low-cost sensors can deliver more precise and reliable air quality data.

TABLE IV. IAQ TESTING RESULTS

No	number of students	CO		CO2		% error CO2	% accuracy CO2	Notification	
		Sensor	Calibrator	Sensor	Calibrator			Buzzer	Apps
1	5	0	0	211.2	204	3.53	96.47	*OFF*	*OFF*
2	5	0	0	211.2	204	3.53	96.47	*OFF*	*OFF*
3	5	0	0	210.1	204	2.99	97.01	*OFF*	*OFF*
4	5	0	0	210.1	204	2.99	97.01	*OFF*	*OFF*
5	5	0	0	215.15	210	2.45	97.55	*OFF*	*OFF*
6	5	0	0	215.02	210	2.39	97.61	*OFF*	*OFF*
7	5	0	0	211.1	207	1.98	98.02	*OFF*	*OFF*
8	5	0	0	211.17	207	2.01	97.99	*OFF*	*OFF*
9	5	0	0	211.17	207	2.01	97.99	*OFF*	*OFF*
10	5	0	0	216.1	207	4.40	95.60	*OFF*	*OFF*
11	5	0	0	250.3	255	1.84	98.16	*OFF*	*OFF*
12	10	0	0	250.3	255	1.84	98.16	*OFF*	*OFF*
13	10	0	0	254.32	262	2.93	97.07	*OFF*	*OFF*
14	10	0	0	260.1	273	4.73	95.27	*OFF*	*OFF*
15	10	0	0	260.15	277	6.08	93.92	*OFF*	*OFF*
16	10	0	0	264.1	281	6.01	93.99	*OFF*	*OFF*
17	10	0	0	266.15	298	10.69	89.31	*OFF*	*OFF*
18	10	0	0	264.17	284	6.98	93.02	*OFF*	*OFF*
19	10	0	0	263.05	279	5.72	94.28	*OFF*	*OFF*
20	10	0	0	267.2	309	13.53	86.47	OFF	OFF

C. Discussion

The testing results include a range of air quality measurements, including information on the number of students attending classes, carbon monoxide (CO) levels, carbon dioxide (CO2), and monitoring equipment. The CO2 parameters can increase dramatically due to increased human activity and respiration. Results from both scenarios are considerably detailed in Table IV. By comparing the data from these two scenarios, insights can be gained into how occupancy rates affect indoor air quality, particularly CO2 levels. Since CO concentration from the sensor and calibrator shows the exact measurement, the calculation of error and accuracy is not done for the CO. According to Table IV, the average accuracy of CO2 level is 95.57%, with an error of 4.43%.

The average values acquired from this measurement under two scenarios are summarized in Table V. The first scenario was performed on a workday with five college students in a 7 x 7-meter room. The average carbon dioxide (CO2) measurement was 212.23 ppm, with carbon monoxide (CO) degrees measured at zero ppm. The average CO2 concentration in this condition was relatively low, which can be attributed to the confined wide variety of occupants in the given area. In the second stage of experiments, with the room occupied with the aid of ten people, the CO2 awareness increased to an average of 259.98 ppm. This rise in CO2 stages is prompted by numerous factors, including elevated occupants, the room's dimensions, and insufficient air stream inside the area.

TABLE V. AVERAGE IAQ TESTING RESULTS

No.	Condition	CO_2 (ppm)	% error	% accuracy
1.	Five people	212.23	2.83	97.17
2.	Ten people	259.98	5.12	93.96

The findings suggest that a 7 x 7-meter room, when occupied with the aid of 10-15 people for prolonged intervals, remains within a secure variety of air quality. This conclusion is supported by the records supplied in Table V, which show that CO2 ranges and other readings range with adjustments in occupancy. The environment remains possible in these situations.

We use the Pearson correlation formula in Eq. (2) to calculate the correlation coefficient between the number of students and the CO2 levels. According to the correlation analysis, the correlation coefficient is 0.982.

$$r = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2-(\sum x)^2][n\sum y^2-(\sum y)^2]}} \quad (2)$$

This coefficient is remarkably close to 1, indicating a strong positive correlation. In other words, as the number of students in the classroom increases, the CO2 levels also increase significantly. The high correlation coefficient suggests a direct relationship between the number of students and the CO2 levels. This is expected because humans exhale CO2, and in a closed environment like a classroom, higher occupancy will naturally lead to higher CO2 concentrations. Elevated CO2 levels can impact cognitive function and overall comfort. Indoor CO2 concentrations should be below 1000 ppm to ensure a healthy and productive environment. The data indicates that classrooms with more students will likely have higher CO2 levels. This is potentially exceeding recommended limits if not correctly managed. The strong correlation highlights the importance of adequate ventilation systems in classrooms. Schools should ensure sufficient ventilation rates to maintain CO2 levels within safe limits, particularly in densely occupied classrooms.

The sample size of air quality and the number of classrooms may constrain this study's findings. This is due to limited resources and time for air quality data collection, which may not be feasible. In the future, this indoor air quality monitoring box can be enhanced by adding more sensors to measure different air quality parameters, such as temperature, humidity, and particulate matter. Since the electronic components and sensors are low-cost, the device can be produced in larger quantities for use in other classrooms. All monitoring devices may store the data in the cloud-based database. Although several studies have implemented the idea of monitoring devices. The work in study [33] and study [34] already studied and enabled comprehensive indoor air quality monitoring in classrooms. The work uses a network of intelligent IoT sensors. It may continuously track parameters such as indoor/outdoor temperatures, relative humidity, and CO2 levels, facilitating centralized control of natural ventilation. However, the idea can be extended by using machine learning to analyze the classroom occupancy level and the air quality index. Therefore, the system allows for real-time data processing that is essential for assessing infection risks and optimizing air quality.

V. CONCLUSION

This paper aims to design and test an IoT-based IAQ monitoring system in a university classroom. The monitoring device allows for real-time monitoring of carbon monoxide (CO) and carbon dioxide (CO2) levels. Real-time monitoring, data display, and warnings signaled by the system are important to improve the classroom environment. Accordingly, the system achieved accuracy in sensing at a rate of 97.17% for five people and 93.96% for ten people's scenarios. The Pearson correlation formula compares the number of people's occupancy and the classroom. The Pearson correlation coefficient between the number of students with CO2 levels was 0.982. This result is close to 1, which recommends a strong positive correlation. That is, with increasing numbers of students within the classroom, drastically increasing levels of CO2 are realized. The high correlation coefficient suggests the increased number of students and CO2 levels correspondingly. Continuous monitoring of IAQ and effective ventilation techniques are essential for maintaining a healthy indoor environment in university classrooms. Further research is required to establish how other environmental parameters can be studied across various indoor environments. Another advanced research can integrate sensed pollution data into machine learning for predictive analytics for these IAQ parameters.

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