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Study on Indoor Air Quality Measurements of Educational Buildlings in Pakistan

Yasir Atlas Khan[1], Dr. Adnan Daud[2]
[1,2]University of Engineering Technology, USPCAS-E Peshawar, Pakistan
yasiratlas.uspcase@uetpeshawar.edu.pk[1], adnan.daud@uetpeshawar.edu.pk[2]
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***Abstract*—**The current technological era has provided humanity with unprecedented luxuries and opportunities for exploration, both on Earth and in space. However, this progress has also introduced significant environmental threats. Recent global awareness has heightened concern for environmental protection, with governments focusing on pollutants that cause catastrophic events like flash floods. Scientists are now identifying and analyzing specific pollutants to mitigate their impact and propose eco-friendly alternatives. This study focuses on the indoor air quality (IAQ) of an educational building at UET Peshawar (USPCAS-E). Sensors and particle monitors were placed in 19 rooms to measure temperature, humidity, air flow, and particulate matter (sizes 0.5 µm to 10 µm). Data was recorded at three different times and averaged for accuracy. The aim is to identify indoor air pollution sources and their adverse effects on health, contributing to better IAQ management strategies.

***Index Terms*—**Indoor Air Quality (IAQ), Environmental Pollution, Airborne Particulate Matter, Sensor Monitoring, Air Quality Analysis, Health Impact, Pollutant Identification, Environmental Protection.

I. Introduction

Technological advancements rapidly transform our world but also pose health threats, particularly from air pollution. Air quality is crucial for human health. In developing countries, biomass is a primary energy source, contributing significantly to indoor air pollution (IAP). Biomass fuels, such as animal or plant matter, are burned for lighting, heating, and cooking, often inefficiently. This inefficient burning releases toxic gases, compounding the effects of outdoor air pollution from sources like neighborhood fires, domestic waste, vehicle emissions, and industrial activities, thereby endangering human health [1].

Advancements in technology have shifted traditional fuel-burning practices to more efficient and eco-friendly alternatives, such as electricity. By 2030, an estimated 1.3 billion people in the Asian subcontinent will still rely on biomass despite these advancements. Pollutants from conventional fuels cause approximately 2.8 million premature deaths annually, largely due to practices like kerosene and candle use for lighting and cooking. The "energy ladder" concept illustrates the progression towards cleaner energy sources, reducing air pollution risks as communities move from animal dung and crop residues to wood, charcoal, gas, and finally electricity [2].

Air pollution extends beyond fossil fuel burning, impacting both rural and urban areas differently. Rural regions, often more vulnerable, urgently require attention from authorities to combat this issue. Meanwhile, urban areas face a complex array of contributors to air pollution, including building materials, HVAC systems like air conditioners and refrigerators, inadequate ventilation, and chemical-laden household products. Moreover, facilities such as hospitals, pharmacies, and laboratories also contribute to indoor air pollution (IAP) due to chemicals and antibiotics, posing significant risks to vulnerable groups like persons with disabilities, the elderly, and children who spend prolonged periods indoors. IAP is responsible for approximately 2 million deaths annually globally, primarily from respiratory diseases such as pneumonia and chronic obstructive pulmonary disease (COPD), which collectively account for a substantial portion of global mortality. Despite advancements in clean technologies, indoor air pollution remains a pressing public health issue, necessitating comprehensive strategies to improve indoor air quality and protect populations worldwide from its detrimental effects [2].

Internal combustion engine vehicles are major contributors to air pollution, especially in developing countries where inefficient engines and low-quality fuel prevail. Industrial waste, emissions from brick kilns, and burning garbage further degrade air quality. Transport vehicles, consuming 47.4% of petroleum products, significantly contribute to pollution. The increasing number of vehicles exacerbates these issues; for example, in Pakistan, vehicles rose from 3.5 million in 1994 to 5.2 million in 2005 (Figure 1). Based on this data, there is an urgent requirement for cleaner technologies and strict policies that can help minimize air pollution [3].

*corresponding author: yasiratlas.uspcase@uetpeshawar.edu.pk

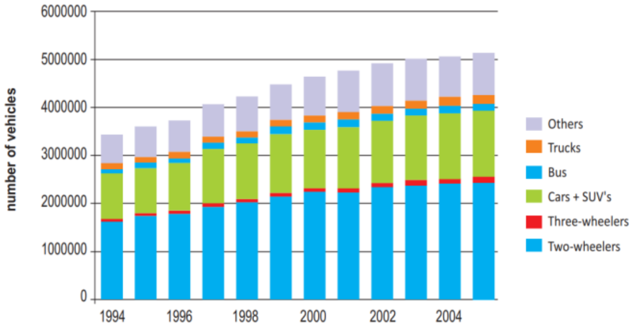

Fig. 1. Number of vehicles registered annually in Pakistan [3]

Another major cause of air pollution in Pakistan is its industrial sector, which plays a major role in degrading air quality. Even though there is no comprehensive data available on the pollution caused by industries in Pakistan, various reports published by several government and non-government organizations suggest that industries, especially power plants, sugar mills, and fertilizer producers, have a key role in polluting air. Moreover, brick kilns, ubiquitous across rural and urban areas, also play a vital role in contaminating air. The pollutants released by these industries often include particulate matter, Sox and NOx, which are toxic in nature and cause potential health risks to humans and animals.

Aside from polluting outdoor air, these industries significantly contaminate indoor air as well, which can be harmful for industrial workers. These indoor air pollutants often contain high concentrations of hydrogen sulfide and ammonia. Such toxic substances are present in high quantities in dyeing and chemical processing industries. On the other hand, one of the major industries in Pakistan, the textile sector, primarily produces harmful and toxic substances such as oil and acid mists, solvent vapors, and dust, which further deteriorate human health.

Moreover, power plants that use fossil fuels as their primary feed, especially coal, are primary air contaminators. These plants emit toxic gases such as sulfur dioxide and nitrogen dioxide, as well as particulate matter, affecting air quality and public health, particularly in areas close to these facilities. The transition from coal to natural gas in some regions has helped mitigate pollution levels at the household level, although coal use persists in rural and underdeveloped areas due to energy accessibility issues.

Despite efforts to shift towards cleaner energy sources, thermal energy remains predominant in Pakistan's energy mix, accounting for over 60% of electricity generation. This reliance on thermal power contributes to indoor air pollution and associated health problems, as highlighted in reports indicating significant annual deaths and respiratory diseases linked to indoor air pollution [4].

II. Literature Review

Indoor air quality (IAQ) significantly impacts human health and the environment. Given that people spend most of their time indoors, evaluating and improving IAQ is critical. Reviewing existing research on IAQ, including measurement techniques, environmental impacts, and methodologies for ensuring standards, is essential for validating new studies. This chapter reviews global research on IAQ, encompassing measurement methods, environmental and health impacts, and strategies to maintain high IAQ standards.

In [5], a concise overview of indoor air quality monitoring systems aimed at enhancing public health is presented. Globally, approximately 3 billion people rely on biomass fuels like coal, petroleum products, crop residues, wood, and charcoal for household energy needs. With humans spending about 80 to 90 percent of their day indoors, exposure to indoor air pollution (IAP) poses significant health risks. The study explores the integration of wireless technologies and cyber-physical systems for real-time monitoring of IAQ. Emphasizing microcontrollers as pivotal components, the research critically examines challenges in system design. Key pollutants such as CO, SO2, VOCs, NO, O3, as well as factors like temperature and relative humidity (RH) are thoroughly reviewed for their impact on IAQ. Additionally, the technical aspects of IAQ monitoring systems are briefly discussed within this context.

Previous IAQ monitoring systems typically use IoT or WSN for data collection and mobile apps or software for analysis. Real-time monitoring is crucial for accurate IAQ assessment, surpassing lab-based or simulated studies. The author suggests predictive IAQ systems capable of preemptively managing pollutant levels in closed environments. Proposed deep learning models like LSTM and GRU can alert users via the internet and cellular networks about pollutant concentration changes. These systems, adaptable through parameterization, enhance prediction accuracy. In conclusion, AI-based IAQ monitoring promises to mitigate health and environmental risks by anticipating IAQ degradation.

In [6], an IoT-based indoor air quality monitoring system is proposed, emphasizing indoor air pollution as a significant contributor to chronic illnesses and respiratory issues. The study explores smart city initiatives aimed at enhancing living standards and predicting adverse conditions to mitigate health hazards. It reviews sophisticated IoT-based monitoring systems, discussing sensor types, controllers, architectural designs, and connectivity. The research identifies knowledge gaps, challenges, and offers future recommendations for developing IoT-based monitoring systems.

Based on the data analysis, approximately 70% of research in this field focuses on thermal comfort parameters, while concentrations of CO2 and PM account for 65% and 27.5%, respectively. Over 70% of monitoring systems proposed utilize Arduino or Raspberry Pi microcontrollers. Notably, only 22.5% of these systems prioritize calibration before implementation, yet 75% claim increased system efficiency. This study evaluates 40 research papers, emphasizing a wide range of air quality parameters including humidity, temperature, COx, PMs, and VOCs. Commonly used sensors include those for thermal comfort, gas, and dust. Choosing appropriate sensors for building types is crucial. Arduino's popularity stems from its open-source nature and availability. Communication protocols like WiFi, Bluetooth, and Zigbee are prevalent, with WiFi noted for higher power consumption. Bluetooth and Zigbee are favored for their lower power usage. Efficient buildings minimize power consumption and discomfort, reducing living costs. User-friendly mobile apps and computer programs are essential for easy system monitoring and control. The study's practical applications benefit researchers, engineers, industrial experts, and public health policymakers. A general structure of the IoT-based Air Quality Monitoring System is shown in figure 2 below.

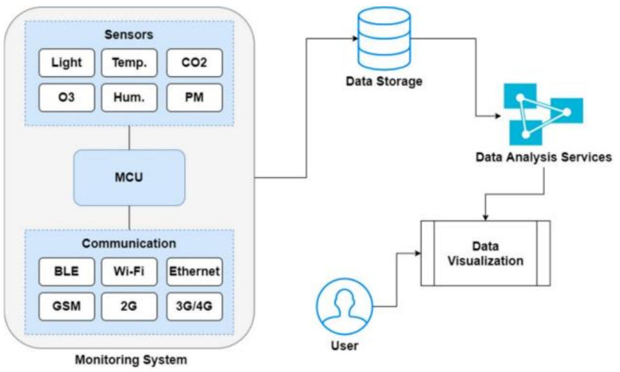

Fig. 2. General Architecture of IoT based Air Quality Monitoring System

In [7], a review of indoor air quality (IAQ) in Pakistan highlights its significance as a rare investigation in this area. The prevalence of indoor air pollution (IAP) in Pakistan is primarily due to 70% of the population residing in rural areas, where biomass fuels are widely used, with 94% dependence for domestic purposes. Even in urban areas, 50% of the population uses biomass fuels like wood and dung, which burn inefficiently, leading to toxic smoke containing harmful chemicals. This contributes to severe health risks, causing approximately 28,000 deaths annually and affecting 40 million people with chronic respiratory issues. Despite being a developing country, Pakistan has not effectively regulated biomass fuel use to control indoor air pollution. The study recommends reviewing existing literature and government reports to formulate interventions. It highlights the impact of tobacco smoke on IAQ and notes the lack of long-term studies on IAP in Pakistan, emphasizing the need for public health interventions. Efforts such as improved stove technology have been proposed but require evaluation. Collaborative efforts involving stakeholders and awareness campaigns are crucial to addressing and improving IAQ in Pakistan.

In [8], a system utilizes a Raspberry Pi processing unit to monitor indoor air quality. It integrates MQ sensor series for Nitrogen Dioxide, Temperature, humidity, and cigarette concentration. Each sensor communicates individually with the Raspberry Pi through dedicated isolated channels, facilitated by an analog to digital converter. The system can detect high concentrations of toxic gases and pollutants within a confined space, triggering an alarm when levels exceed predefined thresholds.

In [9], a novel air quality measurement device based on wireless sensor networks (WSN) has been proposed. Sensors are strategically placed in a defined area, collecting samples that are aggregated in a centralized cloud device. Communication within the system utilizes Zigbee devices, known for their efficiency and low power consumption, ensuring extended operational periods. The sensor network monitors, stores, and processes data on pollutants like xylene, ethylbenzene, and toluene. Data processing employs back-propagation learning algorithms, supported by methods such as support vector machines and principal components analysis [10]. Figure 3 illustrates the configuration diagram of the device proposed.

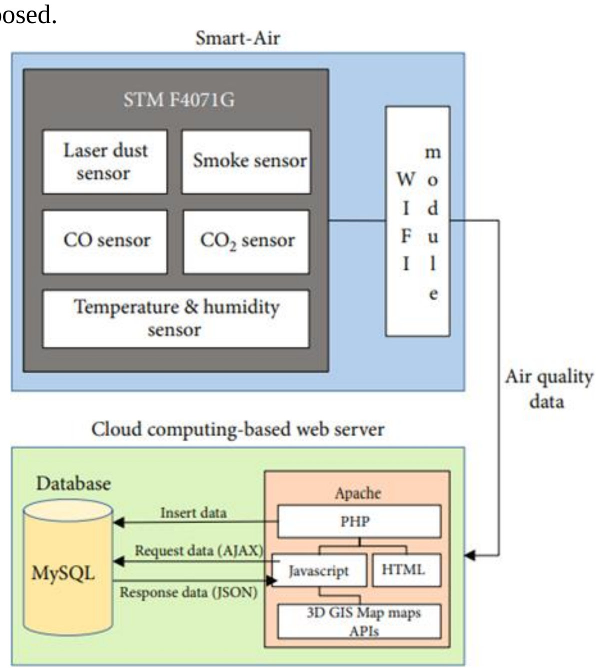

Fig. 3. Configuration diagram from the IoT based indoor air quality monitoring system

III. Methodology

The widespread health implications of Indoor Air Pollution (IAP) have been discussed in previous sections, affecting numerous households, offices, and residences. This study focuses on assessing IAP across various rooms at the University of Engineering Technology (UET) Peshawar. The site was chosen for its accessibility to necessary equipment and varied room types (labs, classrooms, libraries, offices), facilitating a comprehensive study of pollutant presence and intensity. This section provides details regarding the method and approach adopted to carry out the subject study. Moreover, the air pollutants including particulate matter and other toxic gases are also discussed.

A. Impact of Particulate Matter on Indoor Air Quality

Particulate Matter (PM) [11] significantly impacts indoor air quality, arising from diverse sources such as cooking emissions, smoking, and materials within buildings. These particles pose substantial health risks, especially for vulnerable populations like children, the elderly, and those with pre-existing health conditions. Breathing in air with high levels of particulate matter can result in respiratory and cardiac illnesses, including asthma and heart diseases. Particulate matter which is smaller in size such as PM 2.5 or PM 5.0 can pose serious respiratory problems as their size is very small which enables it to penetrate deep inside lungs and eventually bloodstream causing serious health problems.

In order to improve air quality, effective monitoring systems to measure and control the levels of particulate matter in air is crucial. Once the levels of air pollutants are known, different methods and techniques can be adopted to improve indoor air quality which may include ventilation systems, air filters, and controlling or removing the source of air pollutants. The systems responsible for controlling air pollution should be properly maintained and serviced periodically in order for them to function properly.

The particulate matter, which is an essential component of air pollutants, can be of various sizes and each size has its own health implications. For instance, PM10 refers to the particulate matter of size 10 micrometers. Though larger in size, it can still pose threats to human health if inhaled and can also reduce visibility if present indoors. On the other hand, PM 2.5 is smaller in size and is mainly found in vehicle and industrial emissions due to which it is in high quantity in urban areas. The particles of PM 2.5 are smaller and have the ability to penetrate deep into the respiratory system causing chronic illnesses pertaining to lungs and heart. Similarly, PM 1.0 is even smaller and contains ultrafine particles which can easily get inside the bloodstream causing severe health issues.

B. Impact of CO on Indoor Air Quality

Another significant air pollutant which is a major component in contaminated air is carbon monoxide. CO is produced by incomplete combustion of fuels such as wood, oil, and gas. Even a small amount of carbon monoxide, if inhaled, can cause headaches, dizziness, nausea, and fatigue after being absorbed in bloodstream. Higher concentrations of CO in bloodstream can cause permanent damage to brain and even death. Common indoor sources of CO include liquid fuel-burning appliances such as cooking stoves and furnaces; fireplaces; and portable generators and internal combustion engines used indoors. Proper maintenance of these appliances and making sure that they have adequate venting will prevent the build-up of CO [12].

Given the adverse and harmful effects of CO on human health, installation of CO detectors in indoor environment is essential to inform the occupants of raising CO levels. To mitigate the levels of CO, developed countries have devised strict regulatory standards such as in the United States, the Environmental Protection Agency (EPA) has made it compulsory that the CO levels in an indoor environment shall not exceed 9 PPM over an eight-hour period. Moreover, Occupational Safety has set safety limits of CO to be 50 PPM over an eight-hour period. The risks to health related to CO can be reduced by the adoption of different controlling measures such as proper ventilation, frequent servicing of fuel-burning appliances, and installation of Carbon Monoxide detectors. This would ensure safe indoor environments, as this injurious pollutant will be at reduced levels indoors, and thus human health is protected from the damaging effects.

C. Impact of Environmental Parameters on Indoor Air Quality

Indoor air quality is also prone to environmental variables such as temperature, humidity, and airflow. Increased temperature can enhance the flow of air which helps in removing indoor pollutants. However, high temperatures may also raise the levels of pollution through increased rate of evaporation, especially when the pollutant source is situated indoors. Humidity levels also play a vital role in indoor air quality. High levels of humidity cause pollutants to clump together and thus form larger particles that settle easily. In contrast to this, lower levels of humidity help pollutants to remain airborne for extended durations consequently enhancing their adverse effects on indoor air.

Proper ventilation is essential in preventing accumulation of air pollutants indoors through effectively introducing fresh air. Insufficient ventilation systems, when not properly sized for the building, may trap pollutants indoors and pose health risks to occupants. Apart from poor building design, outdoor pollution gets inside the building which further worsens indoor air quality. Due to this reason, the need for monitoring and management of the environment is crucial. Therefore, installation of air quality monitoring devices that measure air pollutants and other important environmental variables like humidity, temperature, and air flow is of crucial importance to maintain safe indoor air quality.

D. Impact of Room Area on Air Quality

The size of the room is also very crucial when it comes to evaluating the quality of indoor air. Ventilation in small rooms need not be as great, since any pollutant introduced builds up more rapidly in the air of a smaller space. On the other hand, the air flow in rooms with larger sizes should be higher to maintain a safe indoor environment by keeping the levels of pollutants low [13].

Additionally, the quality of indoor air also depends upon the number of people or occupancy in a room. Higher occupant numbers in smaller rooms can raise the potential for increased concentrations of carbon dioxide and airborne contaminants. Besides, the internal area of a room could also determine the various types and quantities of indoor air pollutants. This can be thought of as a smaller room having a stove that operates on fossil fuels would have higher concentrations of air pollutants compared to the same size stove in a larger room.

It is important to take the size of the room into account while developing techniques for improving the quality of indoor air. Proper ventilation, air filtration, and minimizing the source of pollutants may be an ideal attempt to improve indoor air quality, considering various room sizes. Such strategies and techniques can help mitigate the amount of pollutant in a room and improve the quality of air, therefore creating a healthy environment for the occupants.

E. Data Acquisition

The technique utilized for analyzing air quality in an indoor environment involves data gathering and monitoring and measuring the levels of air contaminants such as carbon monoxide (CO) and particulate matter (PM). This process is commonly referred to as the study design, which was observational. The observational study does not involve the researchers to intervene or manipulate variables purposefully, but rather independent conditions and phenomena in their natural occurrences are viewed and measured.

Therefore, this study also does not include any alteration of environmental parameters or purposefully introducing contaminants into the environment. Therefore, the study was conducted by measuring and recording the levels of air pollutants in rooms with varying sizes and environ- mental conditions. Through the adoption of this observational design, realistic indoor air quality exposure without interfering with variables being measured was captured.

The conducted observational study helps in providing in depth analysis and understating of the real-world scenarios by providing the details about how these factors influence environment and contribute to the higher levels of pollutants indoors. This methodology ensures that results obtained are based on real observations and the factors influencing indoor air quality in different settings are better understood [14].

IV. RESULTS AND ANALYSIS

Temperature, humidity, air flow, and room size were chosen as critical variables for indoor air pollution in the proposed case study of educational building. The is because these variables are most likely to affect air quality significantly but can be controlled though different modifications and settings. Measuring these variables include placing several environment sensors together with other kinds of equipment around the building.

To measure temperature and humidity, digital thermometers and hygrometers were placed appropriately in rooms where the air quality was to be analyzed. To measure the air flow , anemometer was used which was able to measure both the speed and direction of air. The contaminants analyzed in the proposed study included carbon monoxide and particulate matter of various sizes.

The levels of particulate matter in a good and healthy indoor environment can vary depending upon various factors. As per the standards, particulate matter of size 0.5 um should be kept as low as possible i.e., around 25 μg/m³ due to its ability to remain airborne for extended durations and penetrate deep into the respiratory system. Similarly, particulate matter of size 1.0 um should also be ideally below 25 μg/m³ due to the same reason. On the other hand, particulate matter of size 2 um should be kept below 10 μg/m³ for good air quality indoors. Particulate matter of size 5 um and 10 um is comparatively larger in size however, it still poses harmful effects due to which it should be below 50 μg/m³ in accordance with the air quality standards.

The internationally acceptable levels of temperature and humidity for a comfortable indoor environment are 23 to 27 degree Celsius and 20 to 60 percent respectively. These values are considered standards and serve as benchmarks for a comfortable and healthy indoor environment.

i. Measurements

To implement the described setup, various rooms throughout the building were chosen for the study. These rooms included classrooms, libraries, laboratories, washrooms, offices, and halls. Selection was based on their typical occupancy patterns and accessibility, ensuring a representative sample across different functions within the building. Additionally, consideration was given to the building’s floors, as different levels might provide valuable insights into pollutant distribution and levels.

Specific rooms on the ground, first, and second floors were selected as follows:

1. Ground Floor: Auditorium, Administration Block, Cafeteria, Washrooms
2. First Floor: Thermal Characterization Lab, Fuel Combustion Lab, Photo Voltaic Lab, Energy Audit Lab, Material Characterization Lab, Energy Storage & Combustion Lab, Classrooms, Washrooms, Faculty Offices, Director’s Office
3. Second Floor: Library, Simulation Lab, Power System Lab, Faculty Offices, Student Area

Each of these rooms was equipped with sensors for humidity, temperature, and air flow. Additionally, Carbon Monoxide (CO) [15] gas detectors and particulate matter monitors were installed to monitor and record pollutants within each room. Data from these sensors were collected at multiple time points and averaged to ensure accuracy. The data collected were tabulated for a proper analysis with a view to obtaining constructive conclusions regarding the air quality and the levels of pollutants. The measurements of room area were also taken into the analysis to understand their influence on air pollution dynamics [16].

To analyze the recorded data, various scenarios were considered. The primary analysis focused on detecting particulate matter (PM) of sizes ranging from 0.5μm to 10μm. The scenarios were based on three variables: room area, room temperature, and room humidity. Initially, each of these parameters was plotted individually, as shown in Figures 4, 5 and 6 respectively.

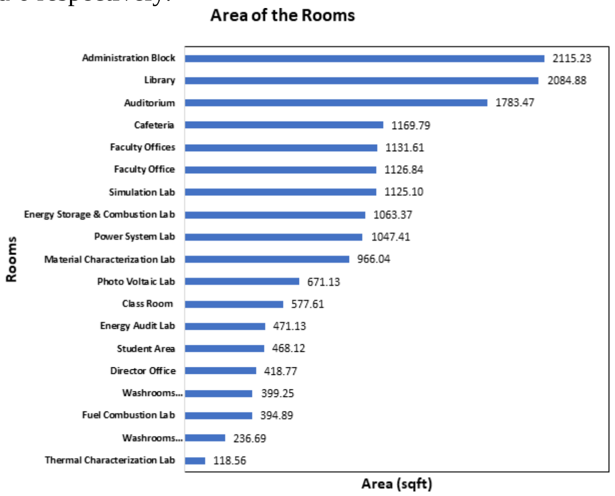

Fig. 4. Area of the rooms

Initially, the area of the rooms was analyzed in relation to the presence of particulate matter (PM). The smallest area measured was the thermal characterization lab, while the largest was the administration block. With room sizes ranging from 118.56 sqft to 2115.23 sqft, the relationship between room size and air pollutant levels can provide crucial information for implementing measures to mitigate indoor air pollution.

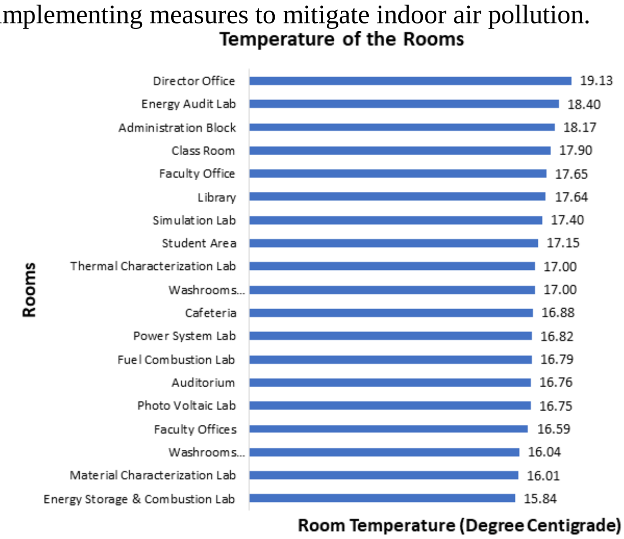

Fig. 5. Temperature of the rooms

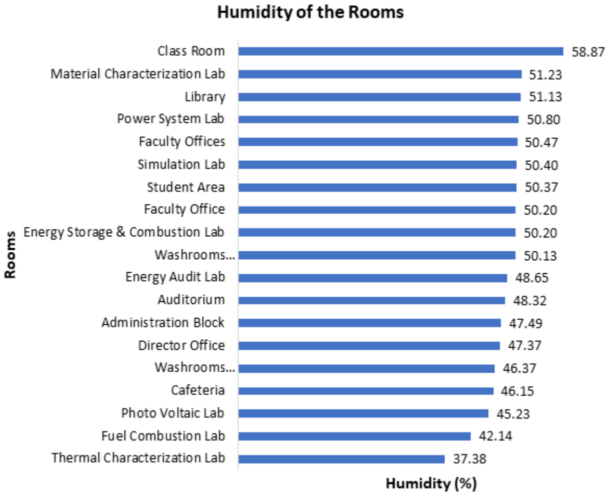

Fig. 6. Humidity of the rooms

For PM 0.5, it was observed that room size did not significantly impact the concentration of this pollutant. Variations in PM 0.5 concentration could be due to other factors such as occupancy, ventilation, and the types of equipment and items in the room, which were not considered in this study. The chart comparing room area with PM 1.0 concentration is shown in Figure 7.

The graph indicates a slight increase in PM 1.0 concentration with larger room sizes. The concentration of PM 1.0 is lower than that of PM 0.5 due to its larger size, but its dependency on room size increases slightly.

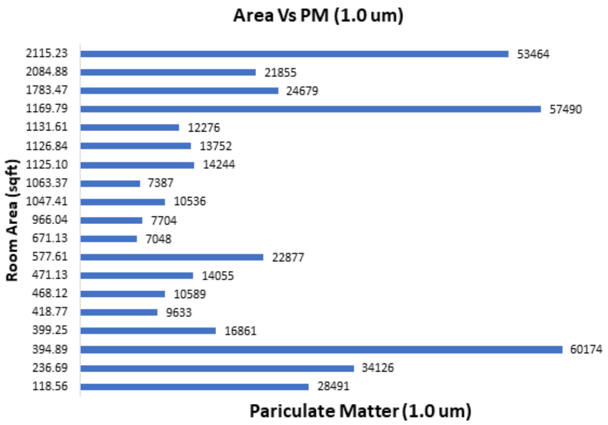

Fig. 7. Area of the Rooms Vs PM 1.0

For particulate matter of size 2.0 micrometers, the analysis revealed a slight increase in concentration with room size, more pronounced than for PM 0.5 and PM 1.0. Although PM 2.0 concentration is lower than PM 0.5 and PM 1.0, its dependency on room size is higher, as depicted in the graph.

Compared to PM 0.5, 1.0, and 2.0, coarser particulate matter is larger and tends to settle out of the air more quickly. Despite their size, these particles can still be inhaled deeply into the lungs, posing health risks. As particulate matter size increases, its concentration generally decreases. For instance, PM 10 concentration is significantly lower than smaller PM sizes, as shown in Figure 8.

In larger rooms, the greater air volume helps dilute and disperse PM 10 particles, leading to lower concentrations. Conversely, in smaller rooms, less air volume results in higher PM 10 concentrations. However, if pollutant sources are present inside the building, higher concentra- tions may occur even in larger areas [17].

Similar to the area, the temperature of these 19 rooms was recorded during the air pollutant monitoring. Figure 5 depicts the recorded temperatures, with three readings taken at different times and then averaged for accurate data acquisition and analysis. The average temperature values for each room are presented in ascending order, ranging from 15.84 to 19.3 degrees Celsius.

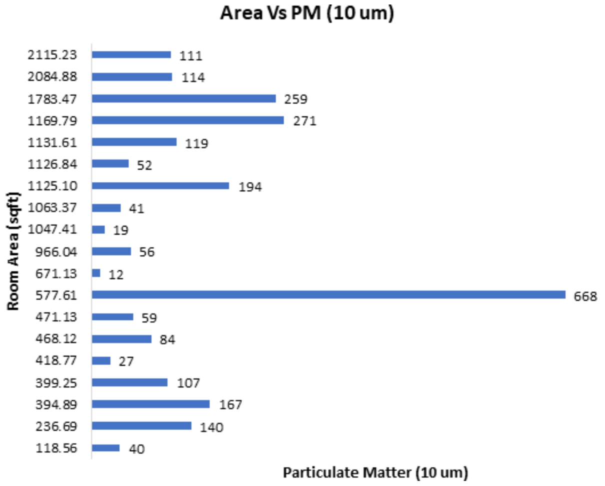

Fig. 8. Area of the Rooms Vs PM 10

Higher temperatures can increase the rate of chemical reactions, leading to the formation of new particulate matter. For PM 0.5 µm, the highest concentration was recorded in the cafeteria, likely due to the presence of various items and the number of people. However, temperature dependence is not prominent in this case, as PM concentrations vary across rooms without a clear temperature impact.

Similarly, PM 1.0 µm concentrations do not significantly depend on room temperatures, although there is a slight increase in PM concentration with rising temperatures. The highest concentrations of PM 1.0 µm were in the same rooms as PM 0.5 µm, particularly in the cafeteria.

For PM 2.0 µm, the concentration pattern is similar to that of PM 1.0 µm, with the highest levels again recorded in the cafeteria at 16.79 degrees Celsius. PM 5.0 µm showed the highest concentration in the simulation lab at 17.40 degrees Celsius, as shown in Figure 9.

The highest concentration of PM 10 µm was recorded in a classroom with 30 students at a temperature of 17.90 degrees Celsius, as shown in Figure 10. Most other rooms had nominal PM 10 µm values, but the classroom's concentration was significantly higher. This elevated concentration is likely due to the presence of the students rather than just the temperature.

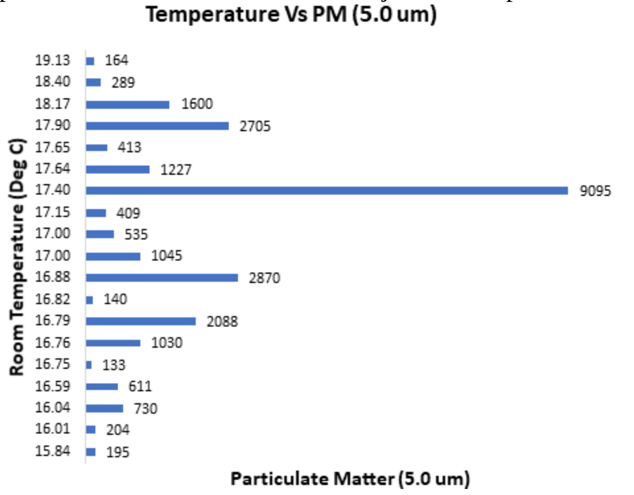

Fig. 9. Temperature of the Rooms VS PM 5.0

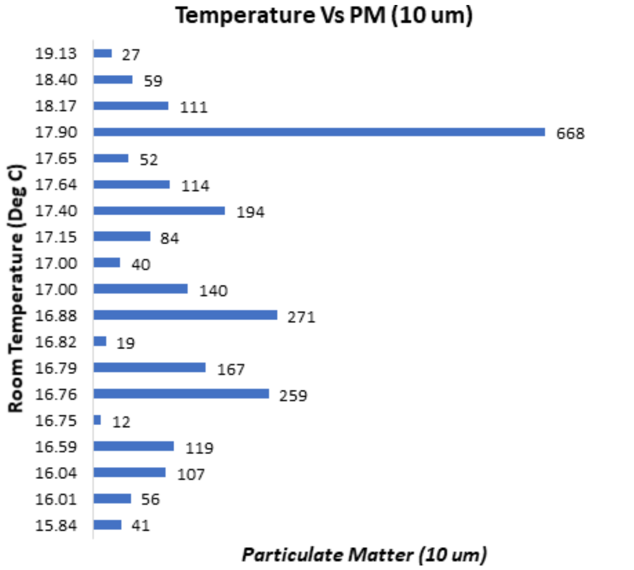

Fig. 10. Temperature of the Rooms VS PM 10

The concentration of particulate matter in an indoor environment can be significantly in- fluenced by humidity. When the air is dry, particulate matter remains suspended more easily, increasing its concentration. Fine particles smaller than 2.5 micrometers are especially prone to staying suspended in dry air and can travel longer distances. Therefore, comparing PM concentration levels to humidity in different rooms is essential. The recorded humidity levels in each room are shown in Figure 6.

For PM 0.5 µm, the cafeteria recorded the highest concentration at 48.15% humidity, while the Director's office had the lowest concentration at 47.37%. This contrasts with expectations from literature, where pollution concentrations typically rise with humidity. From the data, it appears other environmental factors had a greater influence on PM 0.5 levels.

Similarly, PM 1.0 concentrations showed consistent levels across locations. The fuel combus- tion lab recorded the highest concentration, whereas the photovoltaic lab had the lowest, with humidity levels almost identical at 42.14% and 45.23%, respectively.

For PM 2.0, concentrations appeared to decrease with increasing humidity, mirroring trends seen with PM 1.0. The highest and lowest concentrations were again observed in the fuel combustion lab and photovoltaic lab.

Moving to PM 5.0 µm and 10 µm, concentrations notably increased in some rooms. Figure 11 and 12 illustrate that for both particle sizes, pollutant levels rose with humidity. The increase was more pronounced for PM 10 µm compared to PM 5.0 µm. Specifically, PM 5.0 µm showed higher concentrations in the simulation lab, which was approximately 8% less humid than the most humid room in the building.

Similar trends were observed when analyzing PM 10 concentrations, depicted in Figure 4.17. Like PM 5.0 µm, PM 10 µm also exhibited an increase with rising humidity levels. Notably, the highest concentration of PM 10 µm was recorded in the classroom, which coincided with being the most humid room according to the acquired data.

ii. Comparison with Old Building

To compare the results of the current study, an older building, Jamrud College, was selected. This building is notably older than the USPCAS-E building. Rooms in Jamrud College were chosen based on their dimensions, aiming for similarity to rooms in the newer building [18]. Thus, Two rooms on the ground floor and two on the first floor were selected for analysis.

For a direct comparison of indoor air quality between the two buildings, identical sensors and monitors were used in both studies. These included temperature, humidity, air flow sensors, and particulate matter monitors ranging from 0.5 µm to 10 µm. Table 1 presents the sensor data collected from each room in Jamrud College alongside data from corresponding rooms in the new building selected for this comparative study. It is important to note that all PM measurements are reported in particles per cubic meter.

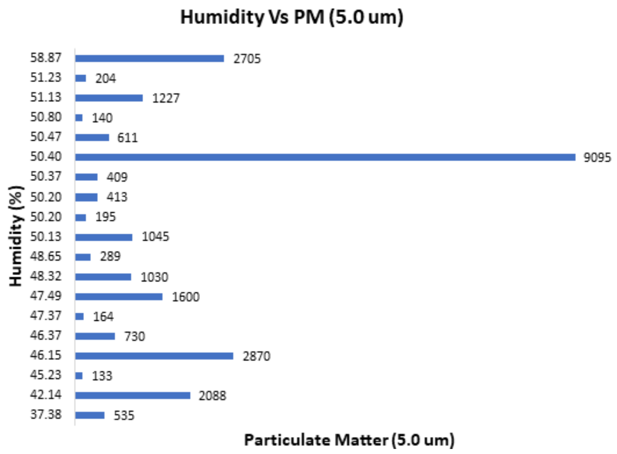

Fig. 11. Humidity of Rooms VS PM 5.0

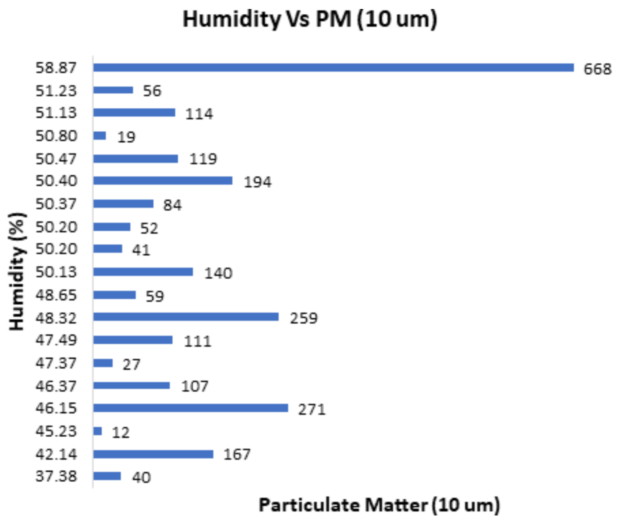

Fig. 12. Humidity of Rooms VS PM 10

Table I

Parameters and PM Concentrarions of Old and New Building

	Halls	Area (sqft)	Temp (C)	Humidity (%)	PM 0.5(µm)	PM 1.0(µm)	PM 2.0 (µm)	PM 5.0(µm)	PM 10(µm)
Old Building	Hall 1	1682.25	33.52	74.61	295715	41389	6730	1693	490
Old Building	Hall 2	914.48	34.94	75.55	144111	19036	2784	784	294
Old Building	Hall 3	634.58	35.19	77.65	117322	18417	2427	605	265
Old Building	Hall 4	502.22	37.21	81.26	105924	16673	4348	470	169
New Building	Auditorium	1783.47	16.76	48.32	264524	24679	5677	1030	259

New Building	Material Characterization Lab	966.04	16.01	51.23	116791	7704	1411	204	56
New Building	Photovoltaic Lab	671.125	16.75	45.23	97724	7048	1192	133	12
New Building	Energy Audit Lab	471.13	18.4	48.65	100663	14055	3308	289	59

Initially, temperature and humidity levels were compared. Figure 13 illustrates that despite the selected rooms in the new building being larger than those in the older building, the temperature in all rooms of the older building is consistently higher than in the new building. Additionally, the chart shows that as room size increases, the temperature difference between rooms decreases.

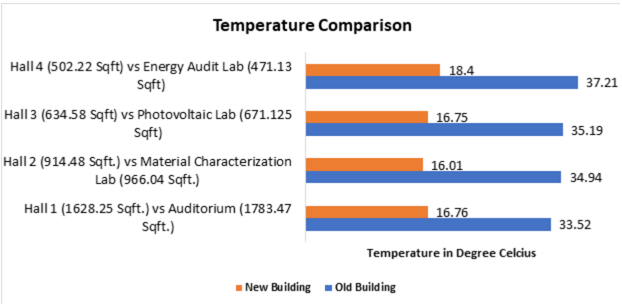

Fig. 13. Temperature comparison of new and old building

Regarding humidity, rooms in the older building exhibit higher humidity levels compared to the new building. Data indicates a decreasing trend in humidity levels as room size increases within the old building. In contrast, room size does not significantly influence humidity levels in the new building. Generally, humidity levels are primarily influenced by temperature and ventilation rather than room size alone. However, building materials and structure play a crucial role; materials vary in their moisture absorption and release capabilities. Factors such as material permeability, insulation, vapor barriers, ventilation systems, sealing effectiveness, and building foundation integrity all contribute to humidity dynamics. Over time, building materials degrade, potentially reducing their ability to manage moisture, thereby contributing to higher humidity levels in older buildings compared to newer constructions. Figure 14 illustrates the humidity comparison between the old and new buildings [19].

When comparing particulate matter concentrations between the buildings, PM 1.0 showed a slightly greater difference than PM 0.5, indicating building materials significantly influence PM levels. This results in higher pollutant levels in the old building compared to the new one. In specific areas like hall 4 and the energy audit lab, differences in pollutant levels are less pronounced, likely influenced by factors such as occupancy, materials present, item placement, and ventilation. Overall, the old building exhibits higher susceptibility to PM 1.0 pollutants. Figures 15 and 16 illustrate PM 0.5 and PM 1.0 concentrations in both buildings, respectively.

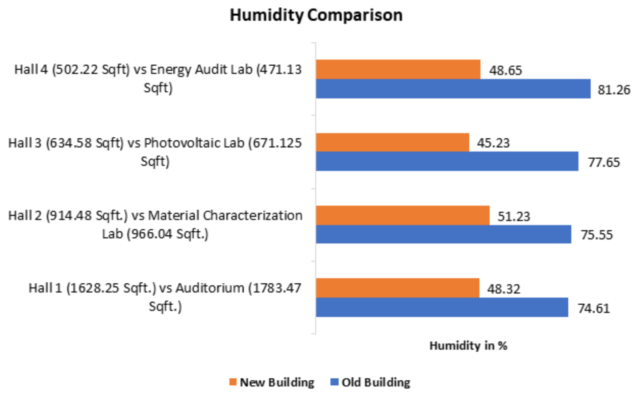

Fig. 14. Humidity comparison of new and old building

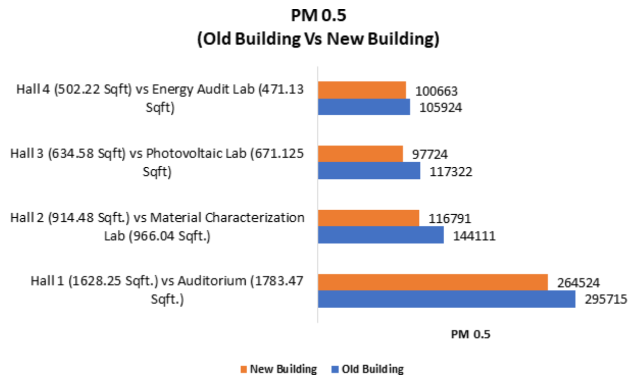

Fig. 15. PM 0.5 Comparison of new and old building

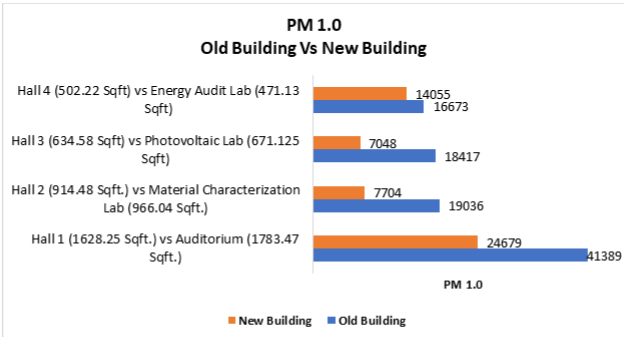

Fig. 16. PM 1.0 Comparison of new and old building

This comparison highlights that besides building materials, other factors significantly influence indoor air quality. For PM 2.0, concentrations are similar to those observed for PM 1.0. In

Hall 1 and the auditorium, PM 2.0 levels are higher in the old building, with a smaller difference compared to other rooms and halls. Hall 2 and Hall 3 show slight differences, while Hall 4 follows a similar pattern as seen in previous data. Factors such as occupancy, ventilation, and other variables likely contribute to these variations, as shown in Figure 17. PM 2.0 concentrations increase more noticeably with room size in the old building compared to the new one, where the increase is slower. However, these factors appear to have a greater impact when buildings have older structures and materials [20].

For PM 5.0, there is a significant increase in pollutant concentration between the old and new buildings. In the first three halls, PM 5.0 levels are notably higher in the old building compared to the new one, with noticeable differences across these halls except for Hall 4, which is compared with the energy audit lab. Unlike PM 1.0 and 2.0, where Hall 4 showed a closer match, PM 5.0 exhibits less influence from other indoor air quality factors. Figure 18 illustrates that PM 5.0 concentrations increase more rapidly in the old building compared to the new one. This increase becomes more pronounced with larger particle sizes, as depicted in the figure, highlighting a widening gap in pollutant concentrations between the two buildings.

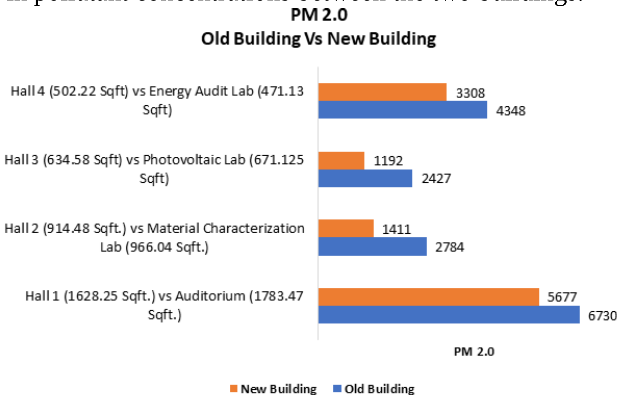

Fig. 17. PM 2.0 Comparison of new and old building

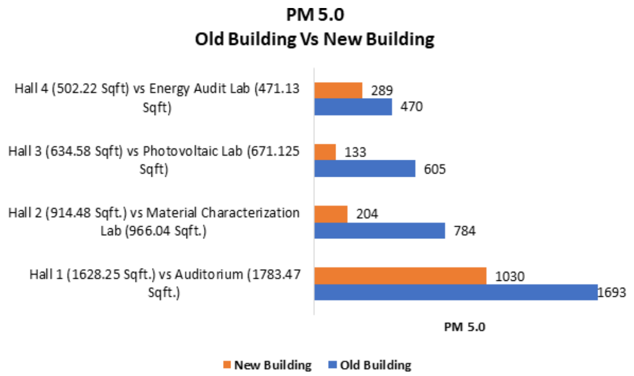

Fig. 18. PM 5.0 Comparison of old and new building

For PM 10, as depicted in Figure 19, there is a significant increase in concentration dif- ference between the new and old buildings. The new building shows markedly lower PM 10 concentrations compared to the old building. This increase in PM size also affects Hall 4, which previously showed lower pollutant levels. In the current graph, PM 10 concentrations in the old building are notably higher than those in the new building, with a clear and prominent difference between them. This observation underscores that as particulate matter size increases, assuming other factors remain constant, pollutant concentrations rise. However, factors such as occupancy, pollutant sources, and ventilation appear to have a greater influence on indoor air quality than building materials and structure.

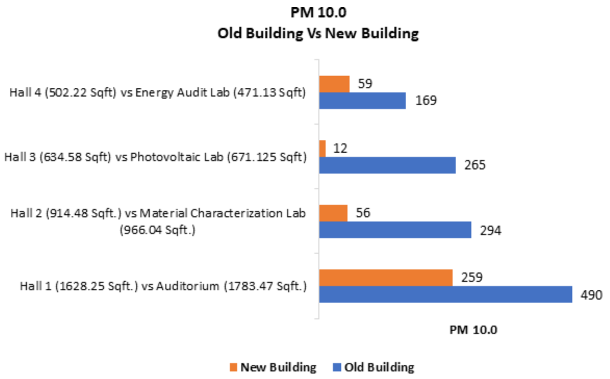

Fig. 19. PM 10 comparison of new and old building

CONCLUSION

This In this study, the indoor air quality (IAQ) of an educational building was analyzed to understand the factors influencing IAQ and to take necessary measures to avoid health issues for the building occupants. Poor IAQ can lead to respiratory problems, allergies, headaches, and other health issues that can affect academic performance and attendance. By conducting an IAQ analysis, it is possible to ensure compliance with local and federal regulations, avoiding potential legal and financial issues, while also identifying energy efficiency opportunities that improve ventilation and reduce energy consumption.

In this research, UET Peshawar, UPSCAS-E was selected as the building under study. The measurements were done in 19 different rooms which were situated on the ground, first, and second floors for temperature, humidity, air flow intensity. To monitor the levels of particulate matter and CO, particulate matter monitors and gas analyzers were used to measure their concentration and size. To analyze the data, MS Excel was used to plot particulate matter concentrations against various environmental variables including temperature, humidity, airflow intensity, and room size.

The study conducted and the analysis carried out suggest that size of the room, temperature, humidity and intensity of air flow are the significant factors which play prominent role in influencing the concentrations of particulate matter to varying extents. The concentration of small particulate matter varying from PM 0.5 to 2 micrometers, was slightly dependent on room size, while the larger ones were more dependent on room size.

Temperature was unimportant for PM 0.5 but affected larger sizes of particles; at higher temperatures causing an increase in concentration levels. Higher humidity levels tend to reduce the concentration levels of small- sized particulate matter but increased the levels of the big ones. The intensities of air flow followed the same trend as humidity: where concentrations decreased for the smaller particles, increasing thereafter for the larger ones. The study suggested that the concentration of particulate matter in indoor environment is a function of environmental parameters and the structure of the room wherein the small particulate behaves the same whereas the larger particles show different behaviors reliant upon the environment.

In particular, there is susceptibility to indoor air pollution in educational buildings, healthcare centers, and other places that involve a high level of occupancy over a long period. Such studies can help identify and mitigate the potential pollutants. For this reason, indoor air quality standards needs to be discussed and established and policies shall be developed to ensure safe and healthy indoor environment.

This study and similar research efforts contribute to understanding and improving indoor air quality, emphasizing the need for comprehensive monitoring and proactive measures to ensure healthier environments in high-occupancy buildings.

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