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Assessing Air Quality at HBCU Engineering Laboratories to Enhance Student Safety and Learning

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Assessing Air Quality at HBCUs Engineering Laboratories to Enhance Student Safety and Learning.

Abstract

Frequent monitoring of air quality in engineering laboratories is crucial for enhancing student safety and learning outcomes. Poor indoor air quality (IAQ) can lead to various health issues, including respiratory problems and decreased cognitive function, which directly impact students' ability to concentrate and perform academically. The lack of air quality monitoring in engineering laboratories often expose students to hazardous air pollutants, which can undermine safety, concentration, and overall learning experience. This paper presents a comprehensive assessment and awareness of air quality in engineering laboratories at an HBCU.

This study, grounded in Environmental Health and Safety (EHS) theory, employs a quantitative approach to assess air quality and student awareness in engineering laboratories. Air quality monitoring will be conducted twice every 10 days, using a portable gas analyzer to measure PM_{10}, $PM_{2.5}$, PM_1, and volatile organic compounds. Measurements will be taken twice per session: before laboratory use and during student operations, with each session following a 4-hour sampling period. Data samples will be compared to OSHA standards exposure limits. A survey will also gauge students' awareness of environmental issues, while the analysis will guide recommendations for improving air quality and enhancing safety in the laboratories.

The results from the study will generate actionable data on air quality, which will not only enhance laboratory safety but also provide students with insights in frequent environmental monitoring. This study will contribute to creating a healthier and more conducive learning environment for engineering students at HBCUs. Moreover, it provides valuable insights for other academic institutions seeking to prioritize student health and wellbeing.

Keywords: Air Quality Monitoring, Engineering Education, Student Safety, Sustainability, Health Hazards

Introduction

The role of engineering education in cultivating a robust technological workforce is increasingly acknowledged as essential for addressing societal and industrial challenges. One of the foundational elements of engineering education is providing a safe and effective learning environment, which is of paramount importance, especially in laboratory settings where hazardous substances may be present [22]. Underfunded Historically Black Colleges and Universities (HBCUs) play a critical role in developing a diverse and representative engineering workforce [14]. Despite their importance, many HBCUs face resource limitations, which can inadvertently affect infrastructure quality, including laboratory environments. Consequently, ensuring air quality within these engineering laboratories becomes an imperative measure to enhance student safety, well-being, and educational outcomes [4].

Air quality in engineering laboratories is a crucial factor that impacts both student health and the overall learning experience. Exposure to contaminants such as volatile organic compounds (VOCs), particulate matter, and chemical fumes can have significant short- and long-term health effects [10]. Suboptimal air quality is particularly concerning in an academic setting where prolonged exposure may lead to respiratory issues, cognitive impairments, or chronic illnesses, ultimately hindering students' academic performance and participation [18]. The relationship between a healthy environment and effective learning cannot be overstated; poor indoor air quality has been linked to reduced concentration, fatigue, and diminished cognitive abilities, which may disproportionately impact the student body at HBCUs, who often already face multiple systemic barriers [18].

The primary objective of this study is to assess the air quality in HBCUs engineering laboratories, identify critical pollutants, and provide recommendations to enhance laboratory safety and learning environments. It is hypothesized that suboptimal air quality in HBCU engineering laboratories negatively impacts student health and learning outcomes, and that targeted interventions can significantly improve both safety and educational experiences. This paper addresses these challenges by assessing the current state of air quality within engineering laboratories at an HBCU. By utilizing a combination of real-time monitoring and sampling, the research identifies critical areas of concern and provides data-driven recommendations to enhance safety protocols and infrastructure improvements [19]. Previous researches have stated the need for increased scrutiny of environmental health in educational facilities, particularly those that serve underrepresented groups in STEM fields [7]. Through this research, we traverse the gap between resource availability and optimal safety standards, thereby ensuring that the students can engage fully in their learning experience without compromising their health [7].

The theoretical framework of this study is the PROGRESS framework utilized by [14] as a guide to selecting relevant indicators for assessing health inequalities, focusing on multidimensional measures of socio-economic status, ethnicity, deprivation, employment, religion, education, and social capital [20]. This framework is particularly relevant in understanding the systemic inequities that affect minority-serving institutions, such as HBCUs, and the role of infrastructure quality in perpetuating or alleviating these disparities [6]. Also, the Environmental Health and Safety (EHS) theory, which supports this study showcases the importance of maintaining safe environments in educational and professional settings to cultivate well-being and productivity [23]. The EHS theory provides a structured approach to identifying hazards, assessing risks, and implementing control measures to mitigate those risks [9].

The overarching objective of this work is not only to identify feasible safety risks but also to nurture an environment conducive to learning, creativity, and innovation. Frequent air quality monitoring and hazard mitigation measures are the critical recommendations proposed because of this study [9]. By implementing these improvements, HBCUs can continue to cultivate an inclusive, supportive, and secure educational setting that empowers their students to excel in engineering disciplines [30]. As such, this work contributes to both the health and safety in engineering education, aligning with broader institutional goals.

This research outlines a systematic approach to assessing air quality and presents a case for the direct impact that laboratory environments have on the academic trajectory of engineering students. By centering the experiences of HBCU students, this work underscores the importance of frequently monitored learning environments and offers a roadmap for other institutions facing similar challenges. The results of this study have far reaching implications for policy-makers, educators, and facility managers, particularly in addressing systemic disparities within the engineering education ecosystem [15]. In doing so, this research serves as a catalyst for ongoing discussions on environmental justice, student safety, and the optimization of learning conditions within minority-serving institutions [20].

Indoor Air Pollutants in Engineering Laboratories

The indoor air quality (IAQ) of engineering laboratories can be affected by a variety of pollutants, including particulate matter (PM_1, $PM_{2.5}$ and PM_{10}), and volatile organic compounds (VOCs) [7]. PM_1, $PM_{2.5}$ and PM_{10} are small particles that can penetrate deep into the lungs, causing respiratory and cardiovascular issues [11]. Sulfur dioxide and nitrogen dioxide, typically produced during combustion processes, can exacerbate respiratory problems and contribute to the formation of secondary pollutants [24]. CO_2 levels are commonly used as an indicator of ventilation adequacy, while VOCs, emitted by laboratory materials and equipment, are associated with headaches, nausea, and other health issues [30].

Impacts of Poor IAQ on Cognition and Safety

Poor indoor air quality has been linked to both short-term and long-term health effects, which directly impact cognitive performance and safety. Existing research demonstrates that exposure to elevated levels of indoor pollutants, such as PM, CO_2, and VOCs, correlates with diminished cognitive function, slower reaction times, and decreased productivity [23]. In an educational context, these health impacts can translate into reduced academic performance, higher absenteeism, and lower engagement [18]. Laboratory settings pose unique risks due to the concentrated use of chemicals and potential for accidental releases, further underscoring the need for effective monitoring and mitigation strategies [2].

Several assessments of air quality in educational institutions have demonstrated the importance of monitoring IAQ to ensure a safe learning environment. For instance, a study conducted at a large university in California found that improved ventilation and regular monitoring of CO_2 and particulate levels led to significant reductions in student-reported symptoms such as headaches and fatigue [21]. Similar findings were reported in a study of high school science laboratories in New York, where the introduction of advanced ventilation systems and air quality sensors led to measurable improvements in both safety and student performance [1]. These case studies highlight the value of proactive air quality management in educational settings.

Despite the existing body of research on indoor air quality in educational settings, there is a notable gap in studies focusing specifically on engineering laboratories at HBCUs. Engineering laboratories often involve more hazardous materials and processes compared to general classrooms which increases the potential risks associated with poor air quality [20]. This research aims to provide a comprehensive assessment of air quality in HBCU engineering laboratories and proposing actionable recommendations to enhance student safety and learning outcomes.

Methodology

This research employed a qualitative research design to evaluate the awareness of air quality in engineering laboratories at an HBCU, as well as raise inquisitiveness in the engineering students. The study area included multiple engineering laboratories that are being used for student instruction and research. The air quality monitoring was conducted using the Atmotube Pro PERSONAL Air Quality Monitor to measure pollutants (PM_{10}, $PM_{2.5}$, PM_1, and VOCs) over a (10) working period. The Atmotube Pro PERSONAL Air Quality Monitor is manufactured with high quality sensors connected with Bluetooth to the phone for taking readings. The unit is calibrated prior to use and the monitor also regulates itself.

Figure 1: Atmotube Pro PERSONAL Air Quality Monitor and Mobile Interface Display

Source: [3]

Data samples were collected every 10 days, with measurements taken twice during each session: pre- and post- laboratory use, each following a 4-hour sampling period. Study participants included engineering students and laboratory staff, selected through a combination of inclusion and exclusion criteria. Participants who regularly used the laboratories and those willing to complete surveys on environmental awareness were included, while individuals with underlying respiratory conditions or those not using the laboratory frequently were excluded. The measured laboratory air quality values will be analyzed against Occupational Safety and Health Administration (OSHA) work exposure limits to identify any violations or concerns.

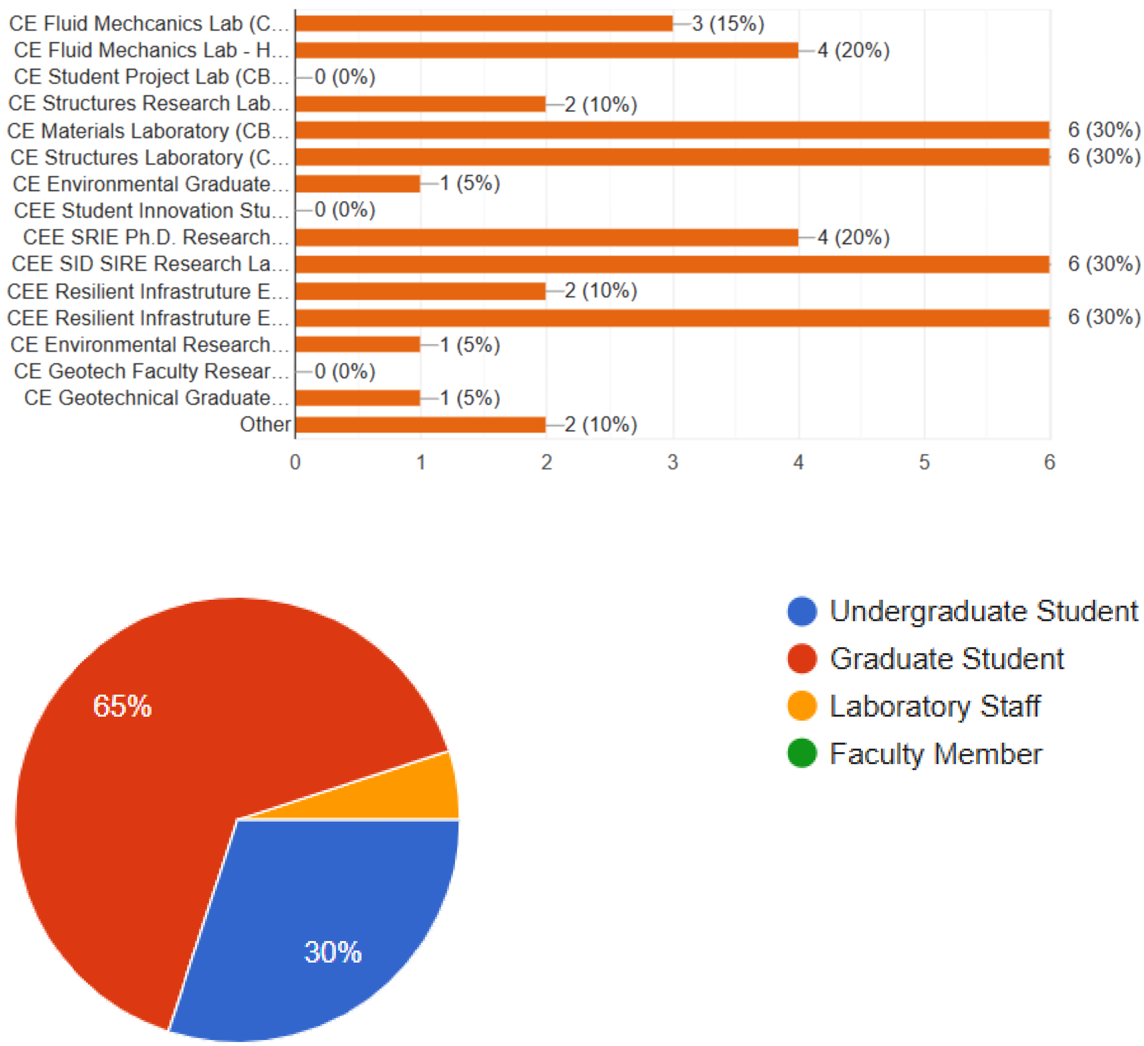

Figure 2: Participants who regularly used the laboratories

Results and Discussion

Results

Precise analysis of measurements of indoor air quality at the HBCU engineering laboratory rooms displays a trend and quite heavy variations on different rooms and time periods (Figure 3). During this analysis, data were collected on key parameters such as particulate matters (PM_1, $PM_{2.5}$, PM_{10}), and volatile organic compounds. The systematically recorded measurements were taken before and after working hours to capture environmental variability occurring over the period. The data were compared against the Occupational Safety and Health Administration Permissible Exposure Limits, while only PM_{10} had a specific PEL as shown in table 1.

Table 1: OSHA Standards PEL

Pollutant	**OSHA Standards (Regulatory) PEL** *8-hour Time-Weighted Average (TWA) Exposure*
PM 1 (≤1 μm)	ND, No Specific PEL
PM 2.5 (≤ 2.5 μm)	ND, No Specific PEL
PM 10 (≤ 10 μm)	5*μg/m³*
VOCs	No general limit for total VOCs; regulated by specific compounds **-Benzene:** 1ppm **-Formaldehyde:** 0.75ppm **-Acrolein:** 0.1ppm

Source: [16]

Legend:

μg/m³ - micrograms per cubic meter; ppm - parts per million

ND - Not Detected

OSHA PEL - Occupational Safety and Health Administration Permissible Exposure Limits

Most of the areas had relatively steady baselines during pre-working hours; PM_1 hovered around the audiovisual levels of 1.0-1.3 μg/m³; $PM_{2.5}$ varied between 1.7-2.9 μg/m³; the PM_{10} was initially stable around 2.8 and 3.9 μg/m³. The VOC levels were almost all the same at 0.01ppm across the various spaces which suggested minor initial indoor air pollution. A significant variation was witnessed in these values post-work readings. The largest difference was found in lab rooms 358 and 360, where VOC levels were raised to 0.09ppm. While the rest of the rooms showed a general increase in particulate matter concentration with a very significant increase in PM_{10} concentration, with lab 124 ranging from 3.9 to 10.1 µg/m³.

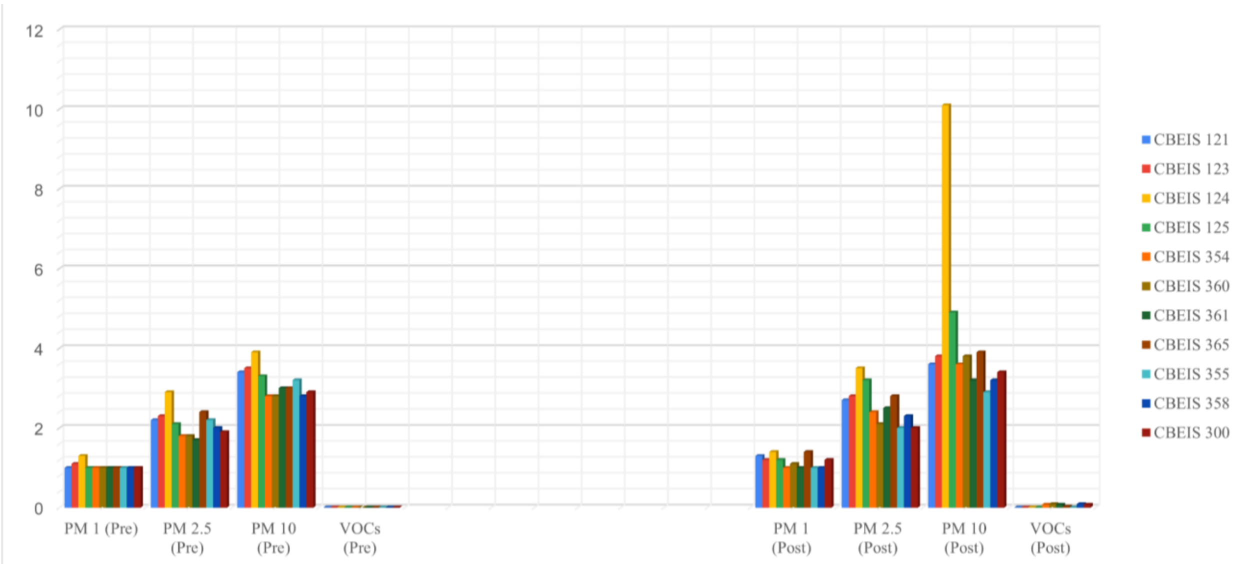

Figure 3: First Day reading of indoor air quality of a HBCU Engineering Laboratory

The second day of air quality monitoring at the HBCU engineering laboratory room presents an intriguing dataset that reveals notable variations and patterns across different rooms (Figure 4). The measurements continued to track particulate matter (PM_1, $PM_{2.5}$, and PM_{10}), volatile organic compounds (VOCs) throughout the facility. Initial pre-laboratory readings showed relatively stable conditions across most rooms, with PM_1 levels consistently around 1.0-1.2 µg/m³, and $PM_{2.5}$ readings ranging between 1.9-2.7 µg/m³. The baseline PM_{10} concentrations fell between 2.8-3.8 µg/m³, indicating generally good air quality at the start of the workday. A particularly significant observation emerged in 125, where initial VOC levels were elevated at 0.13ppm, notably higher than other rooms' baseline readings of 0.01-0.05ppm. This room later experienced a dramatic increase in particulate matter, with PM_1 rising from 1.2 to 5.8 µg/m³, $PM_{2.5}$ increasing from 2.7 to 14.9 µg/m³, and PM_{10} escalating from 3.8 to 25.2 µg/m³.

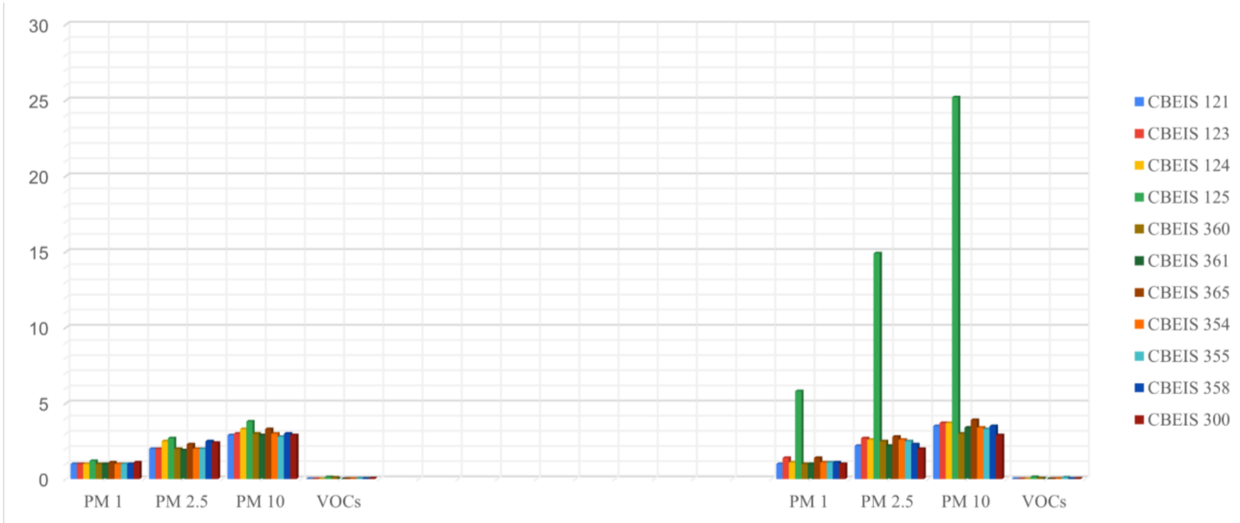

Figure 4: Second Day reading of indoor air quality of a HBCU Engineering Laboratory

The pre-laboratory use measurements in the third day showed relatively higher baseline VOC levels compared to previous days, with readings ranging from 0.01 to 0.11ppm, particularly notable in 360 (0.11) and 123 (0.10). Initial particulate matter measurements demonstrated consistency across rooms, with PM_1 levels ranging from 1.0-1.4 µg/m³, $PM_{2.5}$ between 1.6-2.8 µg/m³, and PM_{10} concentrations varying from 2.7-3.8 µg/m³. Post-work measurements revealed interesting shifts in air quality parameters. Laboratory room 300 showed the most significant increase in particulate matter, with PM_1 rising from 1.4 to 2.1 µg/m³, $PM_{2.5}$ increasing from 2.8 to 3.7 µg/m³, and PM_{10} reaching 4.6 µg/m³.

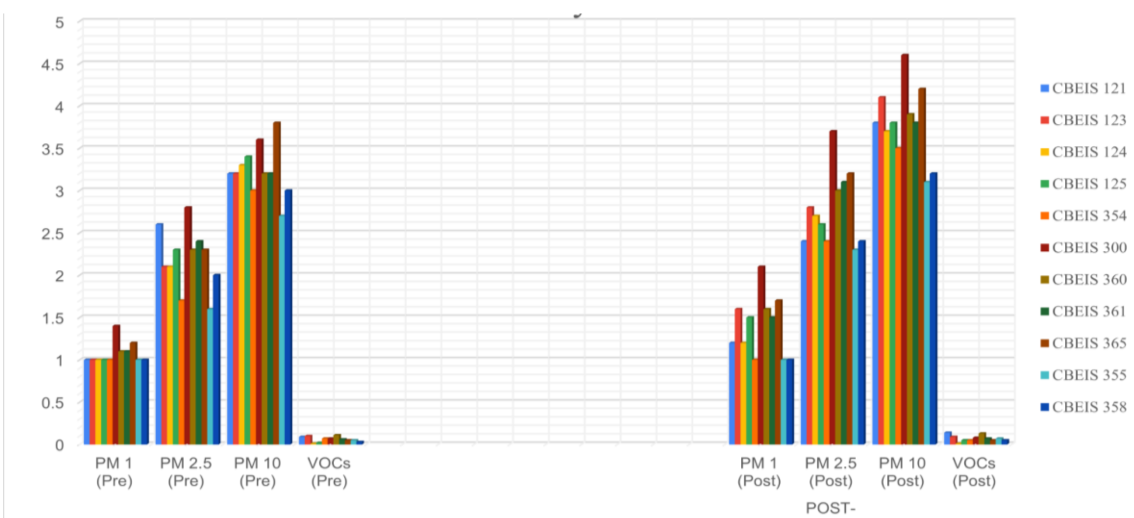

Figure 5: Third Day reading of indoor air quality of a HBCU Engineering Laboratory

The fourth day of indoor air quality monitoring at the HBCU engineering laboratory room presents an intriguing shift in baseline measurements and daily variations (Figure 6). Pre-laboratory readings showed notably lower initial particulate matter concentrations compared to previous days, with PM_1 levels consistently at 1.0 µg/m³ across all rooms, $PM_{2.5}$ ranging from 1.5-1.9 µg/m³, and PM_{10} levels between 2.5-3.0 µg/m³. VOC concentrations showed greater variation in pre-laboratory readings, with laboratory room 124 registering a notably high reading of 0.12ppm, while other rooms ranged from 0.01 to 0.10ppm. The post-work measurements revealed several significant changes. Laboratory room 365 showed the most dramatic increase in particulate matter, with $PM_{2.5}$ rising from 1.8 to 3.0 µg/m³ and PM_{10} increasing from 2.7 to 5.2 µg/m³. Additionally, its VOC levels doubled from 0.10 to 0.20ppm.

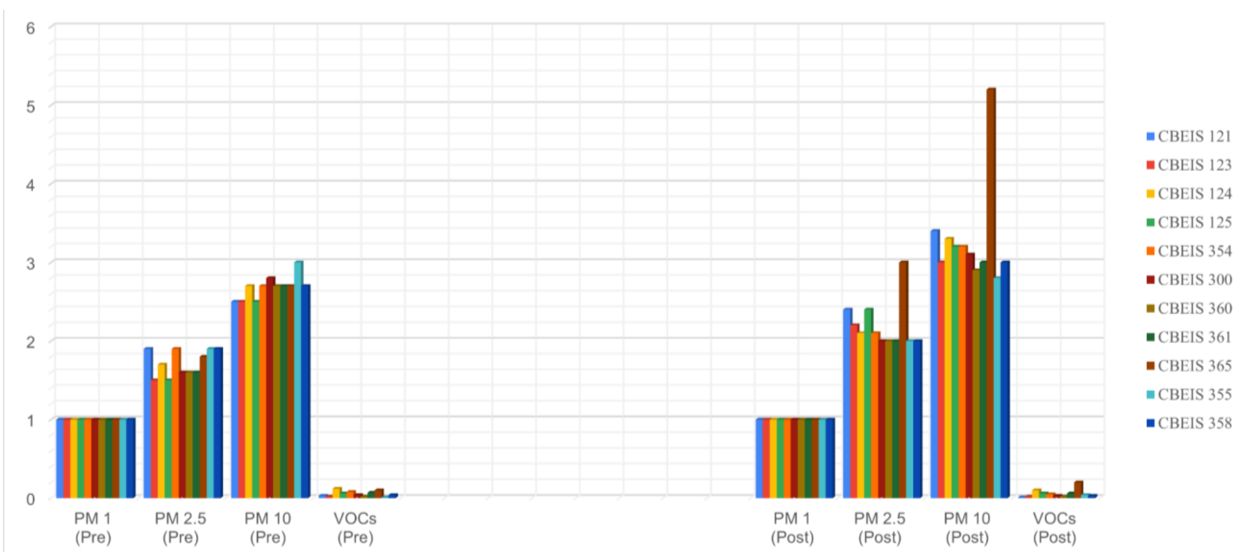

Figure 6: Fourth Day reading of indoor air quality of a HBCU Engineering Laboratory

The fifth day of indoor air quality monitoring at the laboratory room reveals notable stability in some parameters while showing interesting variations in others (Figure 7). Pre-laboratory measurements demonstrated remarkable consistency in PM_1 levels, with all rooms recording exactly 1.0 µg/m³. Initial $PM_{2.5}$ readings showed minimal variation, ranging from 1.3-1.5 µg/m³, while PM_{10} levels remained between 2.3-2.7 µg/m³. VOC concentrations showed more variation, with readings ranging from 0.0 to 0.08ppm, with laboratory room 358 showing the highest pre-laboratory VOC level. Post-laboratory measurements revealed several significant changes.

Multiple rooms, including laboratory room 123, 358, and 360, showed increases in $PM_{2.5}$ levels to 2.0 μg/m³ and PM_{10} levels to 3.0 μg/m³. Notable VOC variations occurred in laboratory room 358, where levels increased from 0.08 to 0.14ppm, and in lab room 300, which saw an increase from 0.03 to 0.11ppm.

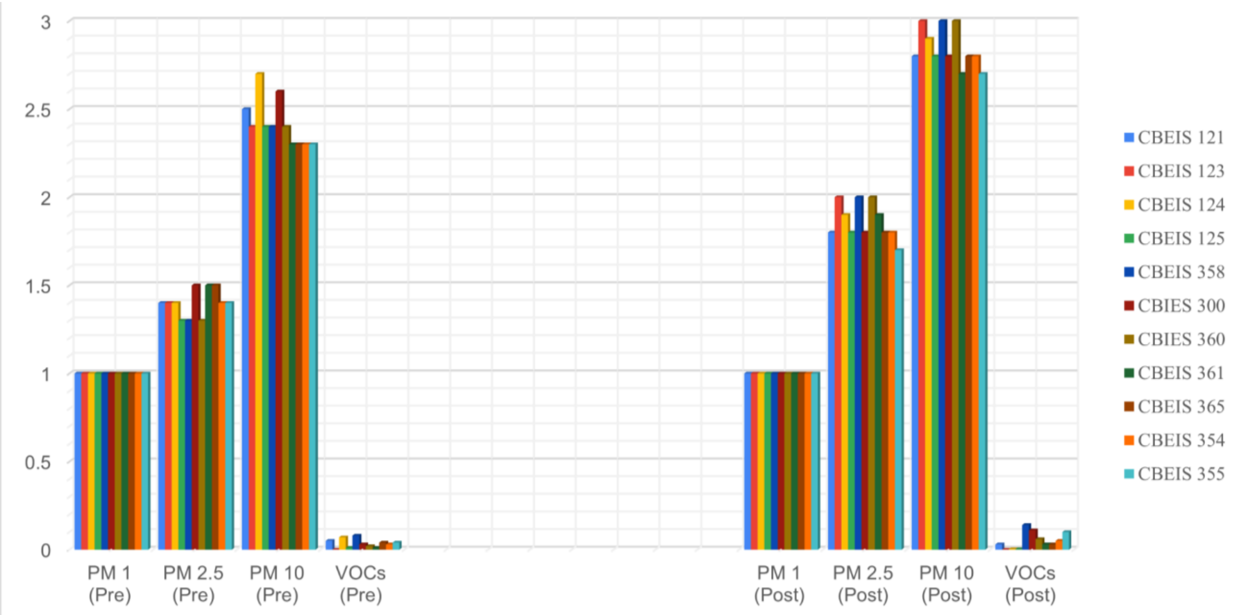

Figure 7: Fifth Day reading of indoor air quality of a HBCU Engineering Laboratory

The data presented in Figure 8 provides comprehensive measurements of indoor air quality parameters across multiple laboratory rooms. The measurements were taken at two different times - pre and post work hours - allowing for a comparative analysis of how occupancy and daily activities impact indoor environmental conditions. The parameters measured include particulate matter (PM) in three size ranges (PM_1, $PM_{2.5}$, and PM_{10}), and volatile organic compounds (VOCs). The results show notable variations between pre and post-work readings. PM levels generally increased across all size ranges after work hours, with $PM_{2.5}$ showing the most significant changes. For instance, in lab room 123, $PM_{2.5}$ levels increased from 3.3 to 5.1 μg/m³, indicating a potential accumulation of fine particles during operational hours. Interestingly, VOC levels generally decreased after work hours, with lab room 123 showing the most dramatic reduction from 0.89 to 0.14ppm. This counterintuitive finding might be attributed to the building's ventilation system effectively removing VOCs throughout the day.

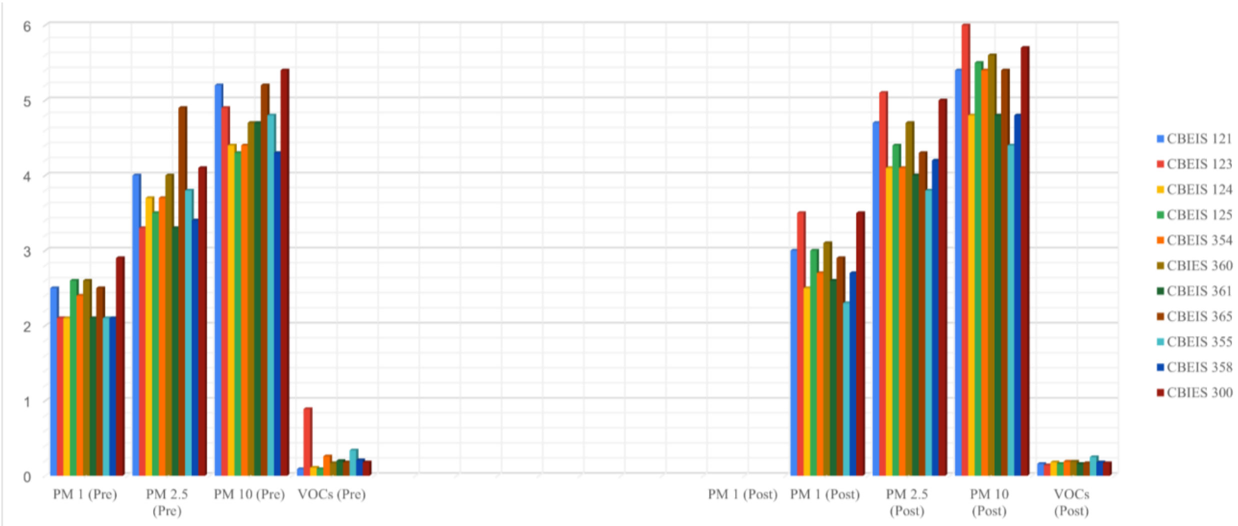

Figure 8: Sixth Day reading of indoor air quality of a HBCU Engineering Laboratory

The seventh day of indoor air quality monitoring at the HBCU Engineering laboratory room reveals significant patterns in environmental parameters across different rooms (Figure 9). The data shows notable variations between pre- and post-laboratory measurements, particularly in particulate matter concentrations. $PM_{2.5}$ levels demonstrated substantial increases throughout the day, with lab rooms 123, 124, and 125 showing the most dramatic changes. For instance, Lab room 125 saw $PM_{2.5}$ levels rise from 4.4 to 6.6μg/m³, suggesting considerable particulate accumulation during operational hours. VOC concentrations remained relatively stable throughout the day, with slight increases in some rooms, particularly lab rooms 354 and 355, where levels rose modestly from pre- and post-laboratory operations.

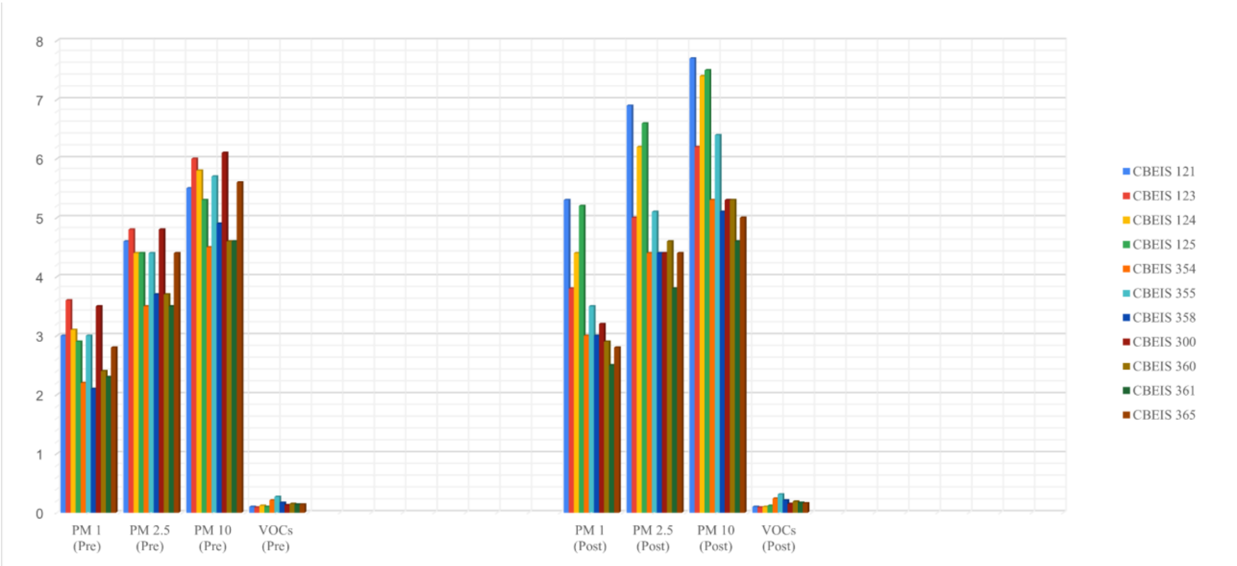

Figure 9: Seventh Day reading of indoor air quality of a HBCU Engineering Laboratory

Eighth day observation in the HBCU engineering laboratory rooms. Compared to the previous days, indoor air quality parameters indicate a totally distinct trend, as shown in Figure 10, with relatively lower levels of particulate matter. PM_1 concentration values remained stably consistent at 1 µg/m³ across all rooms both before occupancy and otherwise, indicative of effective filtration because it removes fine particles. $PM_{2.5}$ and PM_{10} levels differ as follows: 1.5 to 2.4 µg/m³ before occupancy and 1.8 to 2.4 µg/m³ after occupancy; the former had a greater range than the latter. There is a remarkable decline in VOC concentration from before to after measurements: particularly room 123-125 decreased significantly, around 60-70%.

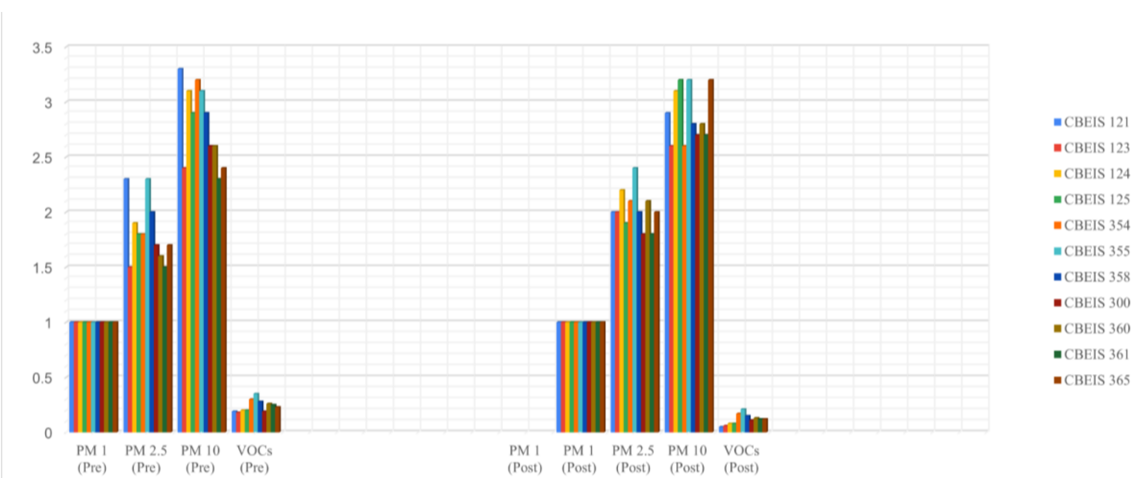

Figure 10: Eight Day reading of indoor air quality of a HBCU Engineering Laboratory

The ninth day of indoor air quality monitoring at HBCU engineering laboratory rooms presents some notable patterns distinct from previous measurements (Figure 11). These values are well below typical indoor comfort ranges. The particulate matter measurements show interesting variations, particularly in laboratory rooms 124 and 125, which experienced dramatic increases in PM levels after work hours. For instance, laboratory room 124 saw $PM_{2.5}$ levels surge from 2.1 to 5.8 μg/m³, and PM_{10} levels increased from 3.1 to 9.5 μg/m³. VOC concentrations were remarkably low throughout the building, with many rooms recording zero or near-zero readings after work hours, suggesting minimal indoor pollution sources.

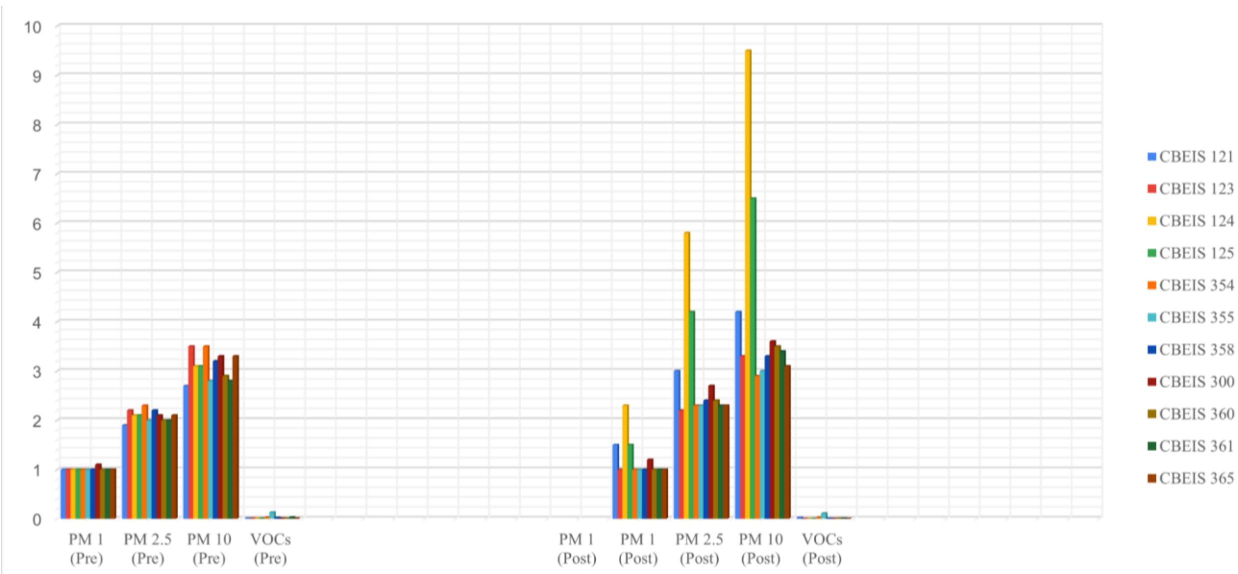

Figure 11: Ninth Day reading of indoor air quality of a HBCU Engineering Laboratory

The tenth day of monitoring at the HBCU engineering laboratory rooms reveals distinct environmental conditions characterized (Figure 12). Particulate matter concentrations showed moderate variations throughout the day, with $PM_{2.5}$ levels generally increasing slightly from pre- and post-laboratory measurements. Laboratory room 123 exhibited the highest PM concentrations, with $PM_{2.5}$ levels rising from 3.5 to 4.0 μg/m³. VOC levels were exceptionally low across all rooms, with many locations recording zero or near-zero concentrations.

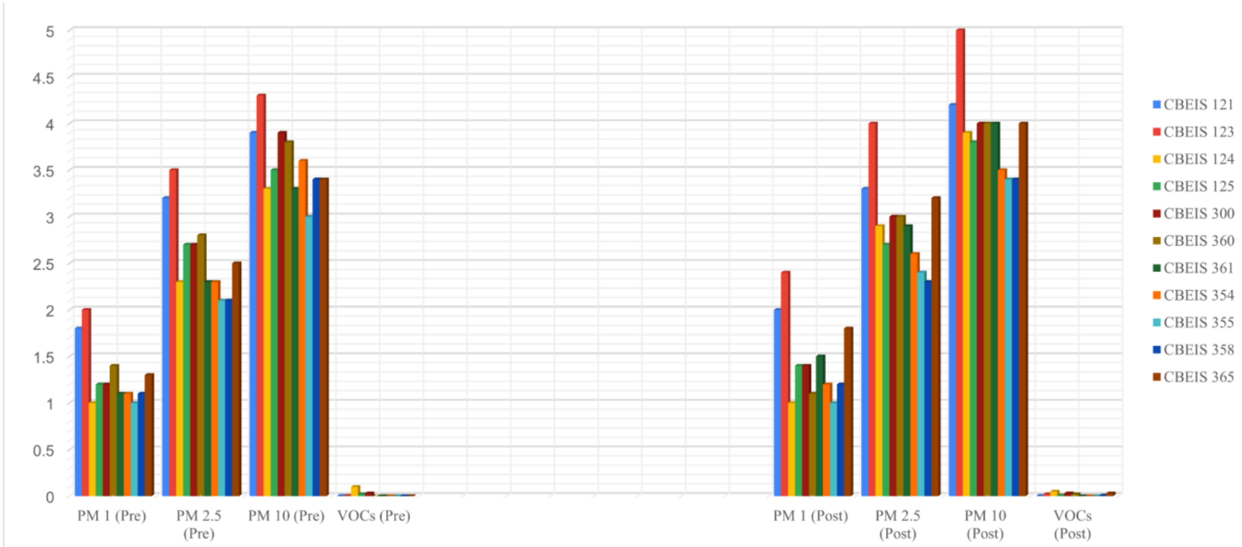

Figure 12: Tenth Day reading of indoor air quality of a HBCU Engineering Laboratory

While some areas were below the OSHA limit of 5µg/m³ at 8-hour Time-Weighted Average (TWA), the below areas exceeded the permissible exposure limit.

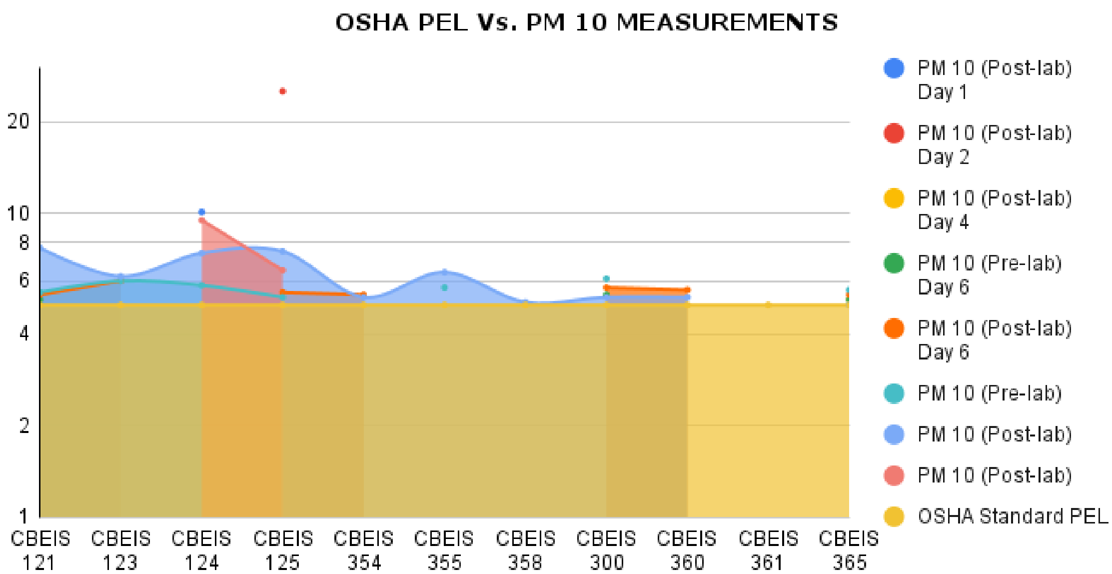

Figure 13: OSHA PEL Vs. PM 10 measurements

Demographics

The evaluation of air quality in the HBCU engineering laboratory often houses processes and materials that generate airborne pollutants. These pollutants can adversely affect the health, safety and academic performance of students and staff. Essential participant information, including roles within the laboratory, frequency of laboratory use, duration of time spent in the laboratory was collected. The inclusion of diverse roles such as undergraduate students, graduate students, laboratory staff and faculty ensure a comprehensive understanding of varying perceptiveness and experiences. Survey highlights attitudes towards air quality alongside general user concerns and practices within such settings, mainly graduate and undergraduate students. Some students used the facilities every day; others visited them several times a week; average use was considered between 1- 4 hour sessions.

Awareness and Perceptions

The survey examined the level of awareness about air quality monitoring practices and participants' perceptions of their knowledge concerning air quality's health impacts. A significant focus is placed on understanding whether participants perceive a direct relationship between air quality and their health or academic performance. The results highlight a mixed level of awareness, suggesting the need for increased educational efforts to enhance understanding and prioritize air quality as a critical factor in laboratory safety.

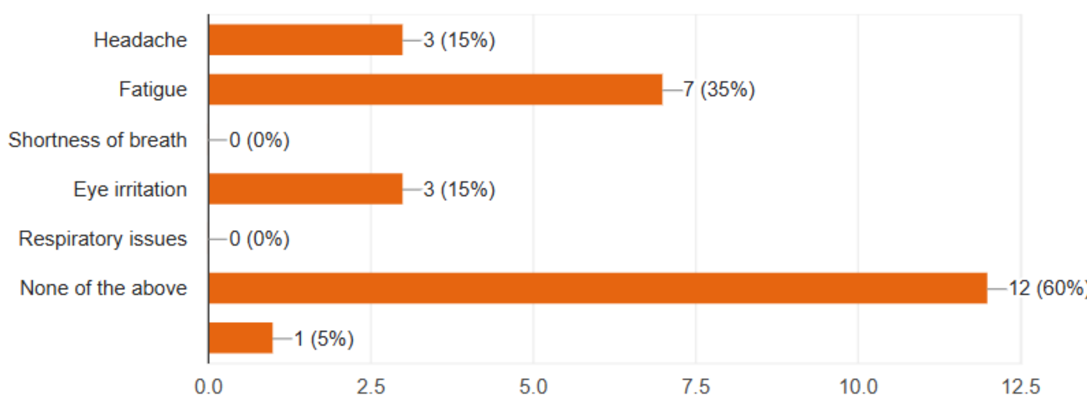

Figure 14: Health and Safety Concerns pre- or post- laboratory work

However, there's a disturbing trend in the awareness of air quality monitoring practices because; most respondents indicated they were unaware of any existing air quality monitoring in their laboratories while very few respondents, including a lab staff member, reported knowing about this practice. However, despite not being very aware, most respondents rated their knowledge of air quality and its health impacts as "Average" to "Good," meaning that they would likely have at least a vague idea regarding the importance of air quality.

The survey indicates that respondents are most adamantly in agreement with one another in terms of air quality correlating with personal well-being. Most respondents either agree or strongly agree that air quality affects their health and their ability to learn effectively. This report is borne out by symptom reporting, as several users complain of experiencing fatigue, headaches, and eye irritation while or after attending laboratory sessions. Remarkably, quite a lot of respondents indicated that they experienced no symptoms at all. Ventilators also received mixed reviews with regards to the physical environment. Some laboratories were termed as having "Effective" or "Very Effective" ventilation, while others were "Neutral" or "Ineffective." Cleanliness ratings mostly fell in the "Average" to "Clean" category, with several problems measured in dust accumulation and inadequate air movement in certain spaces. Most respondents were unclear about how often air filtration and ventilation systems are maintained, suggesting some lack of communication about the schedules for maintenance.

Considering all this, one can see, one uses personal protective equipment (PPE) in very different ways among laboratory users. Never, always, these would be some of the answers to these attitudes. Most of them might believe that they could benefit from PPE in mitigating the harmful effects of poor air quality, but the consistency of their dealing with PPE does not necessarily correspond with this belief. Break patterns vary widely, ranging from taking hourly breaks to finding less and less time out. Strongly favor the direction of continuous air quality monitoring systems. Most respondents either agreed or strongly agreed with such proposals. Improvements include ventilation, regular cleaning of vents, installing air pollution meters, and making more windows or vents for fresh air circulation. Many of them showed interest in possible upcoming workshops or training sessions on air quality issues and safe practices indicating that they wished for more education on this topic.

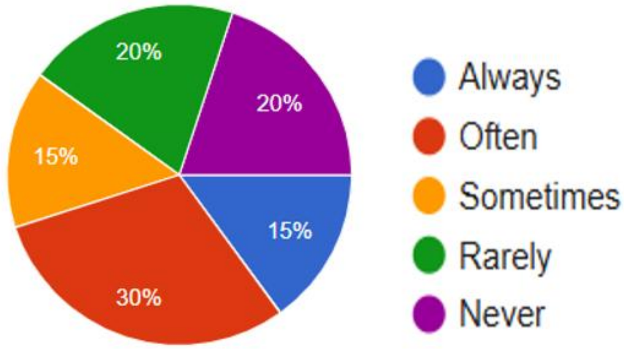

Figure 15: Use of personal protective equipment (PPE) consistently while in the laboratory

Very few of the respondents seemed to report formally, as having received training or information on air quality safety measures. This marked an important gap in laboratory safety education. The absence of such training, coupled with the uncertainty on maintenance schedules and practices for monitoring, indicates that appropriate communication and education are needed to manage air quality within the laboratory environment. Overall, while the laboratories score well concerning air quality according to ratings from users, which hover around 3-4 out of 5, there is ample room for improvement in monitoring, maintenance, and communication regarding air quality practices. Responses are very indicative of a need for more systematic approaches to air quality management, such as regular maintenance schedules, formalized training courses, and revamped ventilation systems in certain laboratory spaces.

Discussion

The indoor air quality monitoring at the HBCU engineering laboratories reveal interesting findings about the environmental conditions existing inside educational facilities and is thus linked directly to several United Nations Sustainable Development Goals (SDGs), particularly those focused on health, wellbeing, and sustainable infrastructure [25]. It shows how different parameters like particulate matter, and volatile organic compounds reflect and define the intricate interplay of indoor environmental quality on academic precincts into a whole range: indoors is confined to just one school. This monitoring brought air quality patterns that would significantly affect the health and comfort of its occupants [8]. For example, particulate matter concentrations usually tend to increase during occupied hours, indicating a direct relationship between human activities and indoor air quality [13]. This connects with SDG 3 (Good Health and Well-being) in highlighting the relevance of maintaining healthy indoor environments where human spend most of their time; e.g., students and the faculty. PM_1 levels did not change much throughout the day; however, concentrations of $PM_{2.5}$ and PM_{10} typically displayed more fluctuating behaviors over the same period in spaces where occupancy rates were higher [30]. This aspect of building performance is linked to SDG 9 (Industry, Innovation, and Infrastructure) because it highlights the importance of strong and sustainable infrastructure in educational facilities [26].

There were interesting temporal patterns noted in the VOC concentrations, with some being greatly inconsistent between pre- and post-laboratory measurements in some rooms. These differences could be indicative of the effects of patterns of occupancy and various indoor activities. The implication of effective ventilation strategies on good indoor air quality comes to the fore [5] of great relevance to SDG 3 is the management of VOC because it directly affects indoor air quality and occupant health. There were some unsettling trends brought to light by the data, that sometimes-dropped way below the ideal ranges for human comfort [11]. The data forebodes improvement areas within building systems to keep the environmental conditions acceptable. The monitoring program illustrated the importance of continuous monitoring of indoor environment quality in educational buildings [28]. Thus, periodic measuring and analyzing of these parameters allows proactive management by the building systems and quick intervention in the much-needed positive reaction towards any divergence from optimal conditions. This directly plays into SDG 4 (Quality Education) in creating environments for learning favorable to students and faculty productivity and wellbeing. The findings will open many opportunities for forward looking improvement in building management strategies. More sophisticated control for humidity could easily mean facilitating more comfortable conditions year-round. Furthermore, the discrepancy across different rooms in a building is likened to high impact activity, it should be compensated by ultimately improving the comfort and energy efficiency needed [17].

A thorough analysis on the indoor air quality parameters at HBCU engineering laboratory indicates avenues for bettering building performance and occupants' quality of life. In understanding the findings, the interdependence of the various environmental parameters and their collective influence on indoor air quality has been elucidated [27]. So, through appropriate understanding of these relationships, building managers and professionals can work towards healthier, more comfortable, and more sustainable indoor environments that embrace both educational and individual purposes within the building. The outcome indicates the necessity to keep indoor environmental criteria optimum in educational facilities and establishes how the careful observance and management of those parameters could count towards several SDGs at once. Continuing with attention to indoor air quality and building performance may help educational facilities fulfill their primary mission while serving a broader contribution to sustainable development.

Conclusion

The indoor air quality monitoring at this HBCU engineering laboratories showcases a view on the environmental conditions that characterize educational facilities. It identified significant patterns for different parameters such as concentration levels of particulate matter and VOC levels which directly affect the comfort of human beings and their wellbeing. The results point to multidirectional targets in the United Sustainable Development Goals (SDGs) particularly in the health, infrastructure sustainability as well as quality education. Changes in these parameter differences among different floors clearly indicate areas in which the building can improve its performance in fulfilling better its obligations as an institution dedicated to education.

There is indeed a need to develop a comprehensive monitoring protocol for continuous and real-time tracking of indoor air quality parameters for reactive action in case of drift from optimal conditions. Also, temperature stratification between floors through enhanced HVAC management and zoning controls must be improved. Ultimately, a schedule for routine maintenance based on patterns established in VOC concentration and particulate matter should be developed. Thereafter, all these changes should be included in the wider SDG compliance agenda with a focus on health and well-being as well as the sustainable infrastructure goals. Such specific improvements will then create a more comfortable and healthier indoor environment but will also further the objectives of the institution in educating students and its commitment to sustainability.

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