

Indoor Air Quality (PM_{2.5}, PM₁₀ and CO₂) in Academic Lecture Theatre in University of Lagos, Nigeria

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Abstract

Purpose – The purpose of this study is to investigate the indoor air quality within a lecture theatre at University of Lagos, Nigeria. With a view to providing credible data for IAQ management and awareness on the effects of indoor air pollutants to occupants.

Method – Quantitative research method was adopted for this study. The research design was a combination of field measurement and a survey design approach (through questionnaire). The study was conducted in Faculty of Engineering lecture theatre (ELT). ELT was selected due to it, being frequently used by a large number of students for lectures. Major considerations for this study are concentrations of CO₂, PM_{2.5} and PM₁₀, temperature and humidity within the building. The data collection instruments were portable handheld air quality monitors, a checklist and a structured air quality questionnaire. This study used time series analysis, relative important index (RII), and equation for data analyse.

Result – The result shows that the average indoor PM_{2.5}, PM₁₀ and CO₂ over 24 hours monitoring at ELT are 17 µg/m³, 28 µg/m³ and 982 pmm respectively. The indoor PM_{2.5} was higher than WHO benchmark while indoor CO₂ was marginally lower than WHO recommendation. Indoor AQI at ELT is 61 (Level 2). Feeling of discomfort (too hot) arose at about 50 % capacity of the theatre with symptoms such as loss of concentration, irritated eye and sweatiness.

Research Limitation – The study focused on ELT, which is a lecture theatre in Faculty of Engineering and did not consider other classrooms in the Faculty.

Conclusion, practical and theoretical implications – The study therefore concludes that the indoor air quality at ELT is poor due to high level of pollutants present. This study brings to fore the pattern of air contaminants at ELT and the need for adequate measures to curtail it.

Keywords: indoor air quality, lecture theatre, particulate matters, pollutants, tertiary institution buildings

Introduction

Atmospheric air quality is a popular issue that has been a topic of concern since the late 1970s. The atmospheric air is highly susceptible to pollutants; hence, it needs to be

present in a quality state (Brink et al., 2024; Zender – Świercz, 2020). Its major influence on the health of humans has been discussed in various meetings and documents by the

World Health Organization (WHO) (Settimo *et al.*, 2020). By virtue of modern society and advancement, human beings tend to spend 90% of their time in indoor environments such as homes, workplaces, office buildings and schools. They are thus, exposed to a variety of pollutants such as particulate matter, allergies, volatile organic compounds, nitrogen dioxide and other biological exposures, which are known to have negative health impacts. (Erlandson *et al.*, 2019; Kelly & Fussell, 2019).

Indoor air pollutants pose high risks to health and remain a top environmental problem. The high population density in urban centres has increased the potential of air pollution (Van der Zee *et al.*, 2017). Household air pollutants have been linked to the cause of some diseases while the top 10 deaths recorded in India is associated with these pollutants, in which women and children are mostly affected (Goel *et al.*, 2021). According to the World Health Organization (WHO) in 2017, about 3.6 billion people (46 % of the world's population) were exposed to household cooking fumes globally (Goel *et al.*, 2021). Apart from fuels used for cooking in households, the concentration of air pollution is influenced through varieties of sources, which includes occupant behaviour, outdoor air, building materials, building practices and operations (Erlandson *et al.*, 2019). Air pollution has been linked to health risks over the course of the past twenty years, such as nitrogen dioxide (NO₂), carbon monoxide (CO), carbon dioxide (CO₂), ozone (O₃), particulate matter (PM), temperature, humidity and volatile organic compounds (VOCs) (Dionova *et al.*, 2020). The health implications for the inhabitants might range from exhaustion, eye irritation, and headache, to more serious issues, which include worsening asthma, difficulties in breathing

and allergic reactions (Erlandson *et al.*, 2019).

In addition to the detrimental effect on the respiratory system and physical symptoms experienced, sick building syndrome (SBS) has been associated with unhealthy indoor air quality (Sarkhosh *et al.*, 2021). This include unproductivity and absence of workers as a result of experiencing several ill-health symptoms which include headaches, fatigue, skin rash, nausea, itching, irritation of the throat, nose and eye (Babaoglu & Sezgin, 2019).

A data by Health Effects Institutes (HEI) in 2018 established that 60 % of the world's population reside in cities having PM_{2.5} that exceed the standard value of 35 mg/m³ set by WHO. Globally, PM_{2.5} has been classified as the 6th major factors leading to premature death and as of 2016 an estimate detected 4.2 million deaths to be attributed to PM_{2.5} (Madureira *et al.*, 2020). According to Gaikwad & Shivhare, (2020), human exposure to indoor air pollutants are 2 to 5 times greater than outdoor air pollutants. Annually, 3.8 million deaths are reported which happen as a result of long-term exposure to air pollutants (Van Tran *et al.*, 2020). Various scientific examinations revealed that indoor air quality has the potential to be compromised by a variety of dangerous chemicals (Tsai, 2019), like combustion products, VOCs, PM, CO₂, CO, NO₂, etc. Typically, indoor air pollutants are generated from building materials, appliances, cleaning supplies, furniture and human activities such as fuel-fired cooking, smoking, or indoor heating, however, spaces with inadequate design, installation and maintenance of the heating ventilation and air conditioning (HVAC) systems may release trapped compounds and airborne biological

materials into the indoor environment (Tsai, 2019). Although, poor indoor air quality may pose mild problems and do not always create an obvious impact on the health and welfare of a population. Despite this, several respiratory problems have been linked to the exposure to Indoor air pollutants which include asthma aggravation, trachea inflammation, runny nose, sneezing, coughing, difficulty in breathing and many other respiratory infections (Shittu et al., 2019).

Nigeria, in comparison to the developed countries is faced with several economic and environmental difficulties such as defective waste disposal systems, inadequate electric power supply, inadequate water supply, unemployment, noise pollution, air pollution, water pollution, etc (Adenubi & Mmom, 2019). The intermittent power supply in Nigeria has made generators a necessity for an average building to be sustainable and efficient in terms of electricity. The study by Adenubi & Mmom, (2019) reported that the mean span between a generator and a household in Nigeria is 5.6 m, which works for an average of 6 hours per day. Hence, exposure to these ambient air pollutants in Nigeria is a major threat to public health and not enough research is being carried out. In the words of Erlandson *et al.*, (2019), tertiary institutions represent a unique environment as they act not just as learning environments, but work and residential environments for the students and the employees. Students and Teachers tend to spend more time in lecture halls during the day and it has been reported by (Vornanen-Winqvist *et al.*, 2020) that the presence of outdoor air pollution sources near schools has a significant impact on student performance. The location of the school is however recognized as having significant impact on

the final indoor air quality performance, particularly on PM₁₀, PM_{2.5}, and TVOCs. Schools located in low traffic, low density metropolitan regions have improved indoor air quality due to fewer sources of outside air pollution, especially for particulate matter (PM₁₀ and PM_{2.5}) and TVOCs, while Higher outdoor PM₁₀ and PM_{2.5} concentrations are reported for schools near industrial regions and in densely populated metropolitan areas with heavy traffic (Becerra, Lizana, Gil, Barrios-padura, et al., 2020). The ventilation system and other openings (cracks and gaps in the building envelope) are few of the ways external air pollutants enter the indoor environment in addition to having an impact on the school's grounds. Previous studies (Becerra, *et al.*, 2020; Branco *et al.*, 2019) looked into ventilation, indoor air quality (IAQ), the link between indoor and outside pollutants, and the entry of external pollution into indoor spaces.

University of Lagos located in one of the populous cities in Africa has a high population density compared to universities in other states in its country, Nigeria. By estimate, the university gets around 87,000 population daily, having more than 52,000 students enrolled and 4,688 members of staff (Shittu et al., 2019; University of Lagos, 2024).

However, studies focused on Indoor Air Quality are limited in university settings (Afolami *et al.*, 2024; Chen *et al.*, 2020; Jayasooriya *et al.*, 2022; Mancini *et al.*, 2020). Therefore, examining the quality of indoor air in university of Lagos will give an insight to the condition of indoor air in an institutional environment located in a metropolitan area. This study thereby investigates the indoor air quality (IAQ) and (PM_{2.5}, PM₁₀, and CO₂) at the Engineering

Lecture Theatre in the University of Lagos, with a view to provide credible data and raising the awareness on the indoor air quality status of the theatre for effect management.

Literature Review

Indoor Air Pollutants

Indoor air pollutants are a critical public health concern, particularly in educational and residential environments where individuals spend most of their time indoor. The presence of various pollutants can substantially have negative effects on air quality, leading to a range of adverse health effects (Mannan & Al-Ghamdi, 2021). Indoor air pollutants are substances, gases, chemicals, or particles released into the air following human activities in the indoor environment (Kelly & Fussell, 2019). According to Altomonte et al., (2020) these contaminants originate from multiple sources, including building materials, combustion, cleaning products and outdoor air infiltration. The most common indoor air pollutants include particulate matter, volatile organic compounds, carbon monoxide, carbon dioxide, and nitrogen dioxide (Settimo et al., 2023). Particulate matter (PM_{2.5} and PM₁₀), Nitrogen dioxide (NO₂), Total Volatile Compounds (TVOCs), Carbon monoxide (CO), Radon, Sulphur dioxide (SO₂), Carbon dioxide (CO₂) and Ozone (O₃) were considered by the World Health Organization (WHO) as critical indicators of indoor air quality (Branco et al., 2019). The impact of these substances cannot be overemphasised on the health and general well-being of the occupants. The pollutants not only pose short-term effects (such as catarrh, asthma aggravation, eye irritation, cough, etc.) on the health of occupants, long-term and life-threatening effects which includes cancer have been connected to some

harmful substances indoor (Van-Tran et al., 2020).

Concentration Pattern of Indoor Air Pollutants in some Institutions across the world

Studies conducted in some schools in the United States of America showed that in California, a school located in urban and traffic region around residential area, that depended on natural and mechanical mode of ventilation had an ultrafine PM of 10,800cm⁻³ (Mullen et al., 2011). A school in Texas located in a mixed environment (both urban and rural), using mechanical ventilation system recorded ultrafine PM_{2.5} = 0.6×10³-29.3×10³ cm⁻³ (Zhang & Zhu, 2012). A similar school in Texas recorded PM₁₀ =6.5-100 µg/m³ and PM_{2.5}=3.4-37 µg/m³ (Raysoni et al., 2013). Other studies conducted in some European countries with similar site characteristics as the schools in US recorded a 10µg/m³ for PM_{2.5} and 30 – 146 µg/m³ for PM₁₀ (Almeida & de Freitas, 2014), in Portugal, having an urban and naturally ventilated setting recorded 140 µg/m³ of PM₁₀ and 95 µg/m³ of PM_{2.5} (Madureira et al., 2012). In a school located in the urban region in Korea PM₁₀ =8-403 µg/m³ and CO₂=268-3,000 ppm were recorded (Yang et al., 2009). A school located along the road side, naturally ventilated in an urban setting, located in Agra, In Chennai India, a naturally ventilated school recorded PM₁₀=942±248 µg/m³, PM_{2.5}=61±17 µg/m³ and CO₂=458±58 ppm (Agarwal & Shiva Nagendra, 2016). In Africa, there are no extensive information and studies based on indoor air quality in tertiary institutions with few that focused on urban areas, distribution of air pollutants due to weather changes and dumpsites. A study conducted in 10 schools in South Africa relating to difference in PM₁₀ values in exposed and unexposed classrooms to

dumpsites. The study reported that schools located between 1 – 2 km distances away from a dumpsite had a range of 9.30–19.40 µg/m³ while schools farther than 5km distances had a range of 3.10–16.50 µg/m³ for an average of 8 hours during the day (Nkosi et al., 2017).

Air Quality Index

The Air Quality Index (AQI) is a color-coded numerical scale that is broken into various distinct ranges. The information provided by the AQI indicates not just the degree of contamination but also the possible health danger to people. The United States Environmental Protection Agency (EPA) uses the AQI to report on the daily air quality. This AQI provides information on the quality of the air we breathe, the level of concern, and any potential health impacts. In order to determine the air quality index for a location,

the formula adopted by (US EPA, 2024) is as stated below;

$$I_p = [I_{Hi} - I_{Lo} / BPHi - BPLo] (C_p - BPLo) + I_{Lo} \dots\dots\dots (1)$$

Where **I_p** = index of pollutant p, **C_p** = truncated concentration of pollutant p, **BPHi** = concentration breakpoint i.e. greater than or equal to C_p, **BPLo** = concentration breakpoint i.e. less than or equal to C_p, **I_{Hi}** = AQI value corresponding to BPHi, **I_{Lo}** = AQI value corresponding to BPLo (EPA, 2018).

The rating of the air quality index is shown in Table 1 below. It can be claimed that the air quality is better when the AQI number is lower and worsens as the AQI increases (United States Environmental Protection Agency (US EPA), 2014).

Table 1: Air quality index (AQI) values, PM_{2.5} and PM₁₀ concentration colour codes and level of health concern

AQI Value of Index	Levels of Health Concern	PM _{2.5} Concentration (µg/m ³)	PM ₁₀ Concentration (µg/m ³)	Daily AQI Colour	Air Pollution Level
0-50	Good	0-12	0-54	Green	Level 1
51-100	Moderate	12.1-35.4	55-154	Yellow	Level 2
101-150	Unhealthy for Sensitive groups	35.5-55.4	155-254	Orange	Level 3
151-200	Unhealthy for Sensitive groups	55.5-150.4	255-354	Red	Level 4
201-300	Very Unhealthy	150.5-250.4	355-424	Purple	Level 5
301 and Higher	Hazardous	250.5-Higher	425-Higher	Maroon	Level 6

Source: (EPA, 2018)

The AQI is broken down into ranges; these ranges are given numbers and then indicated with colour codes, with each colour denoting a different level of health impacts. The ranges show the level of health risk associated with

the air quality, from a healthy standard level of zero to a hazardous level of above 300.

Level 1 denotes good and healthy air quality, as the category's air quality is deemed excellent and provides little to no risk to

health. **Level 2** air pollution is safe, certain (very few) people, especially those who are typically sensitive to air pollution, may be at risk or have mild health concerns. **Level 3** is considered unhealthy for sensitive groups; while it may not have an impact on the public, exposed individuals with certain diseases, such as lung and heart conditions, and vulnerable populations, such as children and the elderly, are more at risk. **Level 4** is considered harmful; while sensitive populations may face more severe health problems, some members of the public may experience some negative health effects from this form of pollution. **Level 5** with the purple colour code is extremely unhealthy for the public and will cause a health alert since at this level, everyone is at an increased risk of serious health repercussions. Last but not least, **Level 6** air pollution is hazardous to human health and will result in an emergency health alert since it is more likely to affect everyone who is exposed to it (Wambebe & Duan, 2020).

Comfort Perception and Health related symptoms

Lecture halls, particularly in urban and tropical regions, often experience compromised IAQ due to overcrowding, insufficient ventilation, and proximity to traffic or industrial zones (Gouge et al., 2023). In naturally ventilated buildings, which are common in universities across Nigeria and other developing countries, the lack of mechanical air filtration means that outdoor pollutants can easily infiltrate indoor spaces (Abulude et al., 2023). Similarly, Uyere, (2024) identified elevated particulate matter levels and inadequate ventilation in lecture halls at the Federal University of Technology, Minna, as major contributors to student discomfort and reduced concentration

In addition, thermal discomfort is also a significant factor in students' dissatisfaction. Aguilar et al., (2022) observed that poorly controlled temperatures in Spanish university classrooms led to frequent complaints about thermal conditions. Furthermore, Al-Jokhadar et al., (2023) demonstrated that overheated environments in design studios led to cognitive strain and lower student productivity while Budiaková, (2019) noted that poor air distribution in large lecture halls contributed to thermal discomfort. Overcrowding is another indoor issue in tertiary institutions. Studies by both Idiung et al., (2022) and Makena, (2025) emphasised how overcrowding and limited ventilation exacerbate IAQ, leading to increased pollutant accumulation and impaired airflow. In another study by Abbaspour et al., (2023), increased student density was observed to elevate carbon dioxide (CO₂) levels due to human respiration, so, as the number of occupants rises, the level of discomfort increases with the space.

On health related symptoms experienced, respiratory issues are among the most commonly reported health concerns resulting from exposure to poor IAQ in lecture halls (Toyinbo, 2023). Madureira *et al.*, (2020) observed that students in poorly ventilated environments exhibited higher incidences of coughing, wheezing, and shortness of breath. These symptoms are triggered by airborne contaminants such as particulate matter (PMs), volatile organic compounds (VOCs), and indoor allergens. In Holden *et al.*, (2023) and Kang *et al.*, (2023), it was reported that prolonged exposure to these pollutants exacerbates wheezing, especially in students with respiratory sensitivities. Students with asthma or other pre-existing respiratory conditions are particularly vulnerable to the consequences of inadequate IAQ. Azlan *et*

al., (2023) posited that there is an increase in asthma symptoms and attacks in schools with poor air quality, attributing these occurrences to the presence of mold, smoke, and airborne chemical irritants.

Awada *et al.*, (2022) on the other hand, found that poor ventilation and elevated levels of CO₂ and VOCs were linked to increased reports of headaches and fatigue among students. Similarly, Brink *et al.*, (2024) observed that these conditions negatively affect students perceived learning quality, concentration, and lead to dizziness. Although less commonly associated with IAQ, gastrointestinal symptoms such as heartburn have been observed in response to exposure to strong indoor odours. Awada *et al.*, (2022) stated that stress linked to poor air quality, coupled with the presence of indoor pollutants, might contribute to such discomforts. Other symptoms like sore throat, sneezing, and nasal congestion are frequently reported among students in dusty or poorly ventilated lecture halls. Rosário Filho *et al.*, (2021) and Idemudia *et al.*, (2021) linked these symptoms to airborne irritants, while Dimitroulopoulou *et al.*, (2023) emphasized the role of dry air in aggravating the upper respiratory tract. Multiple studies have shown that exposure to high levels of CO₂ and airborne pollutants correlates with decreased academic performance, reduced attention spans, and lower memory retention rates and

heightened absenteeism (Azlan *et al.*, 2023; Tsantaki *et al.*, 2020; Wambebe & Duan, 2020). Hence, the cumulative impact of poor IAQ on student health directly translates to diminished learning outcomes.

Research Method

The research method adopted in this study was the quantitative approach. The quantitative research method is the systematic investigation of phenomena through the gathering of numerical data and the use of mathematical, statistical, or computational methods. The present study adopted this method because it involves numerical data collection and analysis. In this method, questionnaire survey and field experimentation (which involved the use of an Indoor air quality monitor) were adopted at ELT. These two designs approach were used because the study involves observation of sample buildings over time (longitudinal) and evaluates the perception of the users (cross sectional) to make inferences. The Engineering Lecture Theatre (ELT) is located in the Faculty of Engineering, opposite the University Senate Building, between longitudes 3°23'00" E - 3°24'30" E and latitudes 6°30'00" N -6°31'30" N, in University of Lagos main campus. Figure 1 shows the satellite view of the University of Lagos, indicating the positions of ELT.



Figure 1: Satellite view of University of Lagos showing the location of ELT

The Engineering Lecture Theatre (ELT) is a 205-seating capacity lecture theatre. The ELT was selected for this study because of its

unique architectural design in terms of ventilation, and its frequency in holding cross departmental lectures within the faculty.



Outside view of ELT



(a) Inside view of ELT

Figure 2: Indoor and outdoor images of ELT

Air Quality Monitors

Two make of monitors were used. Blatn (Model: BR Smart 128s) and the Inkbird (Model No.: MH – 128). The Blatn (Model: BR Smart 128s) is a portable handheld equipment placed on an elevated surface between 700 – 1,000 mm above the ground to ensure dust particles from the floor does not influence the values. This monitor recorded

PM_{2.5}, PM₁₀, CO₂, values while for the outdoor monitoring Inkbird (Model No.: MH – 128), manufactured by the Inkbird was used. The Inkbird is an 8 in 1 multifunctional detector and accurately detects CO₂, PM_{2.5}, PM₁₀, temperature and humidity levels, including a Wi-Fi function. The equipment was mounted on an elevated surface between 700 to 1,000 mm above the ground,

constantly powered by a 20,000 mAh power bank due to its small battery capacity. The data recording was carried out within the month of April 2023 during the University's second semester 2021/2022 Session. The readings were taken between Monday, 17 April to Wednesday, 26 April 2023 (6 days, weekends excluded to reach a total of 24 hours in each location). These monitors were used to record the amount of PM_{2.5}, PM₁₀ and CO₂ values within indoor and outdoor for a total of 24 hours in accordance with WHO. The indoor device, logged data into an SD card at 1 minute interval. For these devices,

the first 15 minutes of the readings were excluded after retrieving the data from the devices in accordance with manufacturer's instruction. This is to ensure that the device is well aerated while taking the readings. The Inkbird device used outdoor, logged data into the internal memory at 10 minutes interval. The data was retrieved by connecting the device to an air quality monitor software app through Wi-Fi. The file formats from the two monitors were in excel files, which were downloaded and further analysed accordingly. Figure 3 (a and b) show the image of the monitoring instrument used.



(a) Portable Hand-held Br-smart air quality monitor, for indoor air recording



(b) Inkbird air quality monitor for outdoor air recording

Figure 3: Images of the air quality monitoring devices used for this study

Questionnaire Survey and Building Checklist

The designed air quality questionnaire was converted to an online form using epicollect5. Epicollect5 is a free mobile and web application to ease data collection process. The questionnaire was accessed by the respondents through an Android phone, filled out and submitted in less than 30 minutes. The questionnaire captures information such as symptoms experienced while in the space and their perception while leaving the space.

In total, 185 responses were received from the students' respondents at ELT. Lastly, building checklist was used to collect building characteristics information such as the floor area, building height, sizes of the building openings, types of openings and the seating capacity.

Method of Data Analysis

For the data extracted from the indoor air quality monitors, trend analysis (in form of graph) was used to understand the concentration pattern and AQI equation (equation 1) was used to estimate the AQI in ELT. On the other hand, frequency, percentage, rank and relative importance index were used to analyse the questionnaire aspect of this study and presented accordingly.

Findings and Discussion

This section presents the results of the air quality monitors and the submitted questionnaires accordingly.

The concentration pattern of indoor and outdoor PM_{2.5}, PM₁₀, and CO₂ at ELT, University of Lagos.

The timeseries of the concern pattern of indoor and outdoor PM_{2.5}, PM₁₀ and CO₂ at the Engineering Lecture Theatre (ELT) are shown and interpreted in Figure 4 – 7 below with the aid of graphs.

Indoor PM_{2.5} and PM₁₀ for all days (Monday 17th, April 2023 to Wednesday 26th, April 2023) in ELT.

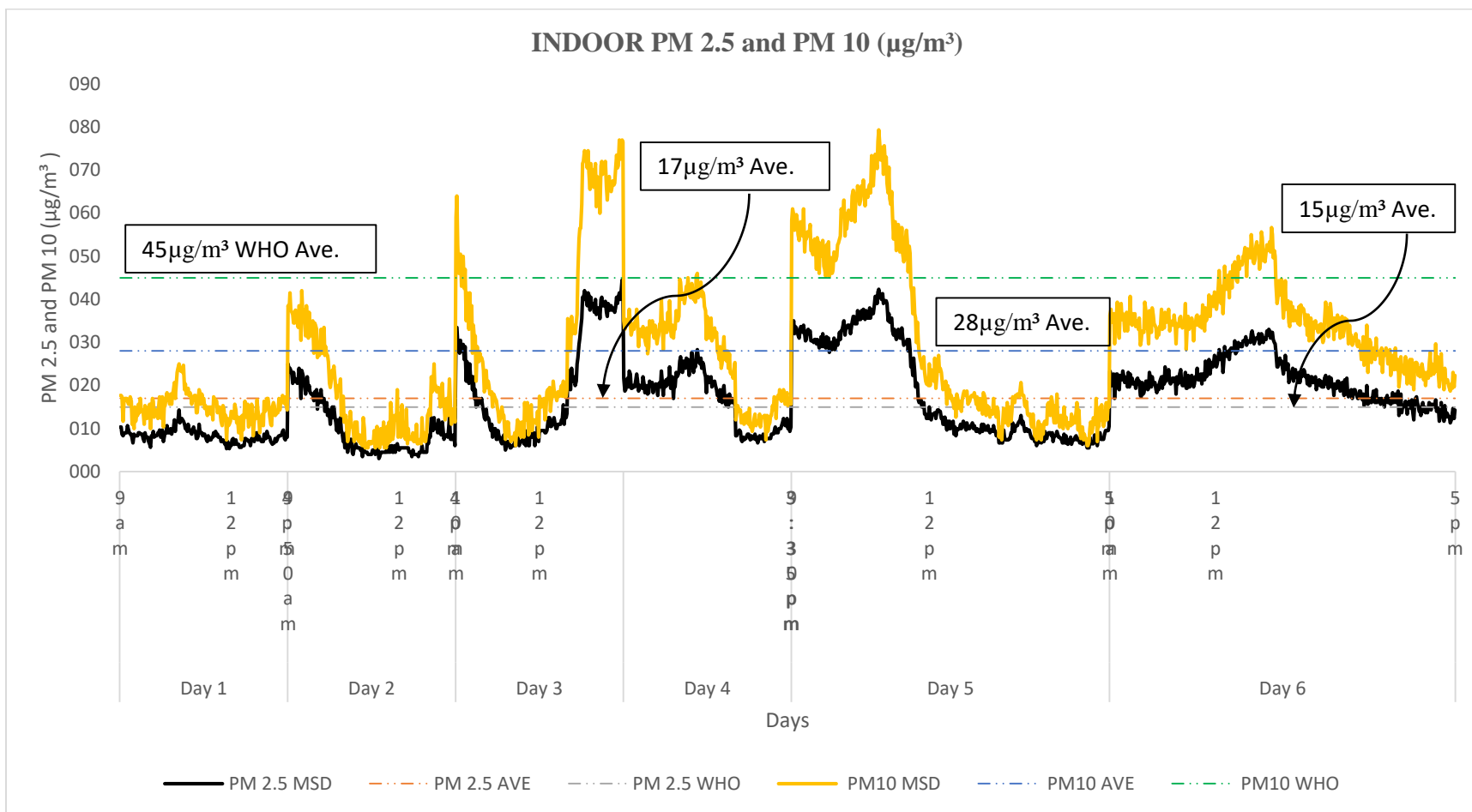


Figure 4: Indoor PM_{2.5} and PM₁₀ for all days at ELT

Outdoor PM_{2.5} and PM₁₀ for all days (Monday 17th, April 2023 to Wednesday 26th, April 2023) in ELT.

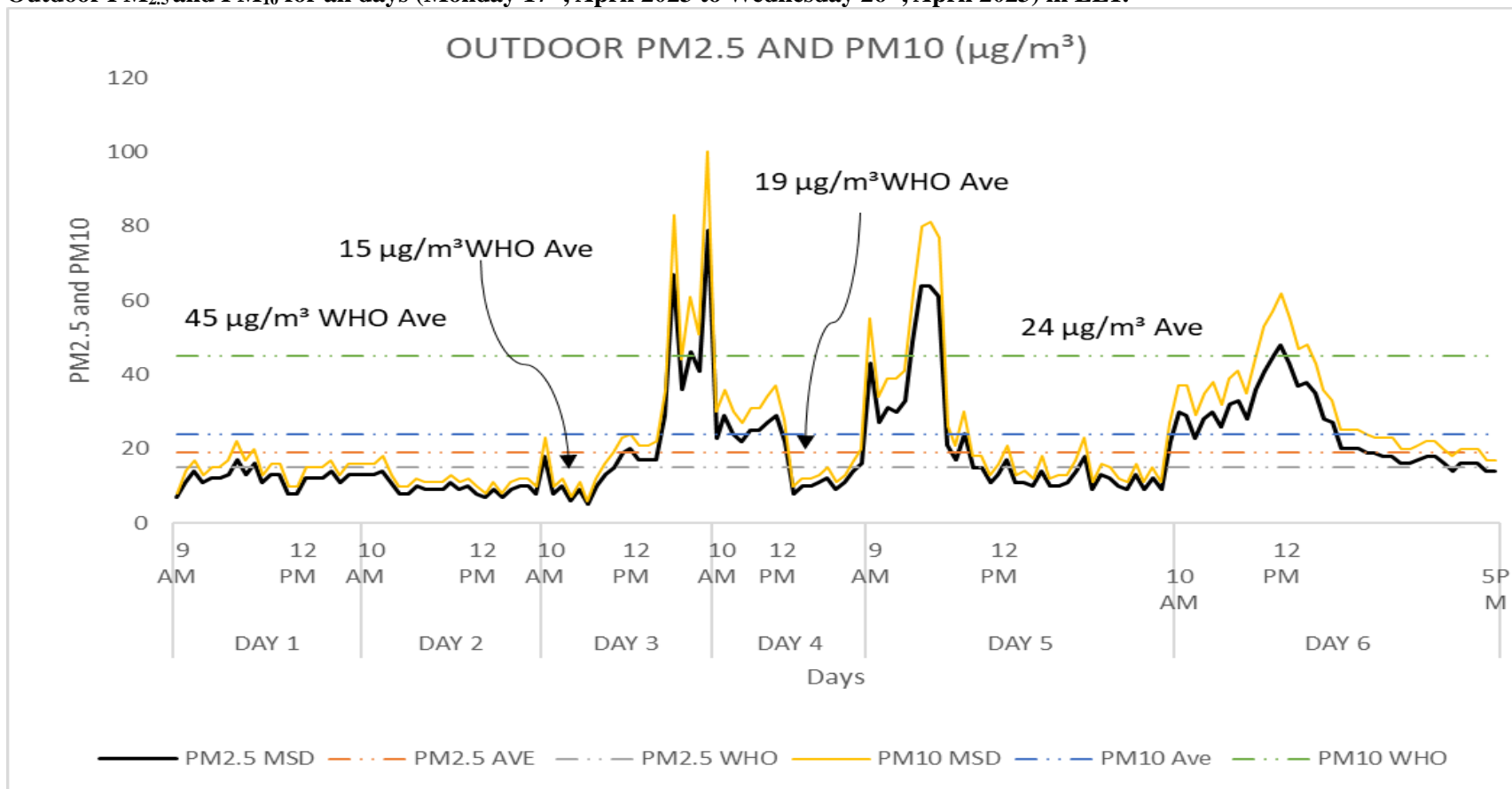


Figure 5: Outdoor PM_{2.5} and PM₁₀ for all days for all days in ELT

Indoor CO₂ for all days (Monday 17th, April 2023 to Wednesday 26th, April 2023) in ELT. Dotted line across the graph represents ASHRAE guideline at 645 ppm

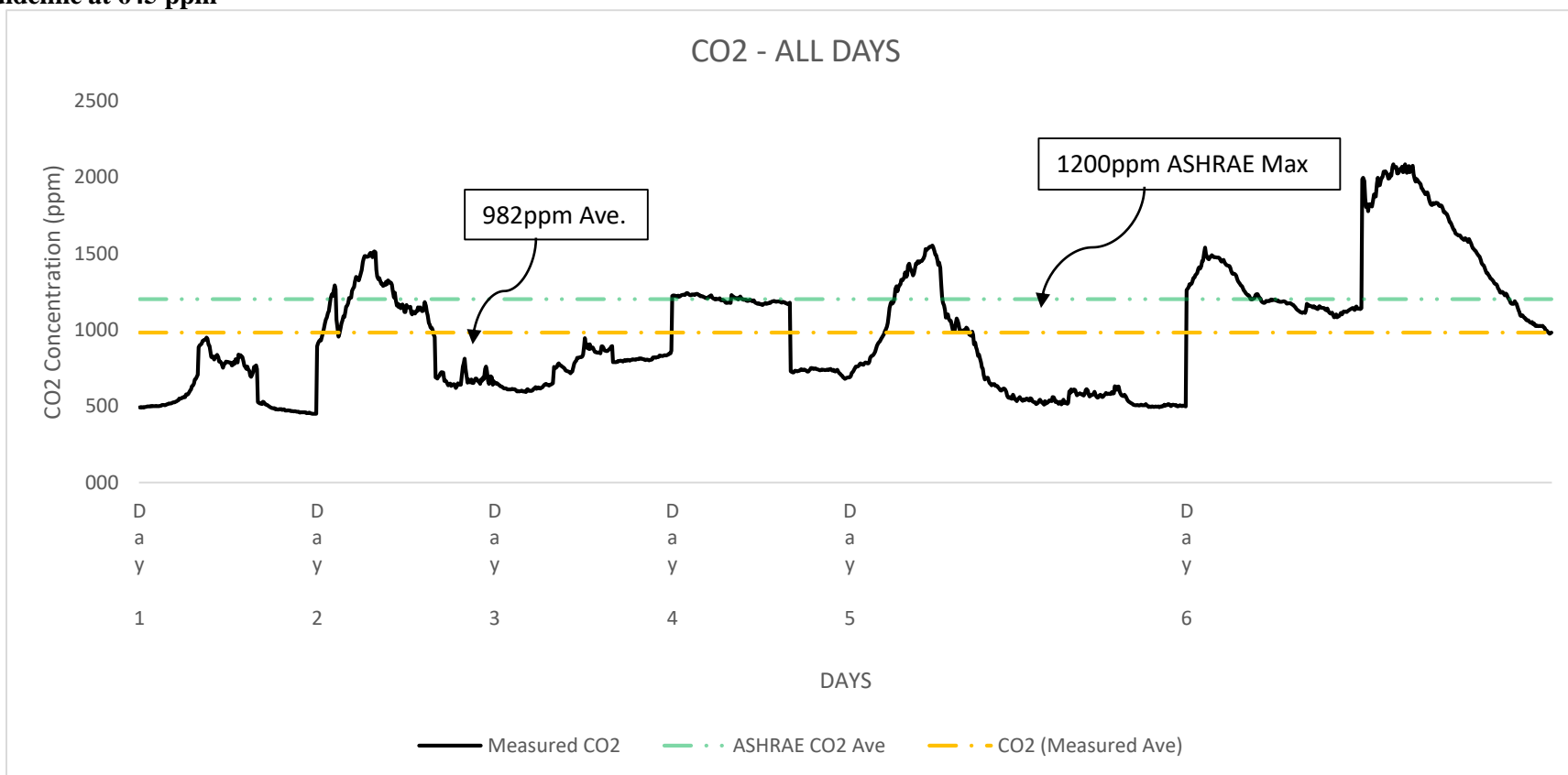


Figure 6: Indoor CO₂ for all days at ELT

Outdoor CO₂ for morning, afternoon and evening for all days (Monday 17th, April 2023 to Wednesday 26th, April 2023) in ELT. Dotted line across the graph represents ASHRAE guideline at 645 ppm

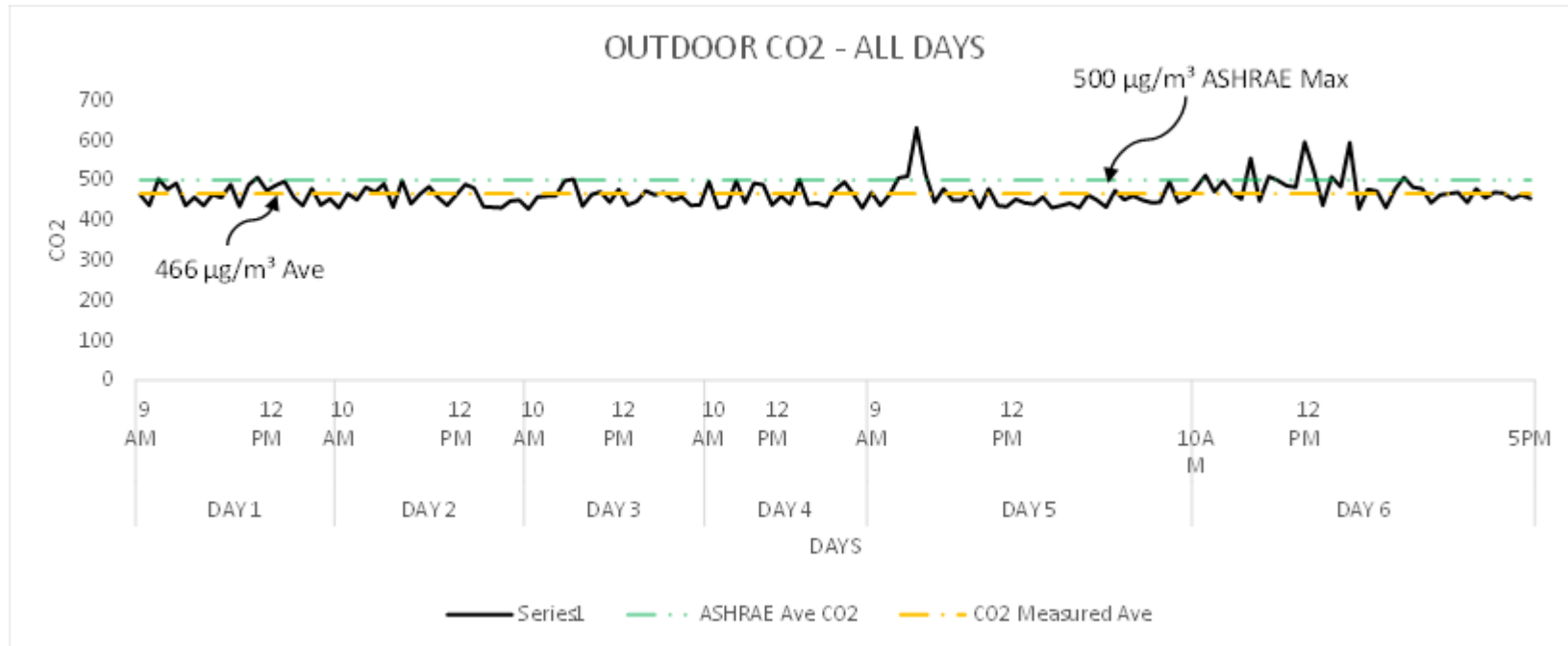


Figure 7: Outdoor CO₂ all days in ELT.

The indoor and outdoor PMs and CO₂ timeseries as shown in Figure 4 – 7, are interpreted below.

Figure 4 shows the pattern of indoor PM_{2.5} and PM₁₀ for all days at ELT with WHO guideline for 24 hours average. According to WHO, the threshold for PM_{2.5} and PM₁₀ is 15µg/m³ and 45 µg/m³ respectively for 24 hours average. The average indoor PM_{2.5} and PM₁₀ measured values in the at ELT are 17 µg/m³ and 28 µg/m³ respectively, however, there were spikes across the measurement duration which are higher than the WHO threshold. During the measuring hours, PM_{2.5} and PM₁₀ rose beyond 40 µg/m³ and 70 µg/m³ indoors at ELT on days 3 and 5 which far exceeded the WHO safe threshold. These elevated values are not safe for students with critical health conditions such as asthma. Another important observation in the pattern is that PM_{2.5} increases as PM₁₀ increases and decreases proportionally. Meaning that the two are influencing each other. Figure 6 shows the pattern of indoor CO₂ for all days in the classroom with ASHRAE benchmark of 1200 ppm average for 24hours measurement. The average indoor CO₂

measured at ELT was 982 ppm, which is less than the ASHRAE benchmark. This is due to the intermittent presence of students in the classroom even when a lecture was not ongoing. However, during GEG 222 lecture, the spike in indoor CO₂ in the afternoon between 2 pm and 3:30 pm rose to beyond 1500 ppm while the hall was about 75 % full. On the outside, Figure 5 shows the pattern of outdoor PM_{2.5} and PM₁₀ all days around the ELT with WHO guideline for 24 hours at 15 µg/m³ and 45 µg/m³ respectively. The outdoor PM_{2.5} and PM₁₀ measured average values around ELT are 19 µg/m³ and 24 µg/m³ respectively but there were spikes on days 3 and 5 as students move in for the lecture. Figure 7 shows the pattern of outdoor CO₂ for all days in the lecture theatre with ASHRAE guideline for 24 hours at 500 ppm on average. It was observed that the average measured value of outdoor CO₂ around the classroom studied is 466 ppm which is very close to the ASHRAE value of 500ppm.

Air Quality Questionnaire Survey Result

This is the section where the 185 filled and submitted responses through the questionnaire were analysed and presented.

Demographic Information of Respondents

The demographic information of the respondents is tabulated below

Table 2: Demographic Information of Respondents

Demographic Information of Respondents	Frequency	Percent
Age		
Below 16years	67	36.2
16 - 20 years	66	35.7
21 - 25 years	52	28.1
Total	185	100.0
Year Level of Respondents		
None	7	3.8
100	109	58.9
200	26	14.1
300	43	23.2

Demographic Information of Respondents	Frequency	Percent
Total	185	100.0
Approximately, how many hours per day do you spend at ELT?		
1 - 3 hours	33	17.8
4 -6 hours	46	24.9
7 -9 hours	106	57.3
Total	185	100.0

Table 2 above shows that 58.9 % and 23.1 % of the respondents are 100 level and 300 level students respectively. Mostly 100 level students hold lectures in this theatre followed by 300 and 200 levels respectively. These students spend around 7 – 9 hours (57.3 %) and 4 – 6 hours (24.9%) within the theatre.

Demographic Characteristics of ELT

During this study, the physical characteristics of the ELT, such as length, breadth and height, were taken and presented in Table 3.

Table 3: Demographic Characteristics of ELT

S/N	Description	ELT
1	Use of the building	For lectures
2	Floor dimension (L&B)	L = 18.5m B = 16.8m
3	Floor area (LxB)	310.8m ²
4	Room height	6.3m
5	Room/space volume (LxBxH)	1958.04m ³
Openings & operations:		
6	Number of windows	64
7	Type of window	Fixed
8	Dimension of windows	0.8 x 0.8m
9	Area of windows	0.64m ²
10	No of doors	3
11	Dimension of doors	2.3 x 1.8m
12	Area of doors	4.14m ²
13	Window material	Glass and aluminium frame
14	Door material	Timber

The ELT has a 310.8 m² floor area, 6.3m height and a total volume of 1958.04 m³. It has sixty-four (64) fixed windows made of glass and aluminium frame and 3 wooden doors of 0.64 m² each.

Respondents Perception of Comfort at ELT during Lectures

The respondents were sampled based on their perception of the level of comfort while in this theatre on a scale of 1 to 5, where 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Often, 5 = Always. The responses are tabulated below

Observation on Table 4 shows that the most frequent complaint reported by the students at ELT is too hot temperature ranking 1st, followed by crowdedness, stuffiness and too

humid, ranking 2nd 3rd and 4th respectively. Hot temperature caused by insufficient ventilation, crowdedness caused when students exceed the hall capacity during some lectures, leading to stuffy air. All of which contributes to sweatiness and uneasiness experienced by the students. Temperature too cold, food smell and pungent smell from the toilet ranking 8th, 9th and 10th are the least complained by students in ELT. This is due to the fact that ELT is not located close the toilets and cafeteria.

Table 4: Perception of Comfort at ELT during Lectures

Factors	RIIC	Rank
Temperature too hot	0.75	1
Crowded	0.56	2
Stuffy air (i.e lack of fresh air)	0.49	3
Too Humid (i.e too much of moisture in the air)	0.45	4
Unpleasant odour	0.45	5
Dusty air	0.39	6
Unpleasant odour from a photocopy machine/ Printer/Computer system	0.34	7
Temperature too cold	0.34	8
Food smells	0.24	9
Pungent smell from the toilet	0.22	10

Note: 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Often, 5 = Always, RIIC = Relative Importance Index of Complaints.

Cold air is not often complained about because the air conditioners are not working at the time of this study, and it is very enclosed with just three doors and windows positioned 5 meters above the ground level, which are mostly fixed.

Health Related Symptoms Experienced at ELT

The respondents were asked if they had ever experienced any of the tabulated symptoms while in the lecture theatre based on a scale of 1 to 5, where 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Often, 5 = Always. The responses are tabulated below

Table 5: Health Symptoms Experienced

Factors	RIIS	Rank
Loss of concentration	0.63	1
Skin or eye Itching	0.44	2
Fatigue/ Drowsiness	0.35	3
Restlessness	0.32	4
Migraine	0.30	5
Headache	0.29	6
Tiredness	0.29	7
Damp skin	0.28	8
Sneezing	0.25	9
Frequent cough	0.25	10
Dry/sore throat	0.24	11
Agitation	0.23	12
Shortness of breath	0.22	13
Heartburn	0.21	14
Asthma	0.21	15
Fainting	0.21	16
Nausea	0.21	17
Irritated eyes	0.21	18
Dizziness	0.20	19
Wheezing	0.20	20
Chest tightness	0.20	21

Note; 1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Often, 5 = Always, RIIC = Relative Importance Index of Symptoms.

Table 5 shows that loss of concentration, skin itching, fatigue/drowsiness and restlessness ranked 1st, 2nd, 3rd and 4th respectively, are the most experienced symptoms in ELT, especially during lectures or while studying. Itchiness on the scalp because of sweat and then itchy eyes due to sleepy eyes with an attempt not to fall asleep. On the other hand, irritated eyes, dizziness, wheezing and chest tightness ranked 18th, 19th, 20th and 21st

respectively, they are the least complained symptoms by the students, and their relative importance index are not significant.

Respondents' Perception of Air Quality Factors at ELT during Lectures

The responses of the respondents' perception on several other air quality factors were tabulated in Table 6.

Table 6: Respondents' perception on moment of feeling the sensation and time

Factors	Frequency	Percent
Moment of Feeling the Sensation		
When 100% occupied	88	47.6
When 75% occupied	63	34.1
When 50% occupied	34	18.4
Total	185	100.0
Time of the day the sensations is felt		
Morning (9am -12pm)	137	74.1
Afternoon (12pm - 4pm)	48	25.9
Total	185	100.0
Ventilation mechanism while in the theatre		
Moving outside	75	40.5
Use of hand fans	58	31.4
By opening the windows and doors	32	17.3
Use of rechargeable fans	20	10.8
Total	185	100.0
specific season of the year do you experience indoor air quality issues in ELT?		
During raining season	29	15.7
During dry season	115	62.2
During harmattan	41	22.2
Total	185	100.0
General rating of indoor air quality at ELT		
Poor	109	58.9
Average	46	24.9
Good	30	16.2
Total	185	100.0

From Table 5, 88 (47.6 %) occupants had the sensation when ELT was 100 % full, 63 (34.1 %) occupants had the sensation when ELT was 75 % full and 34 (18.1 %) occupants had the sensation when ELT was 50 % full. Also, 137 occupants had the sensation in the morning hours, while 48 occupants had the sensation in the afternoon hours. While recording the data, classes from morning to afternoon were often held at ELT than those from afternoon to evening. Therefore, most questionnaires respondent fell between 10 am to 1pm. 40.5 % of the respondents leave the theatre while 31.4 % used hand fan when it becomes uncomfortable due to how

unbearable ELT can get when the mechanical ventilation system stops working and is crowded during lecture hours. Furthermore, 115 occupants experience indoor air quality issues during dry season, 41 occupants experience indoor air quality issues during harmattan, and 29 occupants experience indoor air quality issues during raining season. This is evident that air pollutants thrive more in hot weather than cold weather. Generally, 109 occupants rated the indoor air quality as poor, while 46 occupants rated it average and 30 occupants rated the indoor air quality good at the ELT.

Air Quality Index for ELT

The index provides information on the quality of the air occupants breathe, the level of concern, and any potential health impacts. To estimate the Air Quality Index (AQI) for

the ELT, equation 1, the United States of America Environmental Protection Agency (US EPA) indexes and breakpoints are used. The equation is as stated again below;

$$I_p = [I_{Hi} - I_{Lo} / BPHi - BPLo] (C_p - BPLo) + I_{Lo} \dots\dots\dots (Eqn 1)$$

Hence the Table 7 summarises the indoor air quality indexes for ELT and the level of air pollution within the theatre as estimated based on equation 1.

Table 7: Summary of the Indoor Air Quality Indexes for ELT

Location	AQI Value of Index	Levels of Health Concern	ELT Indoor AQI	Daily AQI Colour	Air Pollution Level
Indoor	0-50	Good	-	Green	Level 1
	51-100	Moderate	61	Yellow	Level 2
Outdoor	0-50	Good	-	Green	Level 1
	51-100	Moderate	66	Yellow	Level 2

Table 7 shows the indoor and outdoor air quality index (AQI) at ELT estimated as 61 and 66 respectively which are within level 2 value of index. The level of concern is *moderate* which indicate that *air pollution is safe, however, certain people, especially those who are typically sensitive to air pollution, may be at risk or have mild health concerns.*

Discussion

In this study, the concentration pattern of PM_{2.5} and PM₁₀ outdoor was similar to the concentration pattern of PM_{2.5} and PM₁₀ indoor due to infiltration from air outdoor, and cleaning method (see Fig. 4), while the indoor CO₂ for buildings were not a function of the outdoor CO₂. The indoor CO₂ was much higher than the outdoor CO₂. This is due to the fact that indoor CO₂ was influenced by the presence of students in the building as a result of the capacity of the lecture theatre being exceeded during lecture times and inadequate ventilation system as there was a

noticeable increased level of CO₂ as soon as the buildings were approaching half of their seating capacity. The present study affirms Weng *et al.* (2023), which indicated higher average PMs values than the benchmark in some of the studied buildings. In the study of Khalil & Kamoona (2022) at University of Baghdad, it was observed that the indoor CO₂ was higher than ASHREA threshold, though he chose a 1000 ppm ASHRAE threshold while the present study adopted the 1200 ppm ASHRAE threshold. CO₂ in a classroom at the University of Baghdad was higher than the threshold but the present study was lower. The observation in the current study however fits well with that reported in Weng *et al.*, (2023) in which indoor CO₂ was lower than the ASHRAE benchmark for the classrooms studied.

A field experiment conducted by Wyon (2004) found that common symptoms like headache, loss of concentration and fatigue coexisted with the adverse effects of poor

indoor air quality on the performance level of occupants. This current study reported same with most ranked health symptoms experienced by the occupants being loss of concentration, fatigue and headache. It was found that both indoor and outdoor AQI was classified as good and moderate similar to the report of study by Kim *et al.* (2022), the air quality indexes in 46 schools in a metropolitan area in South Korean were classified as good and moderate.

Conclusion and Recommendations

This study investigated the indoor air quality (PM_{2.5}, PM₁₀ and CO₂) in the Engineering Lecture Theatre of the University of Lagos, Nigeria and concluded that the average indoor PM_{2.5} is slightly higher than WHO threshold, while indoor PM₁₀ is lower. The outdoor PMs values are generally lower than WHO benchmark, so also, is the CO₂ average values lower than the ASHRAE values. The indoor air quality index (AQI) for ELT reported 61 respondents indicating moderate effect, but may not be safe for sensitive groups, and typically pose danger to their health on a long-term exposure. The indoor air quality at ELT is poor as it is too hot during lecture hour resulting in loss of concentration by the students occurring when the theatre is more than 50% full. This study therefore recommends that the university management should aggressively upgrade (retrofit) or maintain all existing ventilation systems/mechanisms across all lecture facilities for comfortable learning experience to avoid serious health crisis among students with fragile health condition due to the continual dysfunctional nature of these systems. Furthermore, the university management should also invest in continuous low-cost monitoring of the indoor air quality of lecture facilities for informed decision

making on the state of the indoor of these facilities.

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Appendix:

Nomenclature/ Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
AQI	Air Quality Index
ELT	Engineering Lecture Theatre
US EPA	Unites States Environmental Protection Agency
CO ₂	Carbon dioxide
IAQ	Indoor Air Quality
NO ₂	Nitrogen dioxide
O ₃	Ozone
PM _{2.5}	Particulate Matter size 2.5 diameter or less
PM ₁₀	Particulate Matter size 10 diameter or less
PPM	Parts per Million
SBS	Sick Building Syndrome
WHO	World Health Organization
µg/m ³	Microgram per cubic meter
Equation (I):	$Ip = [IH_i - ILo / BPH_i - BPLo] (Cp - BPLo) + ILo.$
	Ip = index of pollutant p,
	Cp = truncated concentration of pollutant p,
	BPH _i = concentration breakpoint i.e. greater than or equal to Cp,
	BPLo = concentration breakpoint i.e. less than or equal to Cp,
	IH _i = AQI value corresponding to BPH _i ,
	ILo = AQI value corresponding to BPLo