

Concentration Pattern of PM_{2.5}, PM₁₀ and CO₂ in a Departmental Lecture Classroom during Wet Season, at the University of Lagos

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Abstract

With the advancement in technology that is influencing the way we build and live, indoor air quality has become a significant issue for concern in the twenty-first century. Many elements, such as the kind of activities indoors, the ventilation situation and the activities outdoors, all have an impact on indoor air quality and the health of occupants. This study therefore aimed to assess the pattern of PM_{2.5}, PM₁₀ and CO₂ in a departmental lecture classroom during wet season, in the University of Lagos. The study adopted a quantitative method of research, through a field study where air quality monitors were used to record air pollutants data both indoors and outdoors simultaneously. The recording of data for this location was carried out during the rainy season, in the month of May 2023, during the second semester of 2021/2022 academic session (this academic session extended to 2023 due to the disrupted academic activities by the 2022 ASUU strike action (February to October 2022)). The classroom is 100.28sqm and seats 50 students at full capacity. The readings were taken for five days. The result shows that the average indoor PM_{2.5}, PM₁₀ and CO₂ for the studied classroom were 12 µg/m³, 20 µg/m³ and 673 ppm while the average outdoor PM_{2.5}, PM₁₀ and CO₂ were 12 µg/m³, 15 µg/m³, and 472ppm respectively for the studied classroom. The study concluded that at peak periods, the level of indoor PM_{2.5} could become unsafe, especially for people with health conditions such as asthma. Therefore, it is recommended that the air conditioners in the classroom must be maintained and kept at functional conditions constantly to prevent the concentration of the contaminants from peaking which could lead to sudden asthma attacks in the classroom especially during lectures.

Keywords: Air pollutants, Buildings, Classroom, Concentration pattern, Indoor air quality, Particulate matters

Introduction

The atmosphere is highly susceptible to pollutants; hence, it needs to be kept in a pure state. Atmospheric air quality is a popular issue which has been a topic of concern since the late 1970s. Its major influence on the health of humans has been discussed at various meetings and documented 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. These has led to exposure to a variety of pollutants such as particulate matter, allergies, volatile organic compounds, nitrogen dioxide and other biological exposures known to have negative health impacts (Erlandson *et al.*, 2019; Kelly and Fussell, 2019; Toyinbo, 2023). There is high population density in urban centers, and this has increased the potential of air pollution. Air pollutants have been linked to the cause of some diseases, and the top 10 death related causes recorded in India are associated with these pollutants. These have affected women and children

mostly (Al-Jokhadar *et al.*, 2023; Goel *et al.*, 2021). These contaminants pose high risks to health (Al-Jokhadar *et al.*, 2023) and remain a top environmental problem. According to the World Health Organization (WHO) in 2017, about 3.6 billion people (46% of the world's population) were exposed to indoor pollutants globally (Goel *et al.*, 2021).

The extent of concentration of indoor air pollution is influenced through varieties of sources which include occupant behavior, outdoor air, building materials, building practices and operations (Erlandson *et al.*, 2019). These indoor pollutants have been identified in studies as nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), particulate matter (PM), temperature, humidity and volatile organic compounds (VOCs) (Al-Jokhadar *et al.*, 2023; Dionova *et al.*, 2020; Khalil and Kamoona, 2022). The health implications of these substances 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 detriments on the respiratory system and physical symptoms experienced, Sick Building Syndrome (SBS) has been associated with unhealthy indoor air quality (Sarkhosh *et al.*, 2021), such as unproductivity and absenteeism of workers as a result of symptoms which include headaches, fatigue, skin rash, nausea, itching, irritation of the throat, nose and eye (Babaoglu and Sezgin, 2019). The study further reveals that high levels of CO_2 were linked to the severity of the Sick Building Syndrome (SBS) symptoms.

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 $15\mu g/m^3$ set by WHO. Globally, $PM_{2.5}$ has been classified as the 6th major cause of premature death and, as at 2016, an estimate of 4.2 million deaths was attributed to $PM_{2.5}$ (Madureira *et al.*, 2020). According to Gaikwad and Shivhare, (2019), human exposure to indoor air pollutants is 2 to 5 times higher than their exposure to outdoor air pollutants (Aljofi *et al.*, 2024; Sadrizadeh *et al.*, 2022). Annually, 3.8 million deaths are reported to have resulted from 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, volatile organic compounds, particulate matter, carbon dioxide, carbon monoxide, nitrogen dioxide, 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 only mild problems and does not always create an obvious impact on the health and welfare of a population, 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 with 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 and Mmom, 2019). The intermittent electricity supply in Nigeria has made power generators a necessity for an average building to be sustainable and efficient in terms of electricity. According to Erlandson *et al.*, (2019), the tertiary educational 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 hence, inadequate air quality in such spaces could result in loss of concentration and reduced learning efficiency among students (Shoukry *et al.*, 2024; Vornanen-Winqvist *et al.*, 2020). Similarly, the location of the school is also recognized as having a significant impact on the final indoor air quality performance, particularly on PM_{2.5} and PM₁₀. 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}), while higher outdoor PM₁₀ and PM_{2.5} concentrations were observed for schools near industrial regions, and in densely populated metropolitan areas with heavy traffic (Becerra *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.

University of Lagos, located in one of the populous cities in Africa, has a high population density compared to universities in other states in Nigeria. By estimate, the university gets around 87,000 people daily, having more than 52,000 students enrolled and 4,688 members of staff (Shittu *et al.*, 2019). However, studies focused on indoor air quality in the university environment are few (Fu *et al.*, 2021; González-Martín *et al.*, 2020; Lu *et al.*, 2016). Crowdedness and inadequate ventilation systems in classrooms due to faulty air conditioning, have led to some students ditching classes and avoiding some spaces in fear of suffocation. Therefore, examining the quality of indoor air in in classroom with the University of Lagos give insights to the condition of indoor air in an institutional environment located in a metropolitan area. Hence, this study aims at establishing the pattern of air pollutants (PM_{2.5}, PM₁₀, and CO₂) within and around a classroom in the University of Lagos, and compare same with the WHO/ASHRAE benchmark, with a view to providing credible data for IAQ management within university classrooms.

Hypotheses for the Study

For this study, the following hypotheses were stated;

- 1) a) Ho: there is no significant difference between the measured values of indoor PM_{2.5} and PM₁₀, and WHO benchmark
b) Ho: there is no significant difference between the measured value of indoor CO₂ and ASHRAE benchmark.
- 2) a) Ho: there is no significant difference between the measured values of outdoor PM_{2.5} and PM₁₀, and WHO benchmark
b) Ho: there is no significant difference between the measured value of outdoor CO₂ and ASHRAE benchmark

Materials and Methods

This study was conducted using quantitative research approach. With this method, a field study which involved the use of an indoor air quality monitor in the classroom was conducted. The study was conducted in the University of Lagos (between longitudes $3^{\circ}23'00''$ E - $3^{\circ}24'30''$ E and latitudes $6^{\circ}30'00''$ N - $6^{\circ}31'30''$ N), in the centre of Lagos metropolis.

Figure 1 shows the satellite view of the University of Lagos, indicating the positions of the selected classroom for this study.



Figure 1: Satellite view of University of Lagos showing the location of the studied classroom.
Source: Google Earth, (2025)

The selected classroom is located on the ground floor of a one-story building, in the University of Lagos. It is a major classroom where students across all levels gather to read or wait for lectures. At night, this classroom becomes a sleeping hall due to inadequate hostel accommodation for all students. The classroom is 100.28sqm (11.02m x 9.1m) and seats 50-student at full capacity. The windows are always closed, and they cannot be readily opened as they are not only stiff but also distant from the ground level. The space depends on four fans and four air conditioners which circulate air mechanically in the classroom. There is a noticeable odor due to the constant presence of students, body heat and poor sanitation as at the time of this study.

Figure 2 below shows the indoor and outdoor pictorial image of the studied classroom.



(a) (b)
Figure. 2 (a & b): Indoor and outdoor images of studied classroom

Figure 2(a) shows the internal arrangement of the studied classroom with students reading while Figure 2(b) shows the outside view of the same classroom in University of Lagos.

Air Quality Monitors

The air quality monitor used to record the indoor air pollutants were Br-Smart. They are portable handheld equipment placed on an elevated surface between 700 and 1,000 mm above the ground to ensure dust particles from the floor do not influence the values. These monitors recorded $PM_{2.5}$, PM_{10} and CO_2 . The air quality monitor used to record outdoor air pollutants was Inkbird air monitoring device, it is an 8 in 1 multifunctional detector and accurately detected CO_2 , $PM_{2.5}$, PM_{10} , temperature and humidity levels, including a Wi-Fi function. The instruments were mounted on an elevated surface between 700 to 1,000mm above the ground, constantly powered by a 20,000 mAh power bank due to its small battery capacity. These monitors are easily calibrated and installed on site with little technical difficulties. Figure 3 (a) and (b) show the images of the air quality monitors, used indoor and outdoor respectively.

The recording of data at the location was carried out during the university's second semester of 2021/2022 session between Wednesday, 3rd May and Tuesday, 9th May 2023 for classroom, exclusive of Saturday and Sunday (this academic session extended to 2023 due to the disrupted academic activities by the 2022 ASUU strike action (February to October 2022)). Lecture times were targeted as the class has the potential of being filled to full capacity during lectures unlike in examination times when the class may not be used at full capacity due to examination regulations. This is the first phase of the study (wet) which started in the second semester (wet session) of 2023. The data for the second phase (dry) of the study is still being processed. The air quality monitoring devices were used to record the amount of $PM_{2.5}$, PM_{10} and CO_2 values in each space both indoors and outdoors for a minimum of 24 hours in accordance with WHO global air quality guideline (WHO, 2021) and American Society of Heating, Refrigerating and Air-Conditioning Engineers (ANSI/ASHRAE, 2013) guide. The hours of measurement spanned through a minimum of five days between the hours of 10am and 7pm with at least one hour

break daily. The portable hand-held monitors used indoor, logged data into an SD card at every one-minute interval. For these devices, the first 15 minutes of the data were cleared after retrieving from the devices. This is in accordance with the manufacturer's instruction of aerating the device for 15 minutes before taking data. The Inkbird device was used outdoor and logged data into the cloud at every 10 minutes interval. These monitors were used for this study because they are portable-handheld, which means they can be easily moved around, they are easily dissembled and assembled and measure accurately their designed parameters. It is also easy to extract data from them without any form of difficulty.

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 thereafter downloaded in excel files for analysis. The time series of the downloaded data were plotted and presented while a one-sample t-test was conducted to ascertain the level of significance between the measured values and the WHO/ASHRAE benchmarks.

Figure 3 (a) and (b) below shows the position of the devices withing and outside the building for real-time measurement.



Figure 3: Pictures of the air quality monitors used for this study; (a) Portable Hand-held Br-smart air quality monitor, for indoor air recording; (b) Inkbird air quality monitor for outdoor air recording.

The device in Figure 3(a) is the Blatn air quality monitor that was used indoor to measure $PM_{2.5}$, PM_{10} and CO_2 . The device was placed on the table at breathable level and away from the interference with the students within the classroom. Device in Figure 3(b) is an InkBird air quality device that was used for outdoor air parameters monitoring and was placed on a table and at distance from the external wall of the studied classroom. Table 1 below shows the technical specification of the devises deployed in this study.

Table 1: Air Quality Monitors Parameters and Specification

Description	Parameters/Technical Details	
	Blatn BR-Smart (128s).	Inkbird 128w 8-in-1 AQM
Product name	Portable Air Quality Monitor	Air Quality Monitor
Model Number	BR – Smart 128s	MH – 128
Item Number	128s	IAQM – 128
Detecting Item	PM ₁ /PM _{2.5} /PM ₁₀ /TVOC/VOC/CO ₂ /HCHO	CO ₂ /Temp/Humidity/PM _{2.5} /PM ₁₀ /TVOC/HCHO
Materials	Electronic Components/Air Sensors	ABS/Acrylic/Electronic Components/Air Sensors
Carbon Dioxide	400 - 5000 ppm	400 – 5000ppm (±50ppm +5%)
PM 10	0 – 999 µg/m ³	0 – 999 µg/m ³
PM 2.5	0 – 999 µg/m ³	0 – 999 µg/m ³
Air Quality Index (AQI)	0 – 499	0 – 499
Temperature	-	0 – 55°C (°C/°F switchable)
Humidity	-	0 – 99%
Li-Battery	2200mAh	2500mAh (About 2hours)
Type – C	No	5V/2A
Power supply		
Wi-fi	No	IEEE802.11/b/g/n 2.4GHz
Bluetooth 5.0	No	BLE 5.0
Display Size	Not specified	25 x 15cm (11.4 Inch)
Weight	220g	850g
Rated Power	-	10W
Wi-fi Support	No	Wi-fi + BT CB3S (Optional)
Connecting Platform	SSD	Inkbird APP/PC tool/Modbus connecting
RS485 Input	-	5V/1A
RS485	-	10Mbps
Transmission Rate		
Data Logger	Update every 1 minutes	Update every 10 minutes, 30 days data storage
Flash Memory	512KB	512KB
Timing	Yes	Yes
Warranty	1 year	1 year

These devices were made of electronic components that can detect air quality parameters such as CO₂ (between 400 – 5000ppm), PM_{2.5} (0 – 999 µg/m³) and PM₁₀ (0 – 999 µg/m³). They are battery powered or can be plugged to an external source for continuous measurement at the location.

Results and Discussion

The downloaded data from the air quality monitors were plotted into graphs on a 24hour average, and the checklist details are presented in this section.

Demographic Characteristics of the Building

The demographic characteristics of the departmental lecture room was extracted through a checklist and presented in the Table 2.

Table 2: Demographic Characteristics of the Buildings

S/N	Description	DEPARTMENTAL CLASSROOM
1	Use of the building	For lectures
2	Floor dimension (L&B)	L = 11.02m B = 9.10m
3	Floor area (LxB)	100.28m ²
4	Room height	3.65m
5	Room/space volume (LxBxH)	365.02m ³
	Openings & operations:	
6	Number of windows	12
7	Type of window	Projected
8	Dimension of windows	2.54 x 0.88
9	Area of window	2.24m ²
	Total area of windows	26.88m ²
10	No of doors	1
11	Dimension of doors	2 x 0.9m
12	Area of doors	1.8m ²
13	Window material	Glass and aluminum frame
14	Door material	Timber

Table 2 summarizes the demographic characteristics of the studied classroom as extracted through a designed checklist for the study. The classroom is 100.28m² in floor area with a room height of 3.65m. The volume of the classroom is 365.02m³, having 12 glazed projectable windows in an aluminum frame and one door made of timber.

Concentration pattern of indoor and outdoor air pollutants ($PM_{2.5}$, PM_{10} , and CO_2) in and around a classroom in University of Lagos.

The pattern of concentration of indoor and corresponding outdoor air pollutants ($PM_{2.5}$, PM_{10} and CO_2) measured in this study at the classroom were plotted and shown in graphs in Figures 4 – 7 below.

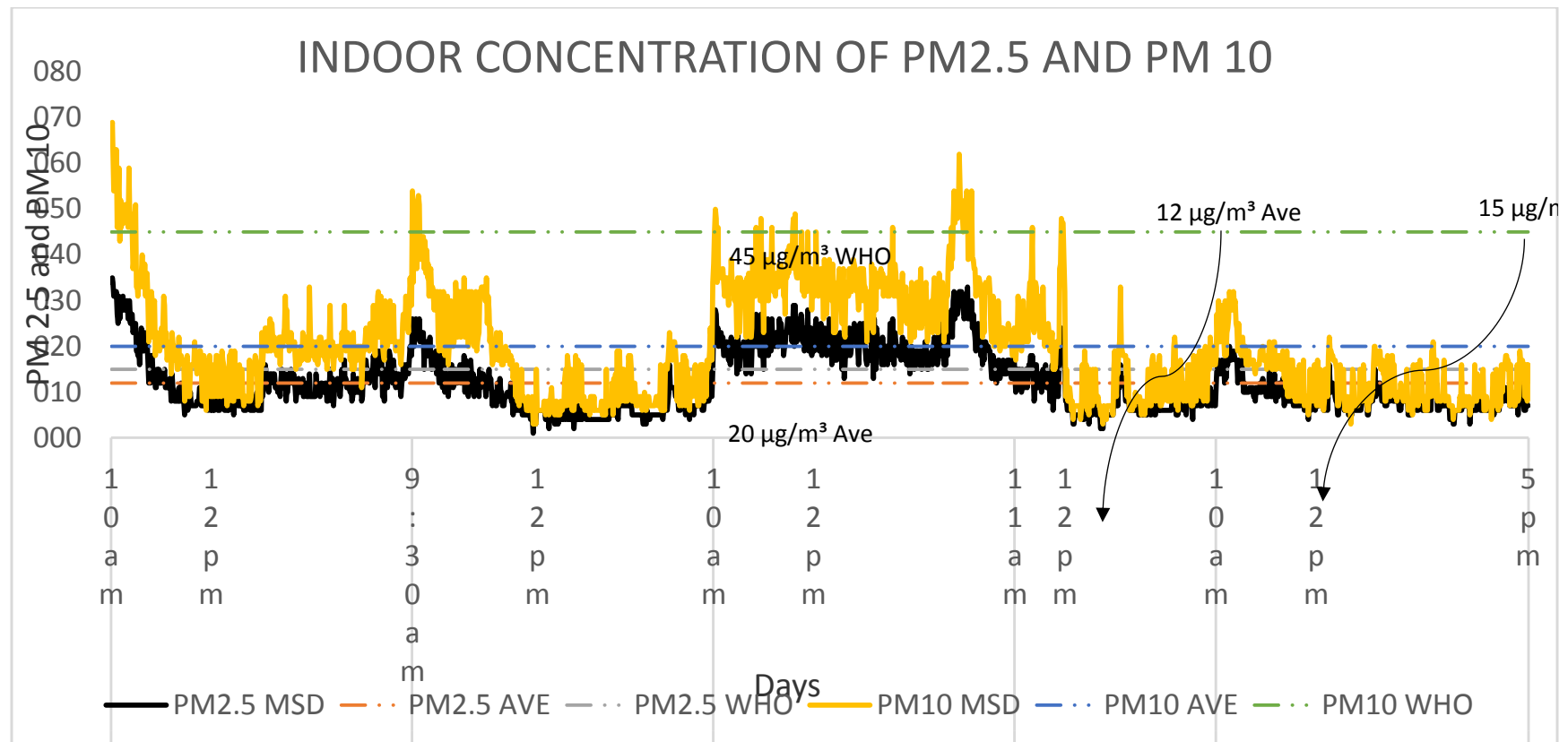


Figure 4: Pattern of indoor PM_{2.5} and PM₁₀ for all days in the classroom with WHO guideline for 24 hours at 15 µg/m³

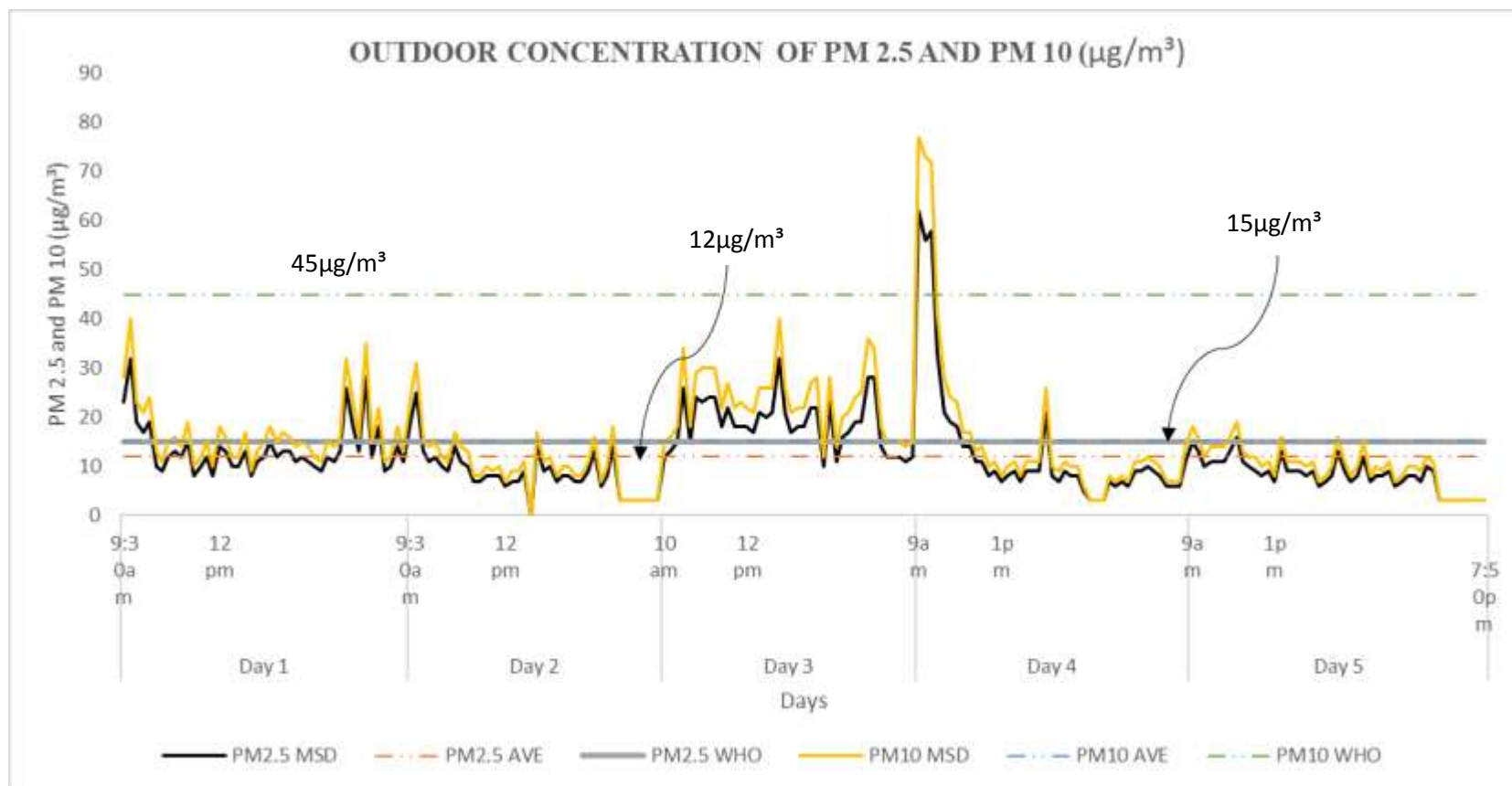


Figure 5: Pattern of outdoor $PM_{2.5}$ and PM_{10} all days in the classroom with WHO guideline for 24 hours at $45 \mu g/m^3$

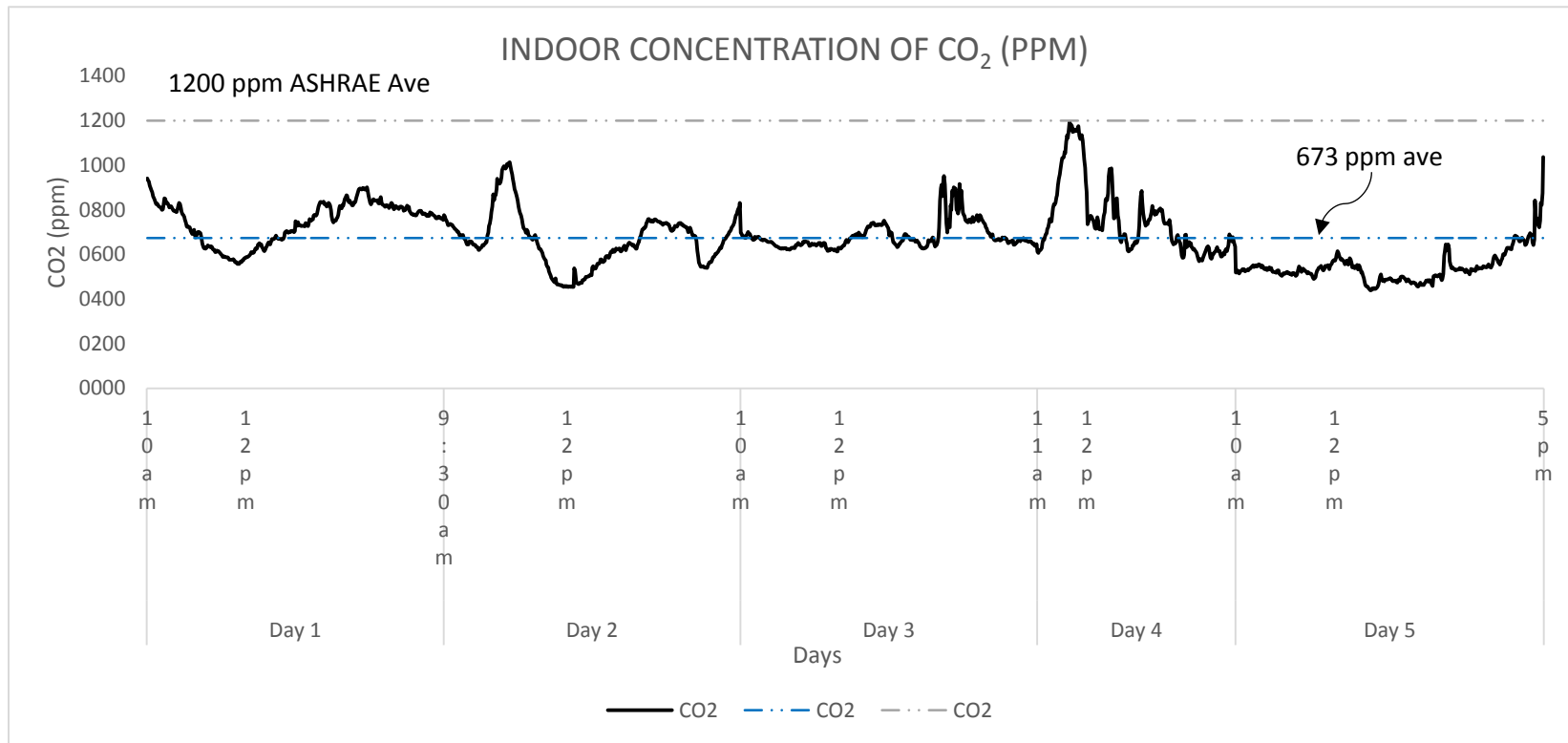


Figure 6: Pattern of indoor CO₂ for all days in the classroom with ASHRAE guideline for 24 hours at 1200 ppm average

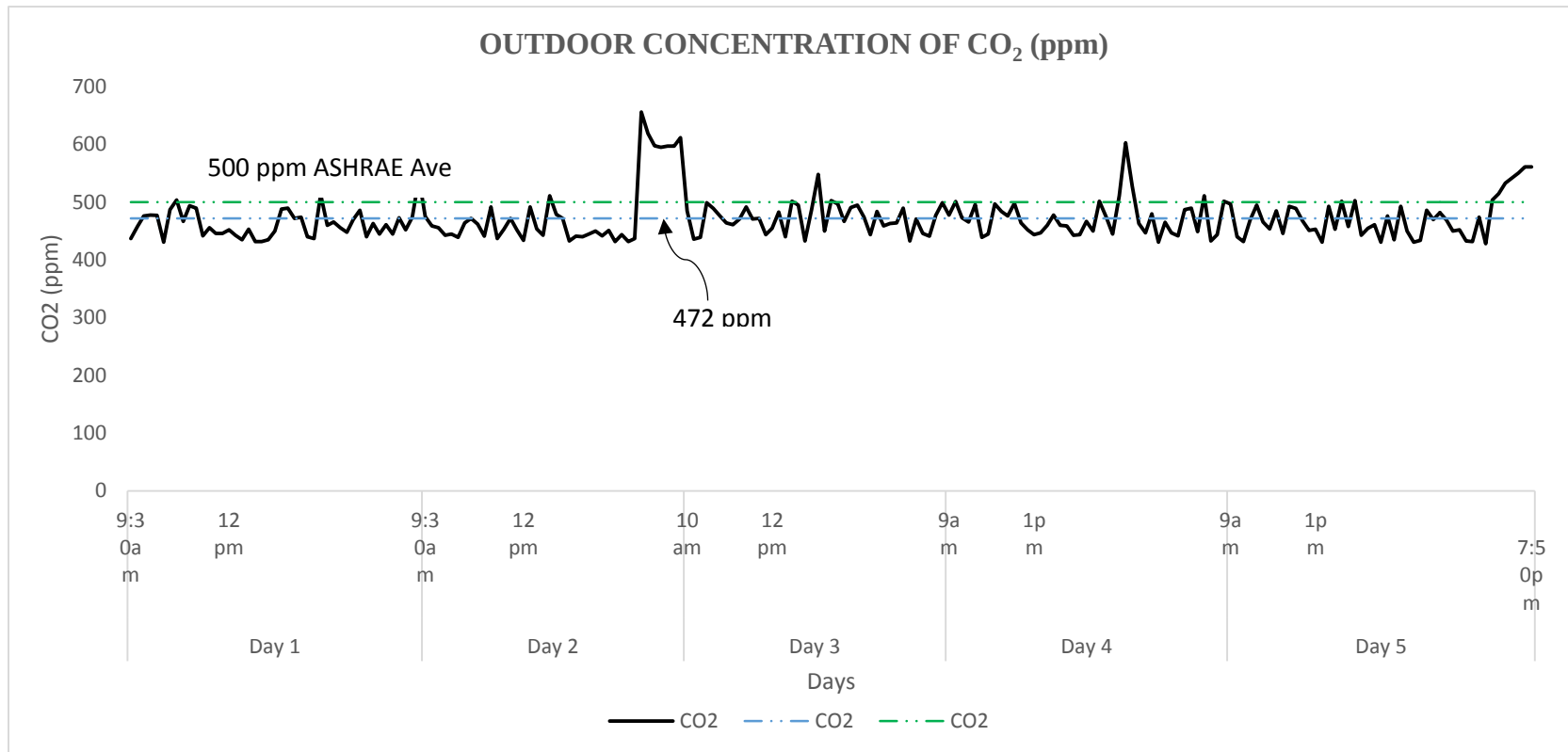


Figure 7: Pattern of outdoor CO_2 for all days in the classroom with ASHRAE guideline for 24 hours at 500 ppm average

Interpretation of Graphs

Figure 4 shows the pattern of indoor $PM_{2.5}$ and PM_{10} for all days in the classroom with WHO guideline for 24 hours average. According to World Health Organization (WHO), (2006), the threshold for $PM_{2.5}$ and PM_{10} is 15 and 45 $\mu g/m^3$, respectively for 24 hours average. The indoor $PM_{2.5}$ and PM_{10} measured average values in the studied classroom are 12 and 20 $\mu g/m^3$, respectively. However, there were spikes across the measurement duration which are higher than the WHO threshold. On day 3, $PM_{2.5}$ and PM_{10} rose up to 33 $\mu g/m^3$ and 62 $\mu g/m^3$ indoors which far exceeded the WHO safe threshold. These elevated values are not safe for students with critical health conditions such as asthma. The spike in the indoor PMs was due to the high number of students going in and out of the class during lectures, and infiltration of pollutants from outside through the windows. Another important observation in the pattern is the $PM_{2.5}$ increases as PM_{10} increases and decreases vice versa. On the contrary, in Weng *et al.*, (2023), two of the studied buildings had average PMs values higher than the benchmark while only at third building that PMs values were lower. The building with a lower average PMs than the benchmark was said to have fresh air system install and was located in the suburb of the city. Figure 6 shows the pattern of indoor CO_2 for all days in the classroom with ASHRAE benchmark of 1200 ppm average for 24hours measurement. The average indoor CO_2 measured in the classroom was 673ppm, 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. Though there were a few spikes, these were relatively lower than the 1200 ppm ASHRAE benchmark. In the study of Khalil and Kamoona, (2022) at University of Baghdad, it was observed that the indoor CO_2 was higher than ASHREA threshold, though he chose a 1000ppm ASHRAE threshold while the present study adopted the 1200ppm ASHRAE threshold. The CO_2 in a classroom at the University of Baghdad was higher than the threshold but the present study was lower. Contrary to Khalil and Kamoona, (2022), Weng *et al.*, (2023) observed that CO_2 was lower than ASHRAE benchmark in the classrooms studied which is in line with the present study.

On the outside, Figure 5 shows the pattern of outdoor $PM_{2.5}$ and PM_{10} all days around the classroom with WHO guideline for 24 hours at 15 $\mu g/m^3$ and 45 $\mu g/m^3$ respectively. The outdoor $PM_{2.5}$ and PM_{10} measured average values in studied classroom are 12 and 15 $\mu g/m^3$, respectively. These values are lower than ASHRAE standard of 15 $\mu g/m^3$ and 45 $\mu g/m^3$ for $PM_{2.5}$ and PM_{10} , but there was a significant spike on the morning of Day 4 which was observed to be due to the increase vehicular activity near the classroom. The class room is actually close to the major road on the campus. Figure 7 shows the pattern of outdoor CO_2 for all days in the classroom with ASHRAE guideline for 24 hours at 500 ppm average. It was observed that the average measured value of outdoor CO_2 around the studied classroom is 472ppm which is very close to the ASHRAE value of 500ppm. Though there was a spike on day 2 that rose as high as 656ppm, the pattern is generally below the benchmark.

Testing of hypotheses

The stated hypotheses for this study are;

- 1) a) H_0 : there is no significant difference between the measured values of indoor $PM_{2.5}$ and PM_{10} , and WHO benchmark
b) H_0 : there is no significant difference between the measured value of indoor CO_2 and ASHRAE benchmark.
- 2) a) H_0 : there is no significant difference between the measured values of outdoor $PM_{2.5}$ and PM_{10} , and WHO benchmark

b) Ho: there is no significant difference between the measured value of outdoor CO₂ and ASHRAE benchmark

To test these hypotheses for this study, a one sample t-test was conducted to examine how the measured values of indoor and outdoor air quality parameters differed significantly from the WHO/ASHRAE benchmark, the results of the t-test are as presented in Table 3 and 4 below.

Table 3: One Sample t-test of Indoor Air Quality Parameters for the Departmental Classroom in comparison with WHO and ASHRAE Benchmark

Indoor Parameters	N	Mean	SD	t	df	MD	95% Confidence interval of the difference.		p	Remark	Decision
							Lower	Upper			
PM _{2.5}	1704	12.03	6.60	-18.59	1703	-2.97	-3.29	-2.66	0.00	Sig	Ho Rejected
PM ₁₀	1704	20.17	11.68	-87.77	1703	-24.83	-25.38	-24.27	0.00	Sig	Ho Rejected
CO ₂	1704	672.60	129.18	-168.54	1703	-	-	-	0.00	Sig	Ho Rejected
							527.40	533.54 521.27			

Note: *p* is significant at $p \leq 0.05$; test value of PM_{2.5} and PM₁₀ = 15µg/m³ and 45 µg/m³ (WHO benchmark) while CO₂ = 1200 ppm (ASHRAE benchmark), SD = Standard deviation, t = t-value, df = Degree of freedom; MD = Mean deviation.

Table 3 shows the one sample t-test result between the indoor air quality parameters and the WHO/ASHRAE benchmarks. The sample consist of 1,704 data of PM_{2.5}, PM₁₀ and CO₂ measured within the classroom. For indoor PM_{2.5}, the t-test result showed that the mean of the measured value of indoor PM_{2.5} (M = 12.03, SD = 6.60) was different from the WHO benchmark (t (1703) = -18.59, $p < .001$). For PM₁₀, the mean of the measured value of indoor PM₁₀ (M = 20.17, SD = 11.68) was different from the WHO benchmark (t (1703) = -87.77, $p < .001$). Similarly, the mean of the measured value of indoor CO₂ (M = 672.60, SD = 129.18) was different from the ASHRAE benchmark (t (1703) = -168.54, $p < .001$). The mean difference (MD) = -2.79 (PM_{2.5}), -24.83 (PM₁₀) and -527.40 (CO₂) with a 95% confidence interval ranging from -3.29 to -2.66 (PM_{2.5}), -25.38 to -24.27 (PM₁₀) and -533.54 to -521.27 (CO₂). This indicates that the average measured values of the indoor PM_{2.5} and PM₁₀, as well as CO₂ are significantly lower than WHO and ASHRAE benchmark respectively. Hence, the null hypothesis which suggested that there is no significant difference between the measured values of indoor air quality parameters and WHO benchmark is rejected and the alternative hypothesis, there is significant differences between the measured values of indoor air quality parameters (PM_{2.5} and PM₁₀) and WHO benchmark is accepted. This statement is also true for indoor CO₂ and ASHRAE benchmark.

Table 4: One Sample t-test of Outdoor Air Quality Parameters for the Departmental Classroom in comparison with WHO and ASHRAE Benchmark

Outdoor Parameters	N	Mean	SD	t	df	MD	95% Confidence interval of the difference.		p	Remark	Decision
							Lower	Upper			
PM _{2.5}	215	12.35	8.26	-4.71	214	-2.65	-3.76	-1.54	0.00	Sig	Ho Rejected
PM ₁₀	215	15.22	10.51	-41.53	214	-29.78	-31.19	-28.36	0.00	Sig	Ho Rejected

CO ₂	215	472.00	38.36	-10.70	214	-28.00	-33.16	-22.84	0.00	Sig	Ho Rejected
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Note: p is significant at $p \leq 0.05$; test value of PM_{2.5} and PM₁₀ = 15 $\mu\text{g}/\text{m}^3$ and 45 $\mu\text{g}/\text{m}^3$ (WHO benchmark) while CO₂ = 1200 ppm (ASHRAE benchmark), SD = Standard deviation, t = t-value, df = Degree of freedom; MD = Mean deviation.

Table 4 shows the one sample t-test result between the outdoor air quality parameters around the classroom and the WHO/ASHRAE benchmarks. The sample consist of 215 data of PM_{2.5}, PM₁₀ and CO₂ measured around the classroom. For outdoor PM_{2.5}, the t-test result showed that the mean of the measured value of outdoor PM_{2.5} ($M = 12.35$, $SD = 8.26$) was different from the WHO benchmark ($t(214) = -4.71$, $p < .001$). For PM₁₀, the mean of the measured value of indoor PM₁₀ ($M = 15.22$, $SD = 10.51$) was different from the WHO benchmark ($t(214) = -41.53$, $p < .001$). Similarly, the mean of the measured value of outdoor CO₂ ($M = 472.00$, $SD = 38.36$) was different from the WHO benchmark ($t(214) = -10.70$, $p < .001$). The mean difference (MD) = -2.65 (PM_{2.5}), -29.78 (PM₁₀) and -28.00 (CO₂) with a 95% confidence interval ranging from -3.76 to -1.54 (PM_{2.5}), -31.19 to -28.36 (PM₁₀) and -33.16 to -22.84 (CO₂). This indicates that the average measured values of the outdoor PM_{2.5} and PM₁₀, as well as CO₂ are significantly lower than WHO and ASHRAE benchmark respectively. Hence, the null hypothesis which suggested that there is no significant difference between the measured values of indoor air quality parameters and WHO benchmark is rejected and the alternative hypothesis, there is significant differences between the measured values of indoor air quality parameters (PM_{2.5} and PM₁₀) and WHO benchmark is accepted. This statement is also true for indoor CO₂ and ASHRAE benchmark.

Conclusion

This study assessed the pattern of PM_{2.5}, PM₁₀ and CO₂ in a departmental lecture classroom during wet season at the University of Lagos and concludes that the average indoor PM_{2.5}, PM₁₀ and CO₂ within the classroom were 12 $\mu\text{g}/\text{m}^3$, 20 $\mu\text{g}/\text{m}^3$ and 673 ppm while the average outdoor PM_{2.5}, PM₁₀ and CO₂ were 12 $\mu\text{g}/\text{m}^3$, 15 $\mu\text{g}/\text{m}^3$ and 472ppm respectively. The average measured values of the pollutants are significantly lower than the benchmark, but at peak periods, the level of indoor PM_{2.5} becomes higher than the benchmark in wet season hence, could become unsafe, especially for people with health conditions such as asthma. Therefore, this study recommends that the air conditioners (mechanical ventilation) in the classroom must be constantly maintained, and kept at working conditions to prevent the triggering of asthma attack among asthmatic students within the classroom. This is important as the windows are usually not being opened.

Limitation

The instruments used in this study were low-cost monitors that are self-calibrated within 15 minutes of exposure to open air according to the manufacturer's manual, hence, no calibration against a reference grade instrument was done. The present study only presented results for wet season, hence may not be sufficient enough to infer for the entire year.

Acknowledgement

The researchers wish to acknowledge and appreciate the financial support from Wits-TUB-UNILAG Urban Lab programme through University of Lagos Centre for Housing and Sustainable Development, during the course of this study.

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Nomenclature/ Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CO ₂	Carbon dioxide
EPA	Environmental Protection Agency, Unite State of America
HVAC	Heating Ventilation and Air Conditioning
IAQ	Indoor Air Quality
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
TVOCs	Total Volatile Organic Compound
WHO	World Health Organization
µg/m ³	Microgram per cubic meter