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Assessment of Indoor Air Quality Parameters and Physical Building Characteristics in Selected University Libraries in Osun State, Nigeria

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Abstract

This study assessed the physical characteristics of university library buildings and indoor air quality parameters in Osun State, Nigeria. Survey research method combining observation of physical characteristics of the selected library reading spaces in relation to indoor air quality, and measurement of concentration of indoor air quality criteria pollutants using Portable hand-held DM 106A air quality monitor and carbon dioxide (CO_2) monitor. The results of the analysis revealed thus: window-to-wall area ratio (WWR) of both OAU and BOWEN libraries exceeded prescriptive maximum limit of 40%; indoor dust concentration through openings contrasted between OUI and BOWEN libraries and confirmed; outdoor temperature and relative humidity were below national metrological range and were significant ($p = 0.0015$ and $p < 0.001$ respectively); indoor CO_2 ranged between 415ppm and 626ppm but was below maximum allowable limit of 1000 ppm; Total Volatile Organic compounds and Formaldehyde levels could not be confirmed due to limitation of instrument; indoor $PM_{2.5}$ was significantly different across the libraries, ($p = 0.004$). Correlations between indoor and outdoor temperatures across the libraries showed very strong, linear and positive relationship, Pearson correlation coefficient = 0.926, p-value = 0.001; between indoor and outdoor relative humidity, Pearson correlation coefficient = 0.915, p-value = 0.001, strong and statistically significant relationship. The study concluded that the indoor air quality status of the selected university libraries was enhanced by appropriate composition of design elements in relation to the prevailing environmental parameters, and users' spatial functional requirements. However, subsequent study may deploy lower-limit sensitivity of gas chromatography or photo ionization detectors to ascertain the extent of Total Volatile Organic compounds and Formaldehyde in the reading space.

Keywords: Indoor Air Quality, Microclimate, Physical Characteristics, University Library, Osun State.

Introduction

Indoor air quality is primarily concerned with cleanliness of indoor air. According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 62.1-2007), Indoor Air Quality (IAQ) has been defined as "the nature of air inside a building that affects the health and well-being of building occupants". Tropical building envelope design composition essentially requires ventilation provision for indoor comfort through the openings. In such environments, windows form the primary means of regulating outdoor-indoor air movement, daylighting, and thermal comfort. Window design parameter, (window-to-wall ratio) and operability have a profound influence on indoor environmental performance, especially the indoor pollutants accumulation. The concerns for IAQ implications have made several researchers across different disciplines delve into its exploration.

Studies have affirmed multi-determinant nature of indoor air quality as consisting of the physical parameters, chemical emissions and biological contaminants (Khalafalla et al., 2018; Slezakova et. al. 2012). Physical factors include air temperature and humidity; chemical contaminants feature Volatile Organic Compounds (TVOC) and carbon dioxide (CO_2); and sources of biological contaminants include indoor growth of fungi and bacteria. The multi-dimensional nature and the impact of IAQ have necessitated several investigations in different facilities within the built environment- residential, health, commercial (office), industrial and educational facilities at both the primary, secondary and tertiary levels.

University communities are special because campuses provide buildings with intricate functions, such as laboratories, lecture halls, sports facilities, libraries and students hostel among others (Sesana et. al. 2016). University library building is a potential learning environment with vast academic resources, often refers to as the 'academic heart' of the institution. It offers personal and collaborative learning to great number of students and researchers who spend considerable time in the library. Therefore, its indoor air quality will impact the reading and learning efficiency of the users.

There are few existing studies on Indoor air quality in university libraries. Yet, university students spend ample time in the library. The library operation time ranges between 8 hours and 13 hours, while some academic libraries operate round the clock. In Nigeria, students spent between 1-2 hours on the average within the library (Cincinelli & Martellini, 2017; Yang (2017). Again, there is presently dearth of information on IAQ studies in library in warm humid climate. Yet, it has been noted that, microclimate and environmental factors like temperature and relative humidity largely influence library optimal functional performance (Afacan, 2017; Valeriani, 2017). Therefore, considering the potential pollutants envisaged within library building resulting from enormous volume of collections, stacked books-new and aging, furniture and state-of-the -art ICT equipment for virtual library; coupled with microclimatic impact, there is need to investigate IAQ of university library buildings especially in the warm humid tropical climate. Therefore, this study attempts to examine IAQ of university libraries within Osun State, Nigeria in a bid to contributing to generation of air sensor data in Osun State and Nigeria at large.

IAQ Measurement

The goal of IAQ measurement is to technically ascertain the presence of pollutants in terms of types and level of concentration within the given space. According to Khalafalla et al., (2018), analytical/experimental approach involving measurement of the concentrations of relevant IAQ parameters (e.g., PM, CO_2, VOCs, biological contaminants, air Temperature, Humidity) in the selected space in the building has been verified. Here, attention is paid to the detailed description of equipment used for measurement in term of type, placement location (height above floor level,

proximity to window and to the source of indoor pollutant) within the measured spaces, need for calibration, and error/accuracy level.

Very significant also are the seasons, duration and time interval of measured IAQ parameters (Khalafalla et al., 2018). Measurement season considers rainy season, dry season or both. Duration for measurement of IAQ parameters may be weekly, monthly or spanning a period of one year or more. On time interval, three stages of measurement task performance have been commonly reported. They are based on the assumption that there is a time evolution of acceptability values on air quality ((Kuchen & Fisch, 2009); Jimoh and Ogunrayewa, 2015). The first stage is until 12:00 am; the second stage starts at noon, between 12:00 am and 2:00 pm; and the third stage begins at 2:00 pm ((Kuchen & Fisch, 2009); Jimoh and Ogunrayewa, 2015). The timing corresponds with resumption hours, break time and closing hours in a study of IAQ in office building according to Jimoh and Ogunrayewa (2015). Besides, observation of possible sources of pollution, number of occupants staying in the space and if windows are opened or not are required during objective measuring procedure (Kuchen & Fisch, 2009).

Indoor Environmental Conditions

Indoor physical condition

Temperature and relative humidity are major physical factors affecting IAQ in the indoor space (Śmiełowska *et al.*, 2017). Uncomfortably high temperatures can cause discomfort, leading to uncomfortable postures such as slouching or slumping in the chair; cool air flowing directly down can cause cold feet and hands as well as increased muscle tension and increased tendinitis risk (Shittu *et al*., 2019).

Humidity greater than 70% causes microbial problems and less than 30% causes dry eyes and nasal membranes, greater rates of infection and skin itching and redness (Drougka *et. al*., 2020). Although 30-70% humidity is considered acceptable for the thermal comfort zone, the optimal range for IAQ is said to be 40-60% (Raymund, 2018). Also, the seasonal differences in the level of relative humidity have been noted to influence concentration of NO_2 in the library. NO_2 concentration tend to be higher in Summer than Winter (Andretta *et al*., 2016). A high relative humidity value facilitates the chemical reactions of NO_2, which form HONO or HNO3. There is high tendency for mould growth under warm condition and high humidity (Yang, 2017).

Indoor chemical condition

Beside hygrothermal air conditions- temperature and relative humidity; earlier investigation of library space especially Baroque in Portugal considered measurement of chemical condition consisting of carbon dioxide concentration values (CO_2, ppm) and concentrations of particulate matters (PM, µg/m3) (Pereira *et al*., 2017; Wu *et al*., 2018). According to Yang (2017), Shandong Women's University Library performed and analyzed the studies on indoor temperature, relative humidity, carbon dioxide, formaldehyde and respiratory particulate matter etc. Other typical indoor contaminants present in libraries are; volatile organic compounds (VOCs) such as organic acids like acetaldehyde, formic acid, and aldehydes (Wu *et al*., 2018).

Indoor Carbon dioxide (CO_2) has been used in evaluating and relating indoor air quality and ventilation in buildings (Kudiváni & Krajčík, 2016). Indoor CO_2 is sometimes considered a measure of the efficiency/adequacy of fresh air recharge in relation to indoor occupant density and metabolic activity. Several relationships exist between the IAQ and the CO_2 concentration include the effect of increased CO_2 concentration on health, the influence of CO_2 on the perceived air quality, the relationship between the CO_2 concentration and the concentration of other pollutants, and the relationship between the CO_2

concentration and the ventilation intensity. The CO_2 can be a good IAQ indicator in cases, when the pollution generated depends on the measure of human occupancy in the space. The CO_2, though a good indicator of human emissions, is often a poor indicator of the overall perceived quality of the air, because it does not consider a number of pollution sources, such as building materials, tobacco smoke and cleaners (Kudiváni & Krajčík, 2016). The effect of strangely high Carbon dioxide within indoors may lead to drowsiness, headaches, or low productivity levels.

Compounds of Aldehyde - formaldehyde is the simplest aldehyde that has a colorless gas with a pungent odour at normal room temperature; and is a reactive indoor pollutant that can cause airway discomfort at low levels (Jalaludin *et al*. 2014). Formaldehyde sources in indoor environments have been categorized into seven groups according to WHO (2010). The grouping includes (i) furniture and wood items containing resins based on formaldehyde like particleboard, plywood and fiberboard with a medium density. (ii) materials used in insulation; (iii) textiles; (iv) do - it-yourself things, such as wallpapers, paints, adhesives, glues, lacquers and varnishes. (v) Household cleaning accessories, such as disinfectants, detergents, carpet cleaner adhesives, and shoe products. (vi) Cosmetics, including liquid soaps, shampoos, nail varnishes and nail hardeners. (vii) Electronic equipment including photocopiers and computers; and (viii) other consumer goods, such as insecticides and paper products. (Wu *et al*, 2018) also observed high level of indoor formaldehyde in the library due to old newspapers and books. The explanation for this may be that a number of VOCs are known to emit during degradation from paper and other cellulose-based materials. There is also a significant increase in the concentration of formaldehyde in newly painted interior surfaces.

Occupants exposed to even low formaldehyde levels may experience irritating effects such as increased sensitization and asthma. The International Agency for Cancer Research (IARC) reclassifies formaldehyde as a human carcinogen (Group 1) from the earlier classification as carcinogenic (Chemical group 2A) based on laboratory animal studies. This is based on “ample epidemiological evidence that formaldehyde induces human cancer of the nasopharyngeal " (*Gune et al.* 2022).

Volatile Organic Compounds (VOC’S) - The description of VOC was given as composed of high vapour pressure organic chemical compounds that can vaporize substantially and enter the atmosphere under normal condition. They have been affirmed to be widely found indoors (*Gune et al*. 2022). VOCs are emitted through different types of indoor products, such as cleaning agents, building materials and furnishings, paints and lacquers, adhesives and wall boards, office equipment such as copiers and printers, carbonless copy paper, correction fluids, permanent markers and photographic solutions (*Gune et al.* 2022).

Pollutant’s secondary reaction is common among VOC’s odours emitted from building materials and furniture (Shittu *et al*., 2019). Śmiełowska *et al.* (2017) opines that attention should be given to the risk of emitting VOC from products made from books: paper, parchment, leather, cardboard, etc. Paper products have also been shown to be a source of formaldehyde in indoor air. Cellulose fibre in the paper structure has been observed to undergo decomposition whereby paper changes to yellow and become brittles whenever there are NO_2 and SO_2 gases in the air and with increased relative humidity that lowers the pH value of paper (Śmiełowska *et al.*, 2017).

The effects of most VOCs have been noted to be nephrotoxic, neurotoxic or hepatotoxic, or can be carcinogenic, and many can harm the blood components and cardiovascular system and cause gastrointestinal disorders (*Gune et al.* 2022).

Indoor particles - “Indoor particles”, “airborne particulates”, or “aerosols”, are the descriptive words used when addressing particles. The term “particulate matter” (with abbreviation PM) is often used as a synonym for particles in pollutants science (Slezakova *et al.,* 2012). Particulate matter, according to

World Health Organization (WHO) is a mixture of small particles and droplets such as solid and liquid acids, organic chemicals, metals, earth, dust, smoke, and soot, which are suspended in air (Özdamar & Umaroğullari, 2018).

Indoor particle generation could either be of outdoor sources and indoor sources. Fine and ultrafine particles concentration have been reported to be from outdoor sources through vehicle exhaust (Quang *et al.,* 2013; Slezakova *et al.*, 2012). Moreover, these particles can be transported into the building by penetrating through the envelopes and mechanical ventilation systems. The particles undergo photochemical reactions and form new particles (Quang *et al.,* 2013). Indoor particle sources are generated through occupants' indoor activities, operation of certain equipment, and indoor deposition either through movement in and out or by transportation through ventilation means.

Of all the different sizes of particulate matters, PM1 has been considered most dangerous because it can be easily inhaled by our respiratory system, and then transported deep down the lung and then metabolizes in the blood stream causing deadly diseases such as heart attacks and lung cancer (Mfarrej *et al*., 2017). The size of the effect depends on the diameter of the pollutants as well as on the individual factors. As the particulate size decreases, the adverse effect on health increases. While PMs with a diameter greater than 10 microns are trapped in the mouth and nose, small particles with a diameter of 10 microns can pass through the mouth and nose to the respiratory system (Özdamar & Umaroğullari, 2018).

MATERIALS AND METHODS

Out of the nine universities existing in Osun State, one of the institutions did not have a purpose-built library building as at the time the study was being conducted. It was therefore discarded. The rest eight were categorized in line with Fantuzzi et al. (1996). The study examined IAQ in sixteen library buildings of the University of Modena, Northern Italy. They categorized the libraries into three based on the total floor area. The first group was referred to as very small library. They have floor area less than or equal to $100m^2$. The second group was labelled large library ($100\text{-}1000m^2$) and the third group were those libraries with area more than ($> 1000m^2$) as wide library. This study adopted total floor area as criteria for library classifications into very small ($\leq 100m^2$.), medium ($100\text{-}1000m^2$) and large library ($> 1000m^2$). The study focused on large library. The reason was due to the large area for users and furniture that could inform better IAQ evaluation. Simple random sampling without replacement was used to select three university libraries; which are Obafemi Awolowo university library, Oduduwa university library and BOWEN university library. Ethical approval for the study was sought via letters of introduction submitted to the authority of the selected University libraries and approval were obtained.

DM 106A air quality monitor supports: formaldehyde (HCHO) test concentration range: 0 ~ 1.999mg / m^3, TVOC test concentration range: 0 ~ 9.999mg /m^3, PM $_{2.5,}$ $PM_{1.0}$ and PM_{10}. It employs semi-conductor sensor technology using diffuse collection method to detect concentrations of formaldehyde and total volatile organic compounds in the air; while the instrument used laser scattering principle to detect particulate matters in three seconds. Instrument calibration was achieved by operating it outdoor where there is no identified pollutant for 5 – 10 minutes.

Perfect prime CO_2 /Temperature/Relative humidity logger uses Non-Dispersive Infrared (NDIR) sensor – a waveguide technology with automatic background calibration (ABC) for its operations. Its parameters detection covers Carbon dioxide (CO_2) range: 0 ~ 9999 ppm (Out of scale) at accuracy level of ± 50ppm ± 5% reading (0~ 2000) in 10 seconds. Temperature range is 10 ~ 70°C (14 ~ 158°F) at

accuracy level of ± 0.6°C / ± 0.9°F) – (0~50°C / 32 ~ 122°F), others ± 1.2°C and Humidity range is 0.1 ~ 99.9% at accuracy level of ± 3% (10 ~ 90%).

The study ensured careful onsite observation of the selected library buildings. The buildings physical characteristics were documented. These entailed building total floor area, floor height, area and headroom of reading room, window type and size, window to wall ratio, window to floor ratio, internal finishes (wall, floor and ceiling) and ventilation system.

Portable hand-held DM 106A air quality monitor and Perfect Prime CO_2 / Temperature/Relative humidity data logger were used to determine concentration level of pollutants in the reading spaces of the selected university libraries. Based on the review of existing literature, the air quality parameters of concern in this study consist of: formaldehyde, volatile organic compounds, particulate matters, CO_2, temperature and relative humidity. The instruments were placed at the middle of the reading rooms, at height of 1.0m and minimum of 4.0m distance from the windows, based on the configuration of the space. Readings of the measured IAQ parameters were recorded at interval of 2 hours for one week (from Monday to Friday), between 8.00am to 4.00pm or 6.00pm depending on library opening schedules. The readings were taken in the month of June 2022. For every indoor measurement, outdoor climatic parameters were recorded. This was meant to facilitate calculation of daily average readings.

FINDINGS/DISCUSSION

Physical characteristics of selected library buildings

Table 1 shows the observed and documented physical features of the selected library buildings. These consist of building form, orientation, building size/area (m^2), number of floors, building age, occupancy (reading spaces capacity), ventilation design, window design/type, potential outdoor pollutants and outdoor IAQ enhancement features.

Library form, orientation, size/area and floor height

Essentially, the forms of the selected libraries are rectangular, and their orientations all conform to North-South direction which has been noted to be advantageous for natural ventilation intake to the building. The library orientation depicts the designers' consciousness of its impacts on building operation. The total area coverage of the libraries varies, OAU Library has total area coverage of $8,830m^2$, OUI Library has area of $1,875m^2$ while BOWEN Library has $4,500m^2$ total area. OAU Library comprises of four (4) floors in all including basement, while OUI and BOWEN Libraries have three (3) floors each. Different factors such as regulations, economy and users' functional requirements might have informed library designed area and floor height among others. The study that examined influence of height as one of the building characteristics on ventilation effectiveness in high rise residential apartment established direct building height impacts on the indoor air temperature and wind (Aflaki et al., 2014). However, the height of the selected libraries may not impose any significant IAQ challenge due to the fact that the library buildings are low rise, and may be subjected to similar indoor condition at that altitude.

Age and occupant-floor ratio of the library buildings

Documentation of field observations on age of the library buildings as shown in table 1 revealed that OAU Library building was 63 years old (1959), OUI Library was 9 years old (2013) and BOWEN Library was 10 years old (2012) as at the time the study was carried out. The association between age of building and IAQ implication has been established in the literature. Older buildings, that is, those in existence more than 10 years have peculiar IAQ problems different from newer ones; that is, less than

10 years in existence. The total estimated occupant capacity for OAU Library building was 2640, while that of OUI Library was 1420, and BOWEN Library was 1480. Occupant per floor ratio for the buildings were thus 0.30 m^2/person, 0.76 m^2/person and 0.33 m^2 /person for OAU, OUI and BOWEN libraries respectively.

Ventilation design of selected library buildings

All the library buildings deployed mixed ventilation design at varying degrees. OAU Library deployed natural ventilation design by several indications (as noted in table 1), however this was supported with provision of fans in the reading rooms. OUI Library ventilation design was a hybrid system. Although windows were installed but rarely opened except during power outage because the building operated air condition most times. Also, provision was made for ceiling fans at the same time. In BOWEN Library, the library building incorporated large window designed for natural ventilation with free-standing split unit air conditioner; a typical of hybrid system. However, the reading space ran constantly on natural means of ventilation during the study. This was due to regular electro-mechanical faults of the air conditioning system that could not be rectified as at the time of data gathering.

The ventilation design of the selected library buildings expresses high level of consciousness of both the advantage and the disadvantage of natural ventilation system especially considering its suitability under warm humid tropical climate of the study area. Several studies have revealed both positive and negative association of natural ventilation with the indoor air quality of buildings (Bortolini & Forcada, 2021; Poza-Casado et al., 2021; Zou et al., 2012).

Window type and use pattern

Louvre blade window with aluminum carrier was installed in library building of OAU. This suggests 100% free running ventilation in the building and its age as a post independent era development. OUI Library window type was a composite of aluminum upper fixed-light and lower projected window while BOWEN Library has a composite of aluminum upper fixed-light and lower sliding window plus aluminum clerestory sliding window. Incorporation of clerestory sliding windows in BOWEN library emphasized in a strong sense the importance of achieving natural ventilation through stack effect.

Table 1: Physical characteristics of selected library buildings

	OAU Library	OUI Library	BOWEN Library
Physical Characteristics of Selected Library Buildings			
Building Form	Rectangle	Rectangle	Rectangle
Orientation	North-South Direction	North-South direction	North-South Direction
Building Size/Area (m^2)	8,830m^2	1,875m^2	4,500m^2
No. of Floors	Four (4), plus Basement	Three (3)	Three (3)
Building Age	1959 (60yrs)	2013 (8yrs)	2012 (9yrs)
Occupant (Reading spaces capacity)	2640	1420	1480
Ventilation Design	Natural + Fans	Hybrid (Natural + A/C and Fans)	Hybrid (Natural + A/C)
Window Design/Type	Louvre	Composite of	Composite of

	OAU Library	OUI Library	BOWEN Library
		fixed-light and openable aluminium projected window	fixed-light and openable aluminium sliding window
Window use	Always opened	Remained closed all days, except during power outage	Always opened
Potential Outdoor Pollutants sources	-Photocopy centre -General car park - Generator plant -Temporary refuse collection point	- Parking lots	- Parking lots
Outdoor IAQ enhancement features	-Adequate landscape/green area -Adequate open courtyard -Cantilevered R.C window hood -Limited paved area	-Moderate landscape/green area -Closed courtyard	-Adequate landscape/green area -Closed courtyard

Source: Authors' field work, 2022

Window use pattern of library building at OAU as observed was frequently opened. At OUI Library, the windows were hardly opened due to the fact that the building ran on air conditioner except during power outage when power back up (generator) was not in operation. Window use pattern of library building at BOWEN was regularly opened. The driving factors for window-opening behaviour have been noted to include; time, indoor and outdoor environmental parameters. Deng et al., (2020) conducted logistic regression coefficients analysis to determine the factors affecting window-opening behaviour. It was found that the main factors affecting the window-opening behaviour were indoor temperature, indoor RH, indoor CO_2 concentration, indoor $PM_{2.5}$ concentration, outdoor PM_{10} concentration and outdoor $PM_{2.5}$ concentration.

Physical characteristics of selected reading spaces

Apart from the general observation of the selected library buildings, the physical characteristics of the selected reading spaces where measurements were taken were documented. As shown in table 2, these consisted of wall/envelope material, window -to- floor ratio, window -to- wall ratio, headroom, occupancy/floor ratio, internal finishes, and furniture and equipment in line with submissions by Senitkova, (2017), Yang, (2017) and Bortolini & Forcada, (2021). These parameters have been noted to impact indoor air quality of a space.

Wall/envelope material

Table 2 shows the wall/envelope material used in all the three selected reading spaces as sandcrete block. The impact of wall envelopes on IAQ through their thermal properties has been generally observed. Sandcrete block particularly has been reported to have good heat absorption that influences indoor environment.

The effect of building envelope constructed with different materials- brick, glass, stone, and gypsum on thermal comfort of buildings was conducted in Jeddah, Saudi Arabia (Omar and Rehumaan, 2022). The

differences in temperature of the indoor and outdoor environments of these materials were taken into consideration. It was found that building envelope with glass and brick were more effective in transferring less heat to the indoor. Building envelope with glass achieved more thermal comfort compared to other materials and at the same time building envelope with brick was more effective if the thickness of the envelope is more. Other factors of building wall/envelope that impact IAQ are: wall-to-floor ratio and wall-to -window ratio.

Window-to-floor area and window-to-wall area ratio of the selected reading spaces

The ratio of external operable window area to useable floor area is an important early window design consideration for good IAQ and thermal comfort. Field observation of the selected reading spaces, using total useable floor area; revealed their window-to-floor area ratio (WFR) thus: 0.22, 0.16 and 0.39 for schools A, B and C respectively. See table 2. These figures correspond to Whole Building standards which stipulate a range of 0.1 – 0.5. Meanwhile, ASHRAE 90.1, (2013) requires 0.4 WFR in order to achieve adequate natural ventilation in the indoor space.

Table 2: Physical characteristics of selected library reading rooms

	OAU Library	OUI Library	BOWEN Library
Physical Characteristics of Selected Reading Spaces			
Wall/Envelope Material	Sandcrete block	Sandcrete block	Sandcrete block
Total Floor Area	765	200.16	448
Useable Floor Area	468	200.16	226.80
Area of enclosed wall	151.12	185.19	204.1
Total Area of Windows	102	31.68	89.1
Window-to-floor ratio	0.22 (21.79%)	0.16 (15.83%)	0.39 (39.29%)
Window-to-wall ratio	0.67 (67.50%)	0.17 (17.11%)	0.44 (43.66%)
Headroom	3.1m	3.55m	4.0m
Occupancy	264	78	72
Occupancy/floor ratio	1.77	2.57	3.15
Internal Floor Finish	Terrazzo	Vitrified tiles	Timber board
Internal Wall Finish	Paint on screeded wall	Paint on screeded wall	Paint on screeded wall
Internal Ceiling Finish	Paint on r.c ceiling	Paint on r.c ceiling	Suspended false ceiling
Furniture	Timber furniture	MDF fab. furniture	MDF fab. furniture
Equipment	None	None	None

Source: Authors' field work, 2022

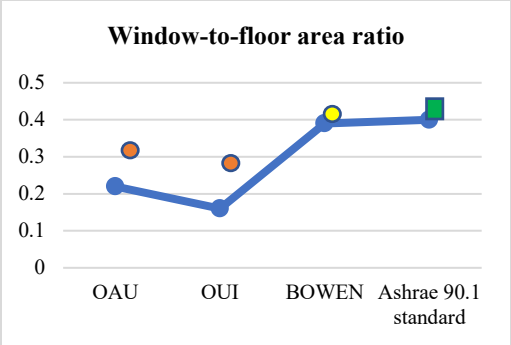


Figure: 1: Window-to-floor area ratio in relation to Ashrae 90.1 standards

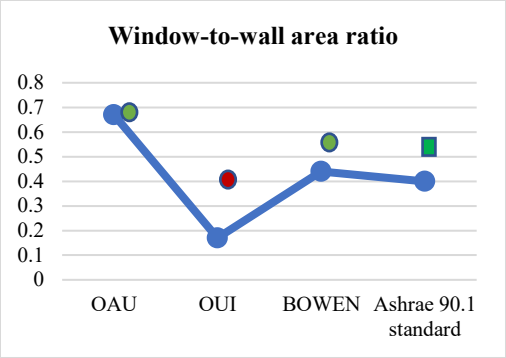


Figure 2: Window -to-wall area ratio in relation to Ashrae 90.1 standard

According to table 2, the window-to-wall area ratio (WWR) observed at OAU Library was 0.67 (67.5%), while OUI and BOWEN Libraries have 0.17 (17%) and 0.44 (44%) respectively. According to ASHRAE 90.1(2013), the prescriptive maximum window-to-wall ratio (WWR) is 40%. The WWR of OAU and BOWEN Libraries reading spaces exceeded the prescriptive maximum figure. This suggests possibility of increased solar heat gain and high concentration of outdoor/indoor movement of particulate matters depending on window opening pattern and other factors. An empirical study conducted by Alwetaishi & Taki, (2020) on the influence of window-to-wall ratio (WWR) in various climatic regions in Saudi Arabia recommends that WWR in hot dry or hot humid climates should not exceed 10% in all directions due to the harshness of the climate, while the WWR can be as high as 20% in moderate climates.

Occupancy/floor area ratio of the selected reading spaces

Table 2 shows the capacity of the selected reading spaces as: 264 in OAU Library, 78 in OUI Library and 72 in BOWEN Library. Occupancy/useable floor area therefore were; 1.77 m^2/person in OAU Library, 2.57 m^2/person at OUI Library and 3.15 m^2/person at BOWEN Library. The minimum floor area required for individual work station in library according to Archi-data is 2.5 m^2. Consequently, the occupancy/floor area of OAU Library reading space was below minimum standard while those of OUI and BOWEN Libraries exceeded the minimum area requirement. At the peak library occupation period, OAU library reading space may likely be over-populated/congested thereby leading to exhaust of indoor air and then poor indoor IAQ.

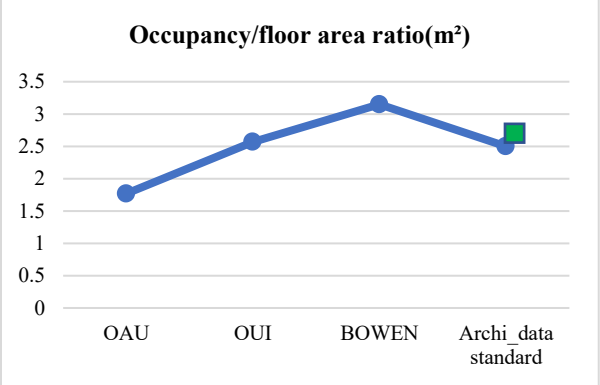


Figure 3: Library occupancy/floor area ratio in relation to Arch Data standard

Indoor air quality parameters

Indoor air Temperature

The measured temperature patterns varied across the University Libraries. From figure 4, the least average temperature measurement was 28.5 ºC at opening hour in OAU Library. The same reading was obtained two hours later at OUI Library as the lowest average temperature. Meanwhile the highest average indoor temperature reading, 35.7 ºC was recorded at 2.00pm in OAU Library. This was followed by 33.6 ºC recorded at 4.00pm in OUI Library and 31.8 ºC recorded both at 2.00pm and at 4.00pm in BOWEN Library. Generally, the highest indoor temperature readings were taken between 12 noon and 6.00pm across the libraries. The average ambient temperature reading from meteorological station during the period the physical measurements were taken indicated a range of 30 – 36 ºC as mild while 41 ºC as harsh temperature for the period. Indoor temperature readings fall within the national ambient readings.

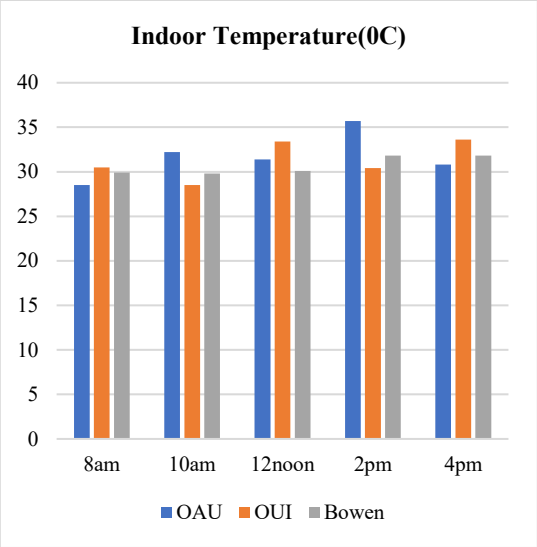


Figure 4: Weekly bi-hourly average indoor temperature

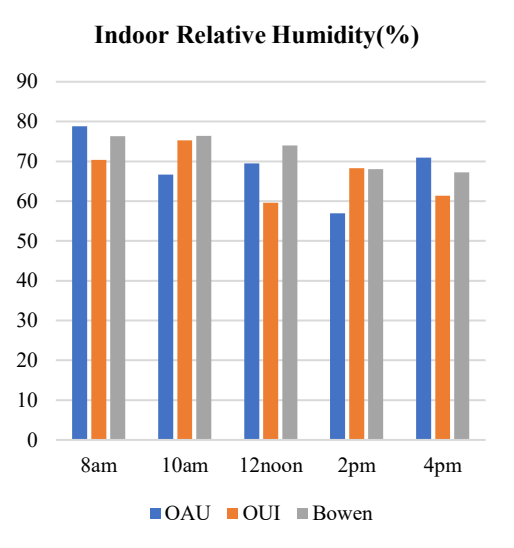


Figure 5: Weekly bi-hourly average indoor relative humidity

Indoor relative humidity

Figure 5 shows the data obtained from measurement of indoor relative humidity (RH). Highest readings were obtained at the morning hour across the libraries. OAU Library recorded 78.8% at 8.00am; OUI Library measured 75.3% at 10.00am while BOWEN Library was 76.4 % at 10.00am. Meanwhile, the lowest RH reading at OAU Library was 56.9% at 2.00pm. At OUI Library, lowest reading was obtained as 59.6 % at 12.00 noon while at BOWEN Library; the lowest reading was 67.2 % at 4.00pm. It is difficult to explain the sharp difference in RH reading at BOWEN Library in which its moisture dispense rate dragged till 4.00pm unlike the other Libraries where the lowest readings were obtained at the period when temperature was at the peak. RH condition at BOWEN Library suggests possibility of condensation in the reading room.

Indoor Carbon dioxide (CO_2)

Carbon dioxide (CO_2,) readings across the libraries according to figure 6 reveals the lowest at OAU Library as 445ppm while the highest was 515ppm. The highest CO_2 reading was obtained at occupants'

peak period at 2.00pm. At OUI Library however, the lowest CO_2 reading was 518ppm at 4.00 pm, while the highest was 626 ppm at 8.00am. In BOWEN Library, the lowest CO_2 reading was 415 ppm while the highest was 450ppm at 12.00 noon. OUI Library exhibits in general term a higher concentration of CO_2 when compared to other University Libraries. This could be as a result of keeping the windows closed almost at all times due to regular operation of air conditioner. Windows were opened only when there was power disruption and the power back up was not in use. According to Deng *et al.,* (2020) high concentration of indoor CO_2 is a function of regular closure of windows. Generally, the CO_2 readings across the libraries were below the maximum allowable limit of 1000ppm recommended by ASHRAE 92.1 (2019).

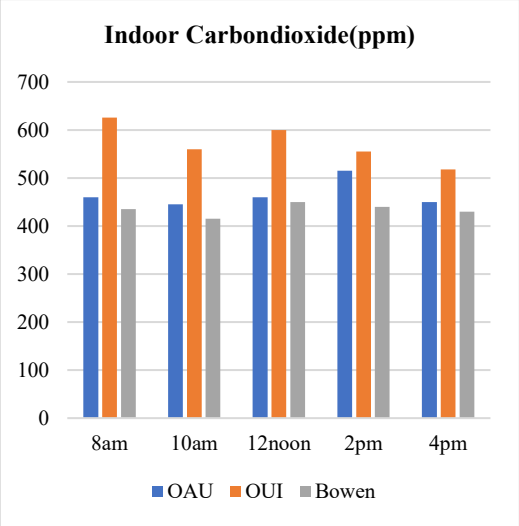


Figure 6: Average Indoor Carbon dioxide (CO_2,)

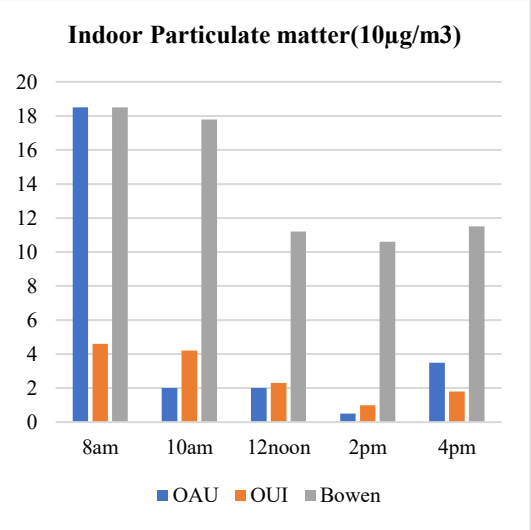


Figure 7: Weekly bi-hourly average indoor particulate matters 10.0 (PM_{10})

Total Volatile Organic Compound (TVOC) and Formaldehyde (HCHO)

On the assessment of the presence of total volatile organic compound (TVOC) and formaldehyde (HCHO) in the reading spaces, the instrument could not detect the presence of the chemical pollutants. This suggested possible limitation of the instrument. Meanwhile, the hand-held DM 106A air quality monitor used for the measurements has manufacturer's sensor specifications for formaldehyde (HCHO) test concentration range from 0 – 1.999 mg/m^3 and TVOC test concentration range as 0 - 9.999 mg/m^3.

Indoor Particulate matters 10.0

Evaluation of indoor particulate matter 10.0 (PM_{10}) from the selected library reading spaces as shown in figure 7 informed thus: in OAU Library, the highest reading was 18.5 µg/m^3 at 8.00am while the lowest reading was 0.5 µg/m^3 at 2.00pm; OUI Library's highest reading for PM_{10} was 4.6 µg/m^3 at 8.00am while the lowest reading was obtained at 2.00pm as 1.0 µg/m^3. Also, in BOWEN Library, the highest reading was 18.5 µg/m^3 at 8.00 am and the lowest was 10.6 µg/m^3 at 2.00 pm. These records showing high concentration of PM_{10} in the morning and low in the afternoon suggest the effect of building maintenance especially morning cleaning exercise which has been established in the existing literature. The concentration of PM_{10} gradually increased toward closing time of the library might be as a result of occupants' movement. As it can be observed in figure 7, the low readings of PM_{10} at OUI Library confirmed outdoor/indoor transmission of dust through infiltration because the windows were mostly closed, the concentration of dust particles was rather low compared to other Libraries where

windows were always opened. Also, the sharp difference in the concentration of PM_{10} at BOWEN Library compared to other Libraries especially at 2.00pm may be traced to its window design on all the enclosing walls of the reading space, window use pattern of regular opening and the use of timber particle board which collect dust as floor finish. This might increase the outdoor/indoor transmission rate of $PM_{10.}$ However, PM_{10} readings across the libraries were below the maximum allowable concentration of 150 µg/m^3 (24-hrs) according to ASHRAE 92.1, (2019).

Indoor Particulate matters 2.5

The readings of indoor particulate matters 2.5 ($PM_{2.5}$) exhibits similar trait as PM_{10}. Figure 8 shows the highest reading of $PM_{2.5}$ at OAU Library to be 16.8 µg/m^3 at 8.00am while the lowest reading was 3.5 µg/m^3 at 2.00pm. In OUI library, the highest reading for the pollutant was 5.8 µg/m^3 at 8.00am and the lowest reading was 3.5 µg/m^3 at both 2.00pm and 4.00pm. BOWEN Library highest reading for $PM_{2.5}$ was 16.8 µg/m^3 at 8.00 am while its lowest reading was 10.0 µg/m^3 at 4.00pm. Again, $PM_{2.5}$ readings at BOWEN library were generally higher compared to other libraries. The factors that might be responsible for this would be similar to those discussed for $PM_{10.}$ However, $PM_{2.5}$ readings across the libraries were below the maximum allowable concentration of 35 µg/m^3 (24-hrs) according to ASHRAE, (2019).

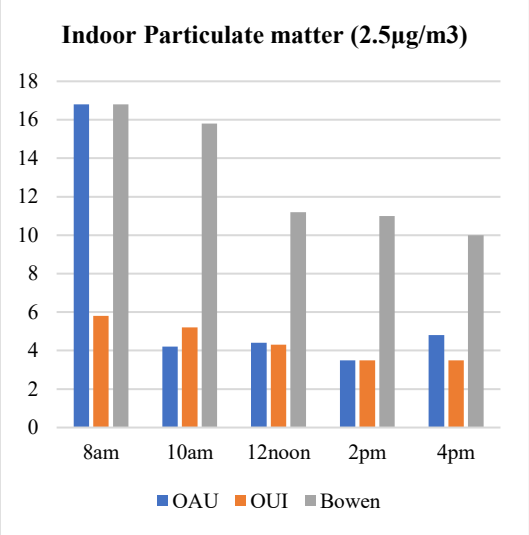


Figure: 8: Weekly bi-hourly average indoor particulate matters 2.5 ($PM_{2.5}$)

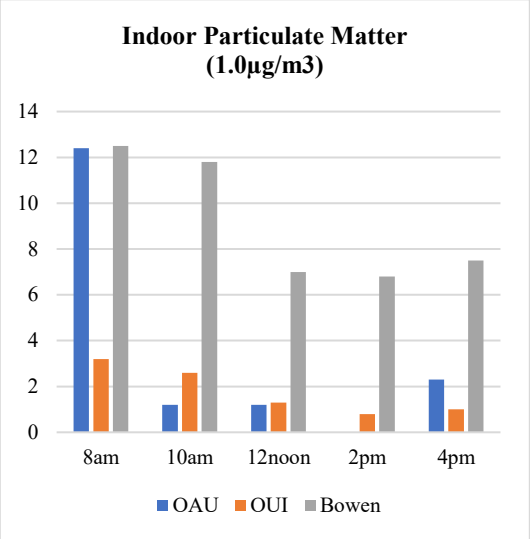


Figure 9: Weekly bi-hourly average indoor particulate matters 1.0. ($PM_{1.0}$)

Indoor Particulate matters 1.0.

Investigation of the extent of the presence of ultrafine particulate matter 1.0 ($PM_{1.0}$) in the selected reading spaces shown in figure 9 reveals that, at OAU Library, the highest value of $PM_{1.0}$ was 12.4 µg/m^3 at 8.00 am while the least reading was 0 µg/m^3 at 2.00 pm. OUI library's highest reading for $PM_{1.0}$ was 3.2 µg/m^3 at 8.00 am and its lowest reading was 0.8 µg/m^3 at 2.00pm. At BOWEN library, the highest obtained reading for the pollutant was 12.5 µg/m^3 at 8.00 am while the lowest reading was 6.8 µg/m^3 at 2.00pm. As earlier observed, indoor particulate matters' behaviour tends to be very similar during active occupation of the space. OUI library, being air conditioner operated most times maintained low concentration of particulate matters $PM_{1.0,}$ however, BOWEN Library exhibit high

concentration of the pollutant more than other Libraries, perhaps due to multiple windows installed on the reading space's envelope.

Relationships among measured outdoor and indoor temperature across the libraries

The mean and standard deviation values for outdoor temperature across the libraries indicated 27.53 and 1.29 at OAU Library, 26.72 and 0.43 for OUI Library while BOWEN Library was 27.16 and 0.97 respectively. Comparison of outdoor temperature across the libraries was not statistically significant, p-value = 0.472. For indoor temperature of the reading spaces, the mean and standard deviation values across the libraries revealed 31.5 and 1.29 at OAU Library, 29.63 and 2.63 for OUI library while BOWEN Library was 29.15 and 2.50 respectively. Meanwhile, the comparison of the indoor temperature was not statistically significant across the libraries, p-value = 0.246.

Relationships among measured outdoor and indoor relative humidity across the libraries

Comparison of outdoor relative humidity across Libraries unveiled the mean and standard deviation values as 70.10 and 4.96 at OAU Library, 65.72 and 5.85 for OUI Library, while BOWEN Library recorded 71.51 and 2.91 respectively.

Comparison of outdoor relative humidity across the libraries was not statistically significant, p-value = 0.193. Meanwhile, comparing indoor relative humidity across the libraries, the mean and standard deviation values were obtained thus: OAU library, 69.01 and 3.54; OUI library, 64.30 and 4.80 while BOWEN library was 72.65 and 2.36 respectively. The result was statistically insignificant, its p-value = 0.130.

Relationships among measured particulate matter $PM_{2.5}$ across the libraries

Comparing the trend of the concentration of particulate matter $PM_{2.5}$ across the libraries, the mean and standard deviation values were obtained for OAU library as 6.36 and 3.60; 4.30 and 0.99 at OUI library while 14.01 and 6.87 was obtained for BOWEN Library. As indicated in table 3, comparison of $PM_{2.5}$ across the libraries was statistically significant, p-value = 0.012.

Correlation between indoor and outdoor temperature across the library

The Pearson correlation analysis between indoor and outdoor temperature of the selected library buildings shown in figure 10 indicated very strong, linear positive relationship between the variables across the libraries. Pearson coefficient is 0.926, which is statistically significant (p-value = 0.001).

Correlation between indoor and outdoor relative humidity across the library

The indoor and outdoor relative humidity across selected library buildings expressed linear, very strong positive relationship across the libraries. Figure 11 shows Pearson coefficient is 0.915, and it is statistically significant (p-value = 0.001).

Table 3: Relationships among measured air quality parameters across selected libraries

Variables	OAU library Mean(SD)	OUI library Mean(SD)	BOWEN library Mean(SD)	Statistics
Indoor temperature	31.5 (1.29)	29.63(2.63)	29.15(2.50)	F=1.581 df=2 p= 0.246
Outdoor temperature	27.53(1.41)	26.72(0.43)	27.16(0.97)	F=0.801 df=2

Variables	OAU library Mean(SD)	OUI library Mean(SD)	BOWEN library Mean(SD)	Statistics
				p= 0.472
Indoor relative humidity	69.01(3.54)	64.30(4.80)	72.65(2.36)	F=6.379 df=2 p= 0.130
Outdoor relative humidity	70.10(4.96)	65.72(5.85)	71.51(2.91)	F=1.893 df=2 p= 0.193
Indoor PM 2.5	6.36(3.60)	4.30(0.99)	14.01(6.87)	F=6.529 df=2 **p= 0.012**

F denotes test of Analysis of Variance; SD denotes Standard Deviation

Source: Authors'field work, 2022.

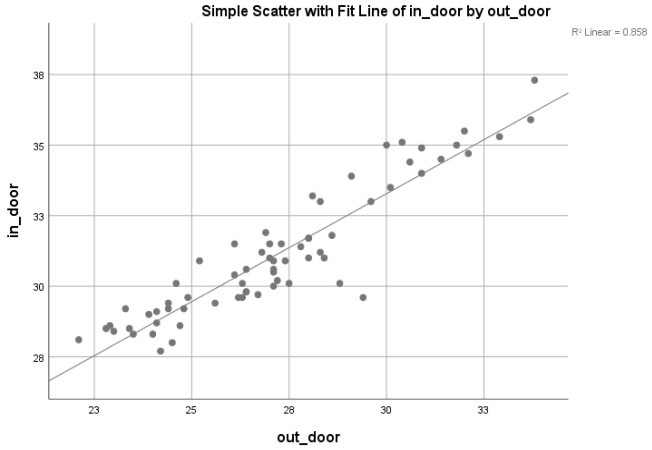


Figure 10: shows positive correlation between indoor and outdoor temperature. Pearson coefficient is 0.926, which is statistically significant (p= 0.001)

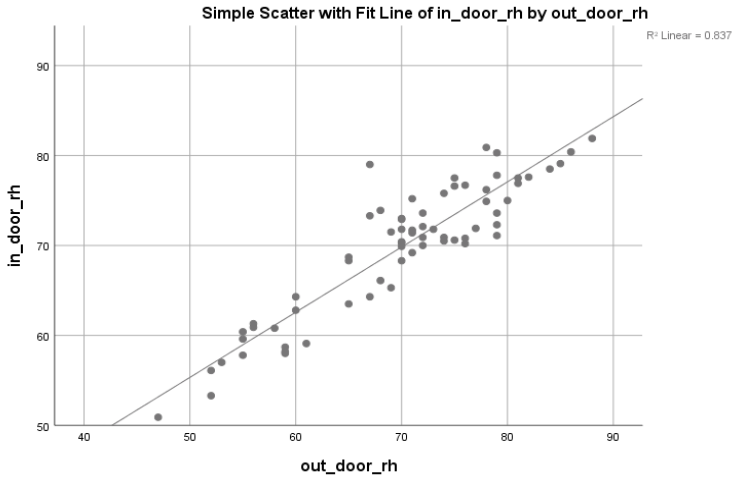


Figure 11: shows positive correlation between indoor and outdoor relative humidity. Pearson coefficient is 0.915, which is statistically significant (p= 0.001)

CONCLUSION AND RECOMMENDATION

The study evaluated indoor air quality of the University libraries in Osun State. Based on the objective measurement, findings reveal that: particulate matters and Carbon dioxide concentration were below maximum limits, Total volatile organic compound and Formaldehydes could not be detected due to limitation of the instrument, average indoor temperature was within mild temperature range by national meteorological reading. There is a strong indication that the indoor air quality of the selected libraries is enhanced. Although the deployment of lower sensitivity gas chromatography detector in subsequent studies may ascertain status formaldehyde and total volatile organic compound in the reading space. It further affirms that, achieving a safe and healthy indoor air quality of an academic library would require appropriate composition of design elements in relation to the prevailing environmental parameters and users' spatial functional requirements with due consideration for their population. Hence the study recommends thus: architects should ensure proactive evaluation of elements of building characteristics with respect to window-to-floor area ratio and window-to-wall area ratio in relation to spatial functional requirements and population of users of an academic library and other similar public buildings. In addition, appropriate level of indoor temperature and relative humidity with innovative design of internal dust exclusion mechanism should be ensured through excellent composition of elements of building design and outdoor environmental planning. Further study would be required on measurement of the library indoor air quality across the seasons.

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