Evaluating indoor environmental performance of laboratories in a Northern Nigerian university

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Abstract: Poor environmental comfort in learning spaces can have an impact on the learning capacities of students. It is not unusual to find learning spaces in Nigerian higher institutions in which the indoor environmental qualities do not meet the occupants' requirements. Despite being in the tropics, where solar radiation is in abundance, Nigerian building industry professionals pay little attention to passive energy utilization. Knowing how buildings perform in the country may appeal to their consciousness in reconsidering this situation. This paper is part of an ongoing study on comfort in higher education facilities involving lecture theatres and laboratories in Bayero University, Kano, Nigeria. Objective and subjective assessments were undertaken during the wet-warm season of August 2016. It reports the assessment conducted on two laboratories, with a view to finding how they perform environmentally in comparison to occupants' preferences and international comfort standards. Although some of the measured and calculated physical parameters, have not met the thresholds specified by ASHRAE-55 and EN 15251, the respondents expressed their acceptance of the laboratories' situations subjectively. This is not surprising as these standards are often based on experiments implemented in developed countries, where the severity of the climatic conditions and the culture are dissimilar to sub Saharan Africa.

Keywords: IEQ, Predicted Mean Vote, Predicted Percentage of Dissatisfied, Kano, Nigeria

Introduction

Indoor environmental quality (IEQ) investigations in several buildings, such as offices, hospitals, schools and shopping malls, have been on the increase since the middle of the last century. Such an increase in the studies could be attributed to the concern of the adverse effect poor IEQ has on people's comfort and wellbeing, which potentially affects their productivity and performance (Dias Pereira et al., 2014; Heath & Mendell, 2002). As vividly captured by Almeida (2014), that it is the combination of rising indoor occupancy levels, health requirements, environmental concern, new construction practices, rising occupants' expectations, development of new indoor finishes and the desire to cut down on energy *costs* that led to the need of the IEQ studies. Similarly, the need to contribute to the effort of decreasing global warming in reducing energy consumption from fossils sources has led to the rise in such types of studies.

Many studies have been evaluating IEQ and analysing indoor conditions through investigating the thermal, visual and aural environments as well as indoor air quality (IAQ) (Catalina & Iordache, 2012; Frontczak et al., 2012; Nimlyat & Kandar, 2015). Frequently reported poor IEQ concerns include discomfort due to high or low temperatures and relative humidity; high level of carbon dioxide concentration (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs) and PM; inappropriate lighting levels and presence of glare and occurrence of noise. Poor thermal environment affects occupants' mental performance as well as increasing stress and fatigue among them (Auliciems, 1972). Appropriate quality and quantity of light are important to building occupants' health and wellbeing, affecting their mood, emotion and mental alertness (Salonen, 2013). Acoustic discomfort is shown to cause fatigue, headaches, annoyance, changes in behavior and attitude leading to decrease in intellectual working ability and sleep disorders (Hodgson, 2000). High level of PM was reported to increase respiratory symptoms and acute lung diseases in schools (Rumchev, 2003). Raised concentrations of CO_2 is also associated with morbidity, absenteeism in school children and office workers (Valavanidis & Vatista, 2006).

Although IEQ studies including those in higher education institutions are on the increase, most of the published works deal with buildings located in temperate climate zones and mainly situated in wealthier parts of the world, and not in Sub Saharan Africa. Some examples of researches conducted in higher education buildings include (Al-Maiyah et al., 2015; Mishra & Ramgopal, 2013; Ogbonna & Harris, 2008; Ugranli et al., 2015).

Furthermore, most of the studies in higher education facilities tend to concentrate on classrooms, lecture theatres, libraries, offices, students housing, and fewer works were done on laboratories (Rumchev, 2003). The few articles published on laboratories were mostly concerned with a single aspect of the IEQ, which is IAQ. Rumchev et al., (2003) investigated 15 laboratories at the Curtin University of Technology, Perth, Australia. Ugranli et al., (2015) investigated IAQ and two comfort related variables (air temperature and relative humidity) in chemistry and chemical engineering laboratories at Izmir Institute of Technology, Turkey.

This paper therefore reports the assessment conducted on two laboratories, with a view to finding how they perform environmentally in comparison to occupants' preferences and international comfort standards. Environmental parameters were physically measured while a sample of students completed paper based questionnaires on comfort parameters.

Methodology

Description of the research location

Bayero University (BUK) is a conventional university, situated in Kano, Nigeria. Kano is located on latitude 12^{o}N and longitude 8.17^{o}E, 473 m above sea level and in the savannah vegetated region of West Africa. Maximum temperature reaches 39^{o}C in April and May and goes down to 12^{o}C in December and January and it is sunny 71% of the daylight hours (climatemps.com, 2017). Relative humidity hovers between 10% and 80% and the annual precipitation is about 700 mm. As with other parts of Nigeria, the city is faced with the problem of perennial haze/dust blown in November to February from Sahara desert.

BUK has about 30,000 students admitted within 14 faculties, undergoing various programmes from three campuses spread across the city of Kano. From the last eight years the university's landscape has been transforming by adding new structures and retrofitting existing ones. The selected laboratories for the study were chosen from the Old campus and Teaching hospital. These are, Multipurpose Laboratory (ML), used for approximately 30 hours per week by Science faculty for their level 100 undergraduate students and Phantom Laboratory (PL), used for about 18 hours per week, by the clinical students of Dentistry faculty. The characteristics of the laboratories are shown in Table 1.

Table 1: Characteristics of the Laboratories

Attributes	Multi-purpose Laboratory (ML)	Phantom Laboratory (PL)
Capacity	120 seats	40 seats
Length x width x height	20 m x 15.50 m x 3.27 m	17.8 m x 7.3 m x 3.48 m
Occupancy density	2.58 m^2/person	*3.25* m^2/person
Wall finishes	Light paint on cement plaster	Light paint on cement plaster
Ceiling finish	White Celotex acoustic boards	White Celotex acoustic boards
Area of glazing	41.86 m^2 (no blinds)	19.80 m^2 (has internal blinds)
Glazing factor	15.76%	15.24%
Number of window-walls	Three	Two
Window-walls orientations	South, East and North	West and East
Window-wall area ratio	South 23%, East 20% and North 15%	West 16% and East 16%
Type of furniture finish	Metal/wood tops and soft seats	Metal/wood tops and soft seats
Presence and type of shading	Shaded by fins	Internal blinds and one sided verandah

Physical Measurement

Both the physical measurements and the surveys were conducted based on procedures consistent with ASHRAE standard 55-2013. A number of instruments were used to measure the indoor environmental parameters. The spot measuring instruments were simple and hand held. They include HOBO loggers for air and radiant temperatures, relative humidity, carbon dioxide (CO_2) concentration, and illumination; Trotec BZ30 for air temperature, relative humidity and CO_2 concentration; Testo 435-2 meter for air velocity; PCE-DT 9880 for particulate matter (PM) and Extech HD600 meter measures sound pressure levels.

Temperature, relative humidity, air velocity, sound pressure levels and CO_2 concentration, using the hand held instruments by the researcher, were spot measured in five locations, each for five minutes and at 1.1m above the floor. Whereas illumination levels were spot measured in nine locations at the same height. Daylight was obtained when electric lights were off and window blinds opened. Photographs of the interiors of the laboratories and points of measurements are marked on the floor plans shown in Figures 1 and 2. Though air conditioners were not in operation, ceiling fans were on most of the time and windows opened. Measurements were conducted in two situations, during occupied and unoccupied conditions. External weather data were obtained using pendants on the buildings' exteriors.

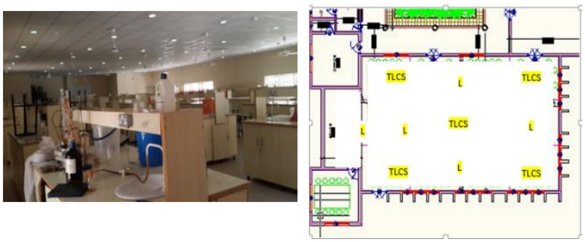

Figure 1: Multipurpose Lab. (ML)

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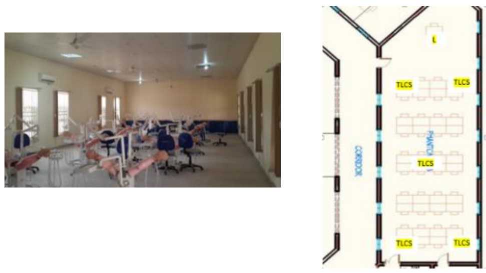

Figure 2: Phantom Lab. (PL)

NOTATIONS: T: Temperature; L: Lighting; C: Carbon dioxide concentration; S: Sound

Subjective Measurement

In line with the capacities of the laboratories, a total of 160 paper based questionnaires were prepared, for the occupants to answer. It contains six sections covering; thermal, acoustic and visual comfort, indoor air quality and demographic information. In addition, sketches of the respective learning environments were included for the occupants to indicate their approximate sitting positions. A total of 105 questionnaires (86 and 19 for the ML and PL respectively) were subsequently distributed, filled and collected back. The surveys were administered between 12 noon and 12:30 pm on 22nd August 2016 in the PL, while in the ML it took place on 29th August 2016 at 10:45 am. The questionnaires were answered by the students, teachers and support staff.

Typical questions on the parameters took the form of: how comfortable are you with thermal condition of this space now? How would you describe the temperature, natural and artificial lighting, noise and odour in this space? Responses required by these questions were made on a mixture of categorical (e.g. acceptable and unacceptable; comfortable and uncomfortable) and seven point Likert scales between two extremes; cold and hot; satisfactory and unsatisfactory; too much and too little; significant and not significant; pleasant and unpleasant, following the methods used in previous studies (Ai Maiyah et al., 2015; Montazami et. al., 2016).

Similarly a list of typical clothing ensembles worn by the respondents in the environment was provided for them to indicate the ones they had on. Thermal sensation vote was to be expressed on the ASHRAE standard 55 seven-point scale (e.g. cold, cool, slightly cool, neutral, slightly warm, warm and hot). This allows the evaluation of “actual mean vote” (AMV) and the dispersion regarding the “actual percentage of dissatisfied” (APD). These were compared with the Fanger’s Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD).

Table 2: Measured Internal Parameters

Laboratories		Air Temperature (°C)		Relative Humidity (%)		Illumination (lux)		CO_2 Concentration (ppm)		Background Noise dB(A)		Air Velocity (m/s)		Particulate Matter (per m^3)	
		Unoccupied	Occupied	Unoccupied	Occupied	Day-light	Global	Unoccupied	Occupied	Unoccupied	Occupied	Fans off	Fans on	$PM_{2.5}$	PM_{10}
Multipurpose	Min	28.1	31.0	71.6	61.4	78	131	602	633	50.0	54.2	0.18	0.28	179	17
	Max	28.5	31.7	74.8	66.5	456	586	807	1028	50.4	62.3	0.21	0.34	222	48
	Mean	28.3	31.5	72.9	64.2	235	262	750	784	50.3	57.1	0.20	0.31	186	31
Phantom	Min	24.1	25.1	68.1	66.7	81	181	593	654	48.9	59.0	0.12	0.34	130	15
	Max	24.4	25.6	68.8	70.7	221	386	660	884	51.0	60.8	0.17	0.43	150	25
	Mean	24.3	25.3	68.4	68.8	188	286	627	727	50.0	59.7	0.15	0.40	139	17
Standards’ Limits and ranges		24.5°C-28°C Summer 23.3°C-25.5°C winter (ASHRAE-55)		30-60% (ASHRAE-55)		500 lux for laboratory (EN-12464)		1200 ppm for any learning environment (ASHRAE 62-2004)		40-45dB(A) for laboratory (WHO 2006)					

Finally, demographic data of the participants was requested for the determination of their personal characteristics, which helped in developing appropriate summary statistics. In order to eliminate the impact of metabolic rate on the respondents, the questionnaires were administered in each space after 30 minutes into the laboratory sessions, adopted from previous study (Montazami et al., 2016). Similarly lighting, acoustic and air qualities parameters were evaluated on categorical and seven point Likert scales.

Results and Discussion

International comfort standards' recommendations offered by ASHRAE Standard-55 2013 and EN 15251 and the grouping method followed by Almaiyah et al. (2014) were used for the evaluation of the laboratories' indoor environmental conditions. Thermal and visual comfort parameters were evaluated through both subjective and objective means. Likewise noise level was evaluated by measuring the background noise level and by asking the occupants about their aural perceptions. Indoor air quality was adjudged by measuring CO_2 concentration, $PM_{2.5}$ and PM_{10}. It is worth noting here that, in this study however, only the singular values of $PM_{2.5}$ and PM_{10} were used due to instrument limitation. The maximum, minimum and mean of the measured internal parameters as recorded during the survey are displayed in Table 2.

Measured Results

Due to the differences in dates and times of measurements and the occupation situations, the air temperatures during the occupied time were generally higher, reaching 31.7 ˚C and 27.6 ˚C for ML and PL respectively. The reverse was the case with relative humidity, in ML it was higher when the space was unoccupied, reaching 74%, while the occupied figures stood at 66.5%. As with air temperature, the relative humidity in the PL was higher during the occupied time, reaching 70.7%. Air speed reached 0.34 m/s with fans on and windows opened in ML but was 0.45 m/s in PL. This variation could be as a result of the differences in the siting of the laboratories, as well as their design features and varied occupancy levels.

Light distribution in the laboratories was uneven, some locations in ML had as low as 78 lux natural lighting and 456 lux by the windows, with uniformity ratio (Emax/Emin) of 5.8:1**.** The daylight situation in PL was a little better, has uniformity ratio of 4.8:1. This could be due to the differences in the laboratories' compactness ratios. Differences exist in background noise levels in the laboratories, in ML had 62.3 dB(A) when occupied and PL 60.8 dB(A). Perhaps this could also be due to the location where PL was sited, being more isolated.

CO_2 concentration during the occupied time reached up to 1028 parts per million (ppm) in ML and was halved when unoccupied, while in PL it was only 884 ppm. These however did not exceed the ASHRAE 62's threshold value of 1200 ppm. $PM_{2.5}$ and PM_{10} values respectively were 222 and 48 particles per m^3 in ML, but at some points they went as low as 179 and 17 particles per m^3. However, these values were considerably lower in PL, which might be due to frequent use of chemicals in ML and less in PL.

Survey results

The survey revealed that females accounted for 47% of the respondents, 94% were students and 89% were below the age of 25. From the clothing ensembles, clo values of 0.67 and 0.71 were calculated for ML and PL respectively (with a range of 0.5 to 0.85 clo). Metabolic rate for laboratory activity was fixed at 1.4 met (Tyler, 2013).

Generally the thermal perception in both laboratories was adjudged acceptable. From Figure 3, about two thirds of the respondents in ML reported that the space was comfortable and no one found PL uncomfortable. Despite this general acceptance, still some 8% and 21% of the respondents reported that the laboratories were "hot" or "too hot". In Figure 4, 41% and 0% reported they were "cold" or "too cold" in ML and PL *respectively.*

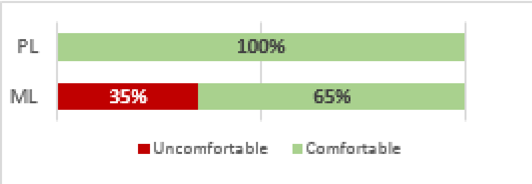

Figure 3: Thermal Acceptability

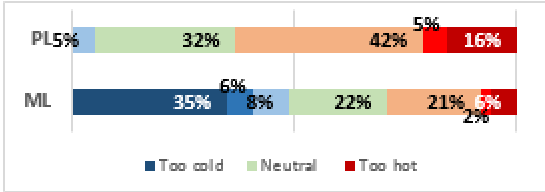

Figure 4: Thermal Sensation

On the quality of visual environment, 65% and 95% of the respondents in ML and PL respectively expressed their satisfaction with the global lighting levels as depicted in Figure 5. Similarly, only 21% and 22% reported that natural light was excessive and 23% and 17% said it was too little in ML and PL respectively. On the other hand, report on the level of glare perception as shown in Figure 6, was generally favourable, only 8% and 0% of the respondents perceived too much glare in the respective laboratories.

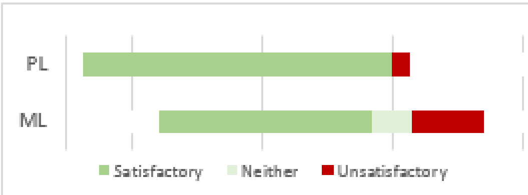

Figure 5: Global Visual Satisfaction

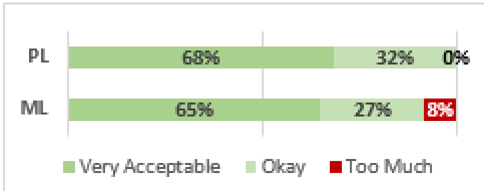

Figure 6: Glare Perception

Acoustically, the respondents showed very good satisfaction with the laboratories' background noise levels, only about 12% of those in ML showed their dissatisfaction, as depicted in Figure 7. It was concluded from the responses that the main sources of the acoustic discomfort in the ML were noise generated by their colleagues, this was reported by 43% of the respondents, while 25% of them said it was by external noise intrusion probably from traffic, as the lab is sited close to students' parking area.

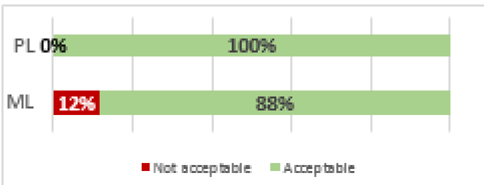

Figure 7: Background Noise Acceptability

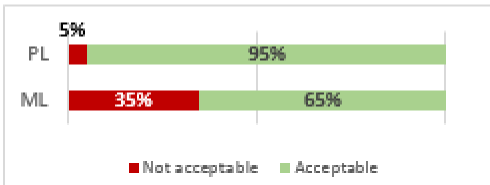

Figure 8: Air quality perception

Similarly the survey examined the respondents' perception about the quality of air in the laboratories. Figure 8 shows that there was general acceptability in the quality of air in ML, 65% attested to that, while 35% of them did not. Sources of the mild discomfort within the laboratory might be as a result of frequent use of chemicals, smoke rising from Bunsen burners, human effluents due to high occupancy level and absence of fume cupboards. However, there was an overwhelming acceptance of the air quality within PL, with as much as 95% of the respondents agreeing and only 5% showed their dissatisfaction.

Comparison

Values of Fanger's PMV and PPD on the survey date, running mean, and operative and comfort temperatures for the laboratories were calculated. The values of the PMV stood at

+1.43 and +0.79 while PPD results were 47% and 18% respectively for ML and PL. These values indicate that the overall thermal sensation in both laboratories was warm, as laid out in the provisions of ISO 7730 (ISO, 2005). On the other hand, the AMV from the survey reported mixed perceptions, with -0.81 (cool) and +0.95 (warm) in ML and PL respectively. This therefore calls for further study. However, the calculated comfort ranges, according to EN 15251 (CEN, 2007) for buildings type II in ML, stood at 25.1˚C to 31.1˚C, while in PL it was 25.2˚C to 31.2˚C. This signifies that EN 15251 could perfectly be used in predicting thermal conditions in Kano, as reported by Mishra and Ramgopal (2015).

According to EN 12464 standard (CEN, 2011), global lighting levels in laboratories should be above 500 lux. The lighting situations in both laboratories were therefore insufficient, having averages of 262 and 286 lux. However, the survey results indicated otherwise. More than two thirds of the respondents were happy with the global lighting situations in both laboratories. Having higher lux and with greater percentage of respondents showing more satisfaction with the global lighting situations in PL, it revealed that PL was visually a preferred space. This could be attributed to PL's compactness, window height above the floor and the presence of high furniture in ML that restricts the passage of daylight.

Measurement revealed that the highest CO_2 concentration of 1028 ppm was found in ML, although it seemed high, it was however within the limit specified by ASHRAE 62, which is above 1200 ppm. Although the CO_2 concentrations in both laboratories were within the ASHRAE threshold, yet about one third of the respondents in ML reported their dissatisfaction and 5% in PL. This showed the subjectivity of comfort, which concurs with findings of Ugranli et al., (2015). The average background noise levels of 57.1 dB(A) and 50.0 dB(A) respectively found in ML and PL, though seemed low, but were found to be higher than the limit of 35 dB(A), as laid out by WHO (WHO, 1999). On the contrary, the respondents indicated their acceptance of the situations, only 12% of them were not satisfied with the aural conditions in ML, while 11% were undecided in PL.

Conclusion

The study, aimed at investigating IEQ in two laboratories in Bayero University, Kano, Nigeria, was conducted during the wet-warm season of August 2016. The scope included the comparison between experimental and surveyed data of the laboratories as well as against thresholds of relevant international comfort standards. Various physical parameters were measured which culminated into calculating some comfort indices. Concurrently, the occupants of the laboratories were subjected to a survey to determine their actual comfort perceptions. In line with the results obtained by some previous IEQ researches, this study, though part of a larger and longitudinal field work, also found discrepancies between measured and surveyed data, as well as with the comfort standards. Generally the results of the measured parameters were found to be higher than most of the standards thresholds with exception of CO_2 concentration. This divergence may not be unconnected with the situations of the dominant climatic conditions of the region at the time of the work. However, the survey data results showed acceptance of the indoor conditions of the laboratories by the respondents. Both the measured and the surveyed data of the PL were more consistent and acceptable to the respondents than those of the ML. This disparity may be explained by the compactness of PL and the siting of the two laboratories. PL is sited at the Teaching Hospital campus, though within the heart of the city, it is placed deep inside the campus and therefore buffered from the city traffic. ML, on the other hand, is sited at the Old campus and very close to the students housing parking area. It is therefore worth noting that good siting, compactness, wide and operable windows as well as control of occupancy levels need to be taken into consideration when setting up a laboratory in the tropics.

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