2021
January
coou African Journal of Environmental Research *Vol 3, No. 1, 2021. pp 78-94*

ASSESSING THERMAL PERFORMANCE IN TWO CLASSROOM BUILDING TYPES IN WARM HUMID CLIMATE IMO STATE, NIGERIA

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Abstract

Achieving energy efficiency in educational buildings in countries located in the tropical regions is a big challenge because of very high temperatures and humidity. The problem is further complicated by designs that encourage the use of mechanical ventilating systems to provide thermal comfort. This paper presents the report of fieldwork carried out in primary schools in Imo State, Nigeria. It involved two naturally ventilated classroom building types categorized as short wall and enclosed wall classrooms. The aim was to determine and compare their thermal performance so as to provide information for use in design of sustainable school buildings in warm and humid environments like Nigeria. The data (environmental parameters and physical measurements) of these classrooms were collected during the rainy season and dry season. Results of the correlation analysis of the retrieved data showed that the two classroom types were in thermal compliance with the requirements of ASHRAE Standard 55. However, the relationship between the outdoor temperature and the indoor temperature in the short wall classroom-type was stronger (r^2= .856), than the relationship found in the enclosed wall classroom-type (r^2= .722). Furthermore, the prevailing daily mean indoor temperatures were higher in the enclosed wall classroom type. The difference in thermal performance in these two building-types is likely as a result of the difference in their building envelopes. It was concluded that the short wall classroom-type has a greater potential to contribute to reduced energy use in buildings. It was recommended that the short wall concept in the design of classroom blocks be adopted in the warm and humid climate, in Nigeria.

Keywords: Building envelope, classroom type, enclosed wall, short wall, thermal comfort, thermal performance.

INTRODUCTION

Buildings are commissioned with the expectation that the indoors will be thermally comfortable to their users. Apart from providing thermal comfort, a building ought to be sustainable as minimal energy is used in its operation. Energy efficiency in buildings has become an important issue of discussion among policymakers. This is because of the serious challenge of providing sufficient energy (for its users to accomplish their tasks in comfort), and because of their significant contribution of CO_2 emissions to climate change. The focus on energy efficiency, in literature, has escalated because of the increasing energy demand in buildings. According to

Mirrahimi et al., (2016), ventilation and indoor thermal comfort environment can be dramatically enhanced by 13% with the increase of window to wall ratio (WWR) size from 12% to 24%. Building features, when properly applied in design, can also help enhance thermal performance. Already, a significant amount of energy is used to provide thermal comfort (Yang et al., 2014).

Lei, Yang and Yang (2016) investigated the energy performance of building envelopes integrated with Phase Change Materials (PCMs) for cooling load reduction in tropical Singapore. The results showed that PCM can effectively reduce heat gains through building envelopes the whole year, indicating the significant advantage of the use of PCMs in the tropics. Sami and Al-Sanea (2002) reported an evaluation of the thermal performance of the roof of a building whose elements were subject to periodic changes in ambient temperature. The building is located in Saudi Arabia, a country with a hot climate. The result showed that a slightly better thermal performance is achieved by locating the insulation layer of polystyrene closer to the inside surface of the roof structure. Hien, Yok and Yu (2007) described how the greenery systems placed at the rooftop of buildings perform thermally in a study. The results showed that low temperatures were exhibited by the green roof and that this was an indication of good thermal performance.

In Nigeria, research has been conducted on the energy efficiency and thermal performance of buildings. Ojo and Lawal (2011) reported an assessment of the thermal performance of four residential buildings in Ibadan that possessed different system designs. The result showed a very strong relationship between the independent factors (building types) and the dependent factors (ambient temperature). Odunfa et al (2015) described a case study of buildings at the University of Ibadan with the view to harness energy saving potentials through building orientation. Results showed that energy efficiency would most likely to be achieved with the North-South building orientation. Similarly, Akande et al, (2015) reported a study on sustainable approaches to developing and improving energy-efficiency in residential buildings. A survey method was adopted in this investigation. From the findings, behavioural changes and proper design of building envelopes were recommended as sustainable approaches to achieving energy-efficient buildings. Furthermore, Bulus et al (2017) described a study of two different courtyard forms (semi-enclosed and fully enclosed courtyards) of residential buildings located in Kafanchan-Nigeria to compare the climatic performance in these two courtyards. Results showed there were differences in the microclimatic conditions in these two courtyards. The fully enclosed courtyard was found to exhibit a more favourable microclimatic performance. These studies suggested that it was important to understand the thermal performance of buildings with the aim of seeking sustainable ways to reduce energy use. However, most of the studies conducted in Nigeria were carried out on residential buildings, only, and their durations included only one geographical season.

Among the many types of public buildings, schools are, perhaps, places where greater social responsibility ought to be shown (Tondo et al, 2016). They offer opportunities for promoting energy efficiency and environmental quality (Jiang et al, 2018; Pereira et al., 2014). This is imperative since indoor environments in classrooms are vital for students' perception, health, and performance (Jiang et al, 2018). Furthermore, since they constitute a significant proportion of the building sector, where people stay over a long period, there is the need to study school buildings in order to enrich the database of thermal performance in buildings. In Nigeria, there are two school systems: public schools and private schools. Public schools are owned by the government, while private schools are owned by individuals or organizations. In the south-east, there appears to be a trend of installing air-conditioning systems in private primary schools, and this may extend to the public primary schools. In this area, there are two typical types of public primary school buildings. These are referred to in this paper as *short wall* (old pattern design) classroom type and enclosed wall (conventional) classroom type. In most of these public primary schools, there still exist a good number of these *short wall* classrooms that are still in use. Knowledge of the thermal performance of the two types of classroom buildings, predominantly found in the study area, may provide vital information for use in the design, construction, and operation of sustainable primary school buildings in warm, humid environments, in Nigeria.

LITERATURE REVIEW

Climate and building

In sub-tropical (and tropical) countries, solar heat gain is the dominant component in the total building envelope heat gain (Lian et al, 2015). Climate management requires heating loads dissipation, and minimizing energy consumption by using passive means, such as natural ventilation, is considered a sustainable option for buildings located in tropical climates. The tropical climate is the prevalent set of weather conditions in the area between the Tropics of Cancer and Capricorn. This climate occurs over an area that is approximately 40 percent of the land surface of the earth, and which is home to half of the world's population (Wong & Chen, 2008). The world's climates, as classified by Köppen Geiger (1936) rely on some climatic parameters; such as temperature and precipitation. As one of the most widely used climate classification systems, the Köppen climate classification divides the world climates into five major groups; tropical climate, dry climate, mild climate, continental climate, and polar climate.

About 90% of people (worldwide) spend approximately 90% of their time indoors, daily (Dimoudi & Tompa, 2008). As a result, buildings (and associated activities) are major energy consumers and have a great impact on the environment. They account for about 40% of the energy consumption in the world (Siew et al., 2011), and there is the likelihood that this will rise to 60% (Shaik et al., 2014). Veller, Fosas and Natarajan (2017) averred that about 30% of global CO_2 is emitted in the provision of thermal comfort. Similarly, Bastide et al., (2006) states that, globally, during their operational stage, Heat, Ventilation, and Air-conditioning (HVAC) systems in buildings account for more than 50% of annual energy consumption. There is, therefore, a growing concern that with the continuous increase in the global surface temperature, and the growing world population, the demand for HVAC systems will continue to rise. Already, there is a continuous rise in the use of this active ventilator, and it is projected that the world market for HVAC equipment for 2022 will be $126.6 billion (Lucintel, 2017; Lopez-Ferez, Flores-Prieto & Rios-Rojas, 2019). As a result of this significant amount of energy consumed by buildings and the attendant high contribution to climate change, the building sector seems to be a priority target for energy savings.

Foundation, walls, windows, doors, and roof constitute the major components of the building envelope. This envelope protects the occupants from rain and direct solar radiation and also regulates carbon emissions and thermal performance. A properly designed building envelope with good passive systems can reduce energy load in buildings (Sadien et al, 2011). Architects (who create this envelope) have to consider the climate of the locality during the initial stage of design. This will help to provide thermal comfort to building occupants with minimal energy consumption. International standards that regulate indoor environmental conditions (e.g.

ASHRAE 55 and ISO) specify that an indoor environment is considered acceptable when 80%, or more, of the occupants, indicate accepting the indoor thermal condition (ASHRAE, 2017). The thermal condition of a building can be assessed using the Predicted Mean Votes (PMV) or the Adaptive Comfort Model (ACM). The PMV is better suited to be applied in determining the thermal conditions in air-conditioned buildings, where the occupants have minimal control over the environment. The ACM is better suited to be used to evaluate the thermal conditions in free-running buildings, where the occupants have the freedom to take control over the indoor environment by taking adaptive actions (such as opening or closing the windows) in order to be thermally comfortable (Nicol et al, 2012). The ACM is usually adopted by researchers to assess indoor thermal conditions in the tropical regions where naturally ventilated buildings are predominantly found. The major advantage of the ACM is that it allows the indoor environment to interact with the outdoor environment, in form of energy exchange between the indoor and the outdoor through openings such as a window, thereby encouraging sustainability.

Determining thermal comfort in buildings

Some international organizations set the minimum standards used in determining thermal conditions in a building environment. Standards are the process of creating a common set of rules for everyone. These international bodies are:

i. ASHRAE (ASHRAE Standard 55-2017); Thermal Environmental Conditions for Human Occupancy
ii. ISO (ISO 7730-2005); Ergonomics of the Thermal Environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local discomfort.
iii. EN/CEN (CEN 15251-2007): The European Committee for Standardization – Indoor environmental input parameters for design and assessment of energy performance of buildings (addressing indoor air quality, thermal environment, lighting, and acoustics).

The Adaptive Comfort Model considers the relationship between the outdoor temperature and the indoor temperature in determining the thermal performance of a building. In Naturally Ventilated (NV) buildings, the outdoor environment relates closely to the indoor environment through the fabrics of the building, regulated by opening or closing windows and doors. People who are indoors, in a free-running building, do adapt to the external temperature around the building mediated through its walls and operable windows, and roofs and floors (Nicol et al., 2012). The difference between outdoor and indoor air temperature and airflow can also affect the perception of comfort (Du, Bokel, & van den Dobbelsteen, 2019). The ASHRAE Standard 55 adaptive comfort model is the preferred choice adopted by researchers to check the thermal comfort in NV buildings in Africa. This is because, ASHRAE RP-884 data was obtained from climate zones that covered all the four continents (de Dear & Brager, 1998), including Africa. The adaptive component from EN/CEN (The European Committee for Standardization) was based on the European SCATs database collected from five west European countries, (Nicol, Humphreys & Roaf, 2012), which excluded the African continent. ASHRAE 55 undergoes constant revisions and updates of its guidelines by considering the current results from field experiments on thermal comfort studies in different climates and cultural areas. The latest revision in ASHRAE Standard 55 adaptive model was in 2017 (ASHRAE, 2017, Carlucci et al, 2018).

ASHRAE Adaptive Thermal Comfort

The major complaint of indoor occupants in the tropics is overheated indoor spaces. Notwithstanding this, it is difficult to specify an environment known to be acceptable to all the building occupants. This is because people respond differently to thermal environments because of the differences in age, health status, type of clothing worn, rate of activity, and how each individual acclimatizes to the environment. Because of this unlikeliness of a given indoor environment satisfying 100% of the people at the same time, ASHRAE Standard 55 suggested that an indoor environment can be assumed to be acceptable when 80%, or more, of the occupants, accept the indoor thermal conditions (ASHRAE, 2017).

The adaptive approach to thermal comfort was considered as a result of the oil shock in the 1970s. This oil shock caused an energy crisis, resulting in high costs of heating indoor spaces to provide the desired thermal comfort to building occupants. According to Humphreys et al. (2015), energy is saved because the adaptive approach allows the indoor temperature to drift closely to the prevailing outdoor temperature, and the reduced difference between the two variables decreases the energy needed to heat or cool indoor environments. The adaptive approach to thermal comfort was also introduced to encourage the reduction of greenhouse gas emissions in the building sector. The adoption of the adaptive model in buildings can help meet the goals set by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Conventions on Climate Change (UNFCC) regarding the reduction of greenhouse gas emissions in the building industry.

According to Nicol, et al (2012), the comfort temperature in buildings can change with the outdoor conditions. This is represented graphically in Figure 1. Similarly, ASHRAE (2017) presents a graph that can be used to estimate temperature zones within which 80% and 90% of building occupants may be thermally comfortable. This is shown in Figure 2. This graph indicates what temperatures are acceptable in a building at outdoor temperatures. The adaptive approach does not express indoor comfort temperature in the form of a standard. It also does not predict what temperatures are comfortable, rather it expresses its standard in terms of the provisions of a building, based on adaptive opportunities adopted to obtain thermal comfort that give a range of comfortable temperature (Humphreys, Nicol & Roaf, 2015). According to the adaptive model of thermal comfort from ASHRAE Standard 55-2010, the range of indoor comfort temperatures for a naturally conditioned space can be determined from the prevailing (weekly or monthly) mean outdoor temperature and the mean daily indoor operative temperature (Efeoma, 2016).

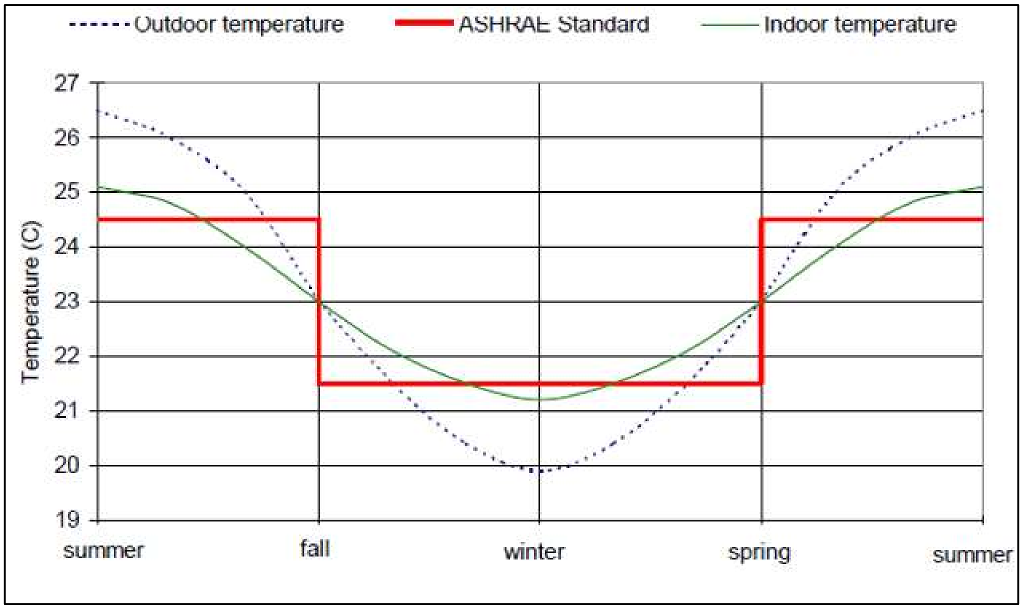


Figure 1: The adaptive model concept @Macquarie University 1996
Source: (De Dear & Brager, 1998)

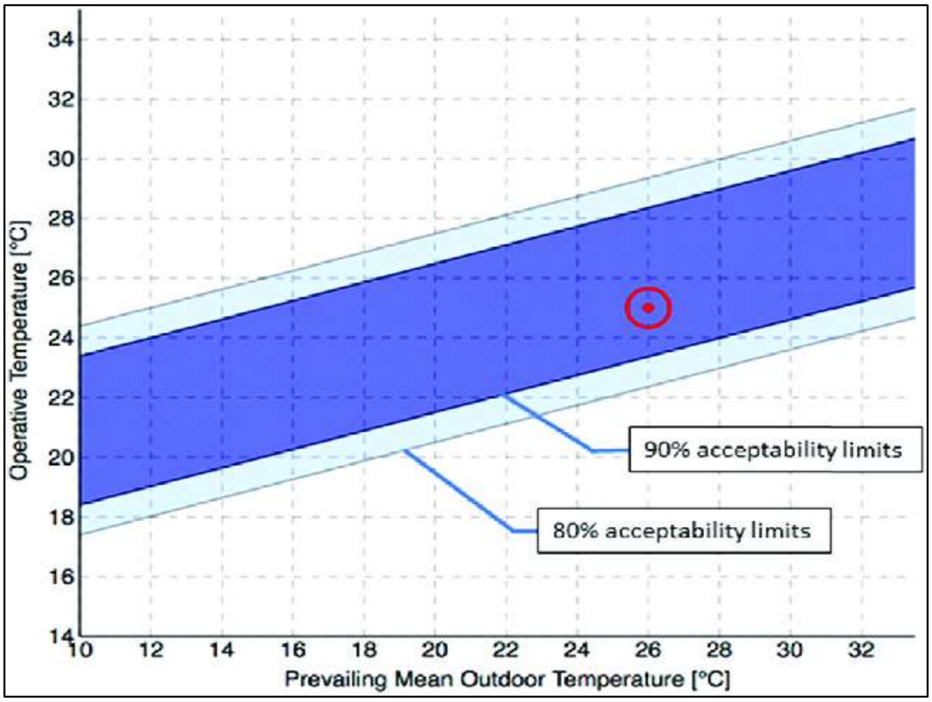


Figure 2: Adaptive thermal comfort chart according to ASHRAE Standard 55-2017

(Adapted from ASHRAE, 2017)

METHODOLOGY

The Study Area

The study area, Imo State, is one of thirty-six states of Nigeria (See Figure 3). It is within the tropical wet and dry or savannah climatic zone (Aw in the Köppen–Geiger climate classification) (Zomorodian, Tahsildoost & Hafezi, 2016). The location of the State is between latitudes 4° 45′N and 7° 15′N, and between longitudes 6° 50′E, and 7° 25′E. The State is generally characterized by a high surface air temperature year-round. The mean minimum temperature is about 23.5oC and the mean maximum temperature is about 32.1oC. The difference between the maximum temperatures in the months does not usually exceed 4.0oC. Two seasons (rainy/wet and dry) are observed in the year. The rainy season begins in mid-April (Okorie, 2015) and usually lasts until late November. The temperatures are constant throughout the year, with the warmest indoor temperatures reported to occur mostly in February. The wind speed in the warm and humid zone area is generally of medium strength with mean annual rainfall ranges from 2500 to over 4000 mm (Tammy-Amasuomo & Oweikeye-Amasuomo, 2016). Other cities with the same climatic conditions as Imo State are Mumbai and Chennai in India, Bangkok in Thailand, Accra Ghana.

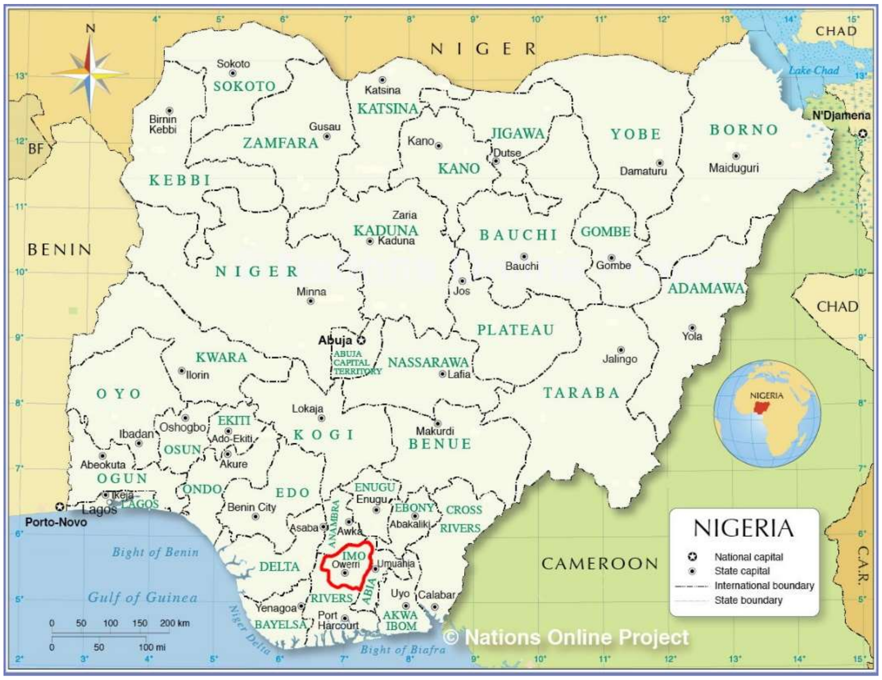


Figure 3: Administrative Map of Nigeria showing the 36 States of Nigeria and Federal Capital Territory (Imo State is highlighted)
Source: (nationsonline.org, 2021)

Choice of Building

Two types of public primary school buildings abound in the south-eastern states in Nigeria. They are referred to in this paper as *short wall* classroom (left side of Figure 4) and the *enclosed wall* (right side of Figure 4) types. The *short wall* classroom concept (old fashioned) was built in the 1950s, while the *enclosed wall* classroom concept is the renovated old-fashioned *short wall* classroom-type equipped with doors and windows. The investigated classrooms are six in number (3 'short wall' classrooms and 3 'enclosed wall' classrooms). The two classroom types were built with mud walls and roofed with galvanized steel resting on timber supports and with PVC ceiling materials**.** The only difference between the two types of classrooms is the nature of the building envelope. The *short wall* classroom concept has more wall openings when compared to the *enclosed wall* type. The Floor plans for these buildings are described in Figure 5.

Figure 4: Sample school view showing 'dwarf wall' classroom (left side) and classroom with 'enclosed wall' classroom (right side)
Source: Fieldwork, 2015

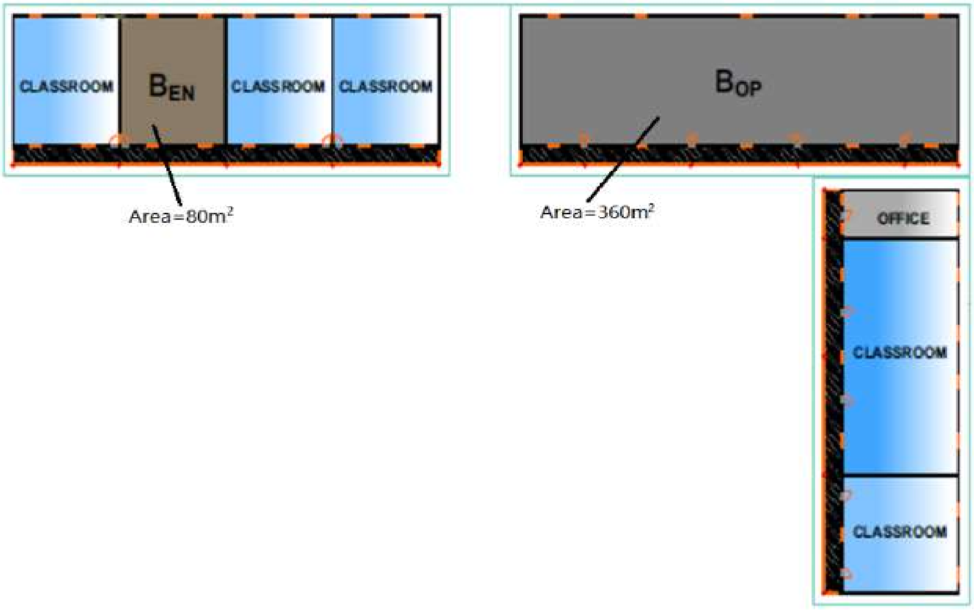


Figure 5: Floor plan of a sampled 'dwarf wall' classroom (denoted B_{OP}) and classroom with 'enclosed wall' classroom (denoted B_{EN})
Source: Fieldwork, 2015

Data Collection

This study aims to determine the thermal performance of the two types of classroom buildings that have different building envelopes. An objective approach was adopted in this study. While determining the thermal conditions of building occupants, it is also important to remember that the buildings and the rooms they occupy are equally important to study (Nicol et al, 2012). For the case study, a school was randomly selected from each of the three senatorial zones that constitute Imo State. Before this random selection, the shortlisted schools were expected to meet the following criteria:

i. Must be a public (government) primary school
ii. Must be naturally ventilated (NV)
iii. Must have the *dwarf wall* and *enclosed wall* concepts

The survey was from October 2017 to June 2018, covering the rainy season and dry season. The details of this are shown in Table 1. Tinytag Ultra 2 (TGU-4500) was used to record the indoor temperature and indoor relative humidity (RH), while Tinytag plus 2 (TGP-4500) Gemini loggers measured the corresponding outdoor temperature of the immediate outdoor environment of the indoor spaces being monitored. Measurements were taken every 5 minutes at the height of 1.0 meters from the ground in compliance with the prescriptions of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) and International Standard Organization (ISO). The outside data logger was well sheltered, avoiding direct sunlight and rainfall. Kestrel 3000 Pocket Wind Meter was used to measure the indoor air velocity (see Table 2). Data collected with these instruments were exported to an Excel spreadsheet, organized, and statistically analysed.

Table 1: Survey period (rainy season & dry seasons)

School	Adw	Aew	Bdw	Bew	Cdw	Cew
Rainy Season	Oct 13-24/2017	Oct 13-24/2017	Oct 25-Nov3/ 2017	Oct 25-Nov 3/ 2017	May 9-29/2018	May 9-29/2018
Dry Season	Feb 6-28/2018	Feb 6-28/2018	April 2-27/2018	April 2-27/2018	Jan 15-31/2018	Jan 15-31/2018

***sw** ='short wall' classroom; **ew**= 'enclosed wall' classroom*

Source: Fieldwork, 2015

Table 2: Technical characteristics of the measuring instruments

Instrument and Make	**Measured parameter**	**Range**	**Resolution**	**Accuracy**
Tinytag ultra 2 (TGU-4500) logger	Indoor air temperature	-25 to +85ºC	±0.01ºC	±0.3%
	Indoor relative humidity	0% to 100%	±0.3%.	±1.8% RH
Tinytag Plus 2 (TGP-4017) loggers	Outdoor Temperature	25 to +85 ºC	±0.01ºC	-
Kestrel 3000 Pocket wind meter	Air velocity	0.30 to 40.0m/s	-	±1.66%

Source: Fieldwork, 2015

Data Analysis

The objective data from the fieldwork was analysed by comparing the results of the measured thermal variables in these two classroom types with the adaptive thermal comfort to determine their compliance to ASHRAE Standard 55 acceptable comfort limits. Three approaches were adopted in this regard. First, the measured thermal variables retrieved from the data loggers were analysed to check if the prevailing mean outdoor temperatures are within the approved ASHRAE adaptive comfort range (between 10 - 33.5ºC) for assessing thermal comfort in NV buildings. In the second approach, a paired sampled T-Test and Bivariate correlation testing of the indoor operative temperature (Top) and outdoor temperatures (Tout) of the two types of classrooms were carried out. The adaptive comfort model suggests that the relationship between these two variables (Top and Tout) influences the thermal comfort of building occupants. In the third approach, regression analysis between Top and Tout was carried out. The outcome was compared with the 80% acceptable comfort ranges of the ASHRAE Standard 55-2017 (ASHRAE, 2017). Where the classroom under investigation does not comply with the requirements of the standard, the variables are further analysed using the Centre for Built Environment (CBE) thermal comfort online tool to check the indoor thermal conditions with enhanced indoor air velocity. ASHRAE Standards 55 allows the use of a CBE thermal comfort tool to enhance thermal comfort by increasing airflow to more than 0.3m/s provided that the mean outdoor temperature in the space does not exceed 33.5°C (ASHRAE, 2017; Jindal, 2018).

RESULTS AND DISCUSSION

Measured Indoor and outdoor temperature

The results, summarized in Table 3, show that during the fieldwork the prevailing maximum mean outdoor monthly temperature (29.6ºC), and the prevailing minimum mean outdoor temperature (28.6ºC) of the two classroom types were within the ASHRAE Standard 55 acceptable temperatures (less than 33.5ºC and more than 10.0ºC) for NV buildings. Graphical representation of data on indoor temperature and relative humidity retrieved from the data logger is shown in Figure 6. As shown in Table 4, the indoor operative temperatures seem to be exhibiting similar behaviour with the outdoor temperature by reporting mean values that also fall within the ASHRAE Standard 55 range.

Table 3: Summary of outdoor temperature in the schools

School	Classroom	Season	Max (ºC)	Min (ºC)	Mean (ºC)	St Dev (ºC)	Coefficient Of variation
A	**Asw & Aew**	Rainy	37.4	23.0	29.2	1.7	0.058
		Dry	36.2	24.0	29.6	1.5	0.051
B	**Bsw & Bew**	Rainy	35.6	25.4	28.6	1.2	0.042
		Dry	33.8	23.7	29.1	1.1	0.038
C	**Csw & Cew**	Rainy	36.6	24.1	29.4	2.0	0.017
		Dry	31.8	24.3	29.1	1.9	0.066
All Short walls		**All season**	37.4	23.0	29.6	1.7	0.054
All Enclosed walls		**All season**	37.4	23.0	29.6	1.7	0.054

Source: Fieldwork, 2015

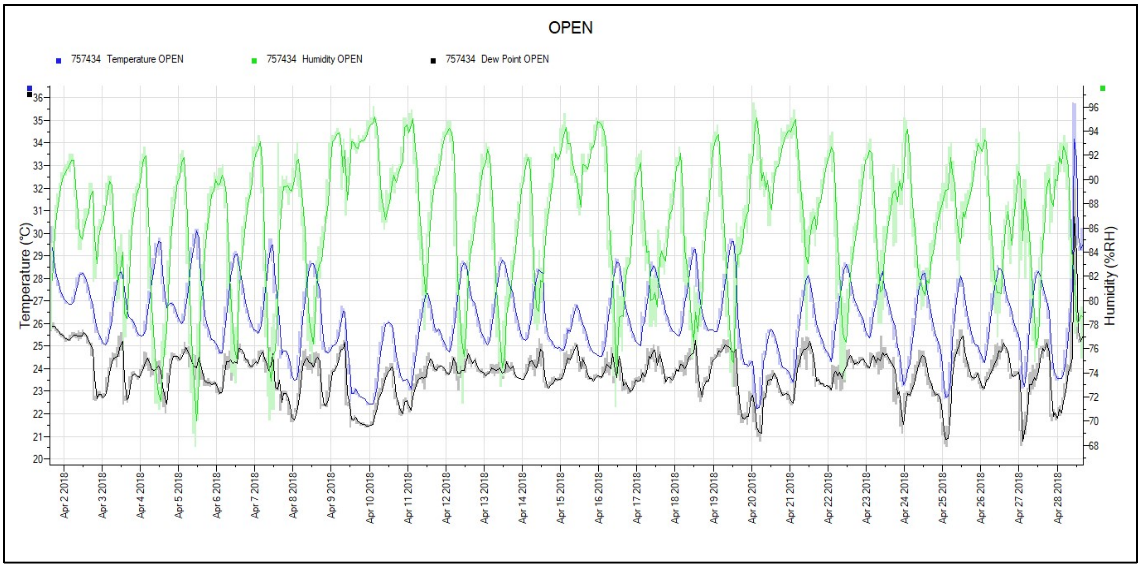


Figure 6: Sample graphical representation of indoor temperature and relative humidity retrieved from data logger

Source: Fieldwork, 2015

Using Paired Sampled T-Test

A paired sampled T-test and bivariate correlation were adopted to check the extent of the relationship between the outdoor temperature in the two classroom types and their corresponding indoor temperatures. Results show a strong correlation between these two variables of interest (indoor temperature and outdoor temperature) in the two classroom types (r^2 =.856 for the *short wall* classroom and r^2=.722 for the *enclosed wall* classroom). This shows that the indoor temperature of the *short-walled* classroom-type followed more closely with the corresponding outdoor temperatures compared to the *enclosed wall* classroom. Furthermore, a breakdown of each of the surveyed classrooms shows a stronger correlation between the indoor and outdoor temperatures in the *short wall* classrooms compared to the correlation in the *enclosed wall* classrooms.

Table 4: Paired sample t-test and bivariate correlations between TOP and outdoor temperature

School	Class	Season	Indoor temperature vs outdoor temperature			
			Mean Indoor OT (ºC)	Mean Outdoor Temp (ºC)	Sign (2-tail)	Pearsons Corr
A	A_{sw}	Rainy	28.6	29.2	0.000	.888
		Dry	29.4	29.6	0.001	.729
	A_{ew}	Rainy	28.7	29.2	0.000	.802
		Dry	29.5	29.6	0.042	.497
B	B_{sw}	Rainy	28.2	28.7	0.000	.947
		Dry	28.9	29.1	0.008	.493
	B_{ew}	Rainy	28.3	28.6	0.000	.918
		Dry	28.9	29.1	0.000	.760
C	C_{sw}	Rainy	28.7	29.4	0.000	.547
		Dry	28.8	29.1	0.060	.771
	C_{ew}	Rainy	29.2	29.4	0.000	.697
		Dry	29.0	29.1	0.205	.257
Short walls		All	28.7	29.4	0.000	.856
Enclosed walls		All	29.2	29.4	0.000	.722

*When **p-<0.05** it shows significance; when **p->0.05** it shows no significance*
Source: Fieldwork, 2015

Using regression analysis and CBE comfort tool

The result of the thermal performance in the two classroom types is further presented in Table 5 and Figures 7-10. To compare the thermal performance of the two classroom types with ASHRAE Standard 55 adaptive comfort, the prevailing weekly mean outdoor temperature retrieved from the data loggers were plotted against the corresponding daily mean indoor operative temperature. These were compared with the 80% acceptable comfort range of the ASHRAE Standard 55-2017 adaptive comfort model (ASHRAE, 2017). Results show that for the combined *short wall* classrooms (all season) almost all the points fall within the 80% adaptive comfort zone. This suggests that the combined *short wall* classrooms comply with the ASHRAE Standard 55 at the prevailing mean indoor air velocity of 0.28m/s as shown in Figure 7. The few points that were outside the 80% adaptive comfort zone of ASHRAE Standard 55-2017 were further analysed using the Central for the Built Environment Thermal Comfort Tool. At an air velocity of 0.3m/s (slightly more than what was prevailing) the combined *short wall* classroom was in full compliance (Figure 8). In the combined *enclosed wall* classrooms, most of the points were also inside the 80% adaptive comfort zone at the prevailing mean indoor air velocity of 0.29m/s (Figure 9). However, it was also brought into higher compliance at an elevated airspeed of 0.3m/s (Figure 10).

Comparing the thermal performance of the two types of classrooms shows that the *short wall* classroom reported more compliance with the standard than the combined *enclosed wall*. Furthermore, more of the points in the *enclosed wall* classrooms (Figure 9) were outside the 80% acceptability comfort range compared to the points in the combined *short wall* classrooms (Figure 7). Also, when the same indoor air velocity (0.3m/s) was applied to both classroom types, the dot in the *enclosed-plan* classrooms tended more to the periphery of the 80% acceptability limit. This suggests that the occupants in the combined *enclosed wall* classrooms will likely be more uncomfortable than those in the combined *short wall* classrooms. The reason may be linked to the differences in the building envelope. The building envelope in the enclosed classroom-type appears to have retained more heat as evidenced in the recorded higher mean indoor temperature.

Generally, the compliance exhibited by the classrooms suggests that the adaptive model is very applicable to naturally ventilated classrooms in the study area. Thermal comfort can be achieved in the classrooms without the use of any air-conditioning systems, and thus the classroom designs are capable of contributing to reduced energy use.

Table 5: Summary compliance of the classrooms to ASHRAE Adaptive model

Classroom type	Season	Prevailing mean temp (ºC)		Air Mov for compliance (m/s)
		Indoor	**Outdoor**	
Asw	Rainy	28.6	29.2	0.27√
	Dry	29.4	29.6	0.18 x
Aew	Rainy	28.7	29.2	0.21√
	Dry	29.5	29.6	0.20 x
Bsw	Rainy	28.2	28.6	0.19√
	Dry	28.9	29.1	0.11√
Bew	Rainy	28.3	28.6	0.12√
	Dry	28.9	29.1	0.16√
Csw	Rainy	28.7	29.4	0.17 x
	Dry	28.8	29.1	0.15√
Cew	Rainy	29.2	29.4	0.30 x
	Dry	29.0	29.0	0.25 x
All Short	All season	28.7	29.4	0.28√
All Enclosed	All season	29.2	29.4	0.29√ (boarder line)

Source: Fieldwork, 2015

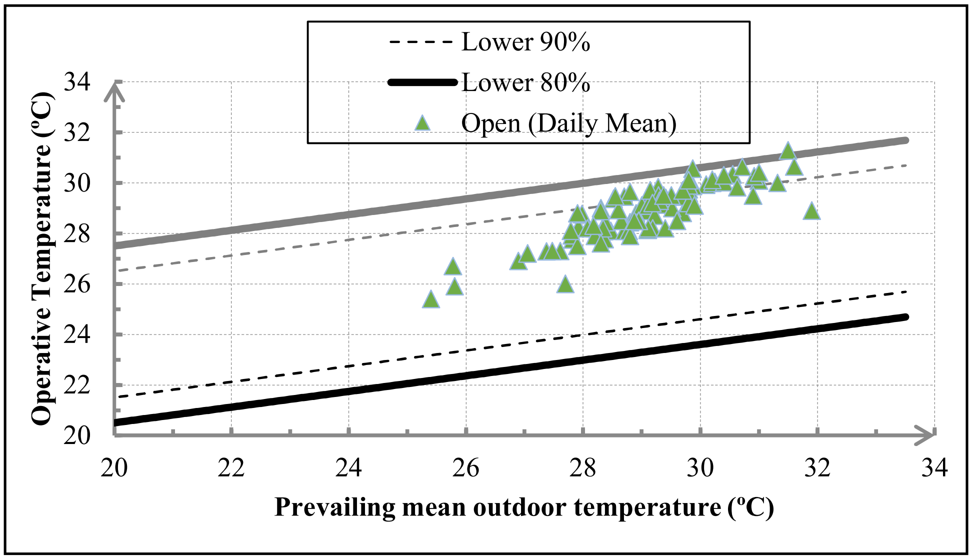
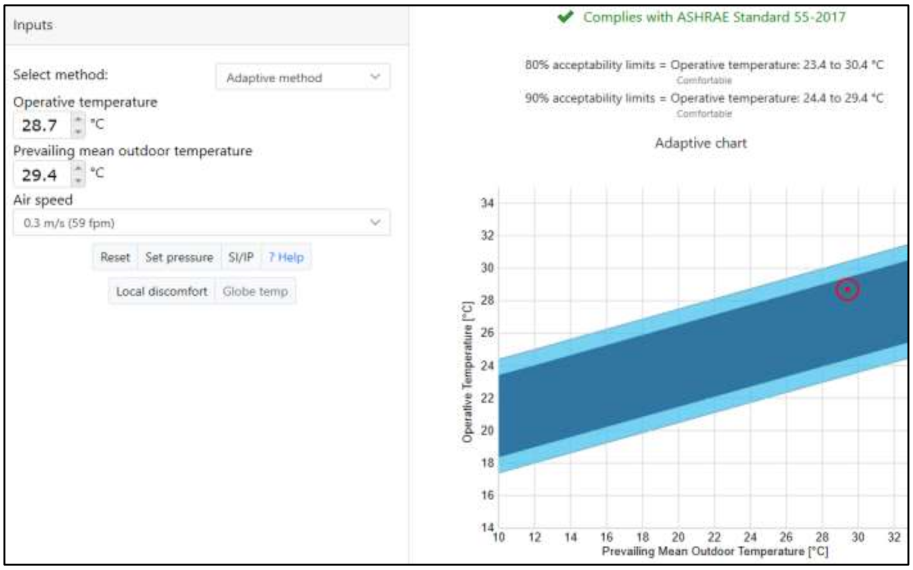


Figure 7: Indoor operative temperature plotted against the prevailing mean outdoor temperature

Source: Fieldwork, 2015



Inputs

Select method: Adaptive method

Operative temperature
28.7 °C

Prevailing mean outdoor temperature
29.4 °C

Air speed
0.3 m/s (59 fpm)

✓ Complies with ASHRAE Standard 55-2017

80% acceptability limits = Operative temperature: 23.4 to 30.4 °C
Comfortable

90% acceptability limits = Operative temperature: 24.4 to 29.4 °C
Comfortable

Figure 8: Analysis of combined 'short wall' classroom with air velocity of 0.3m/s using CBE thermal comfort tool

Source: Fieldwork, 2015

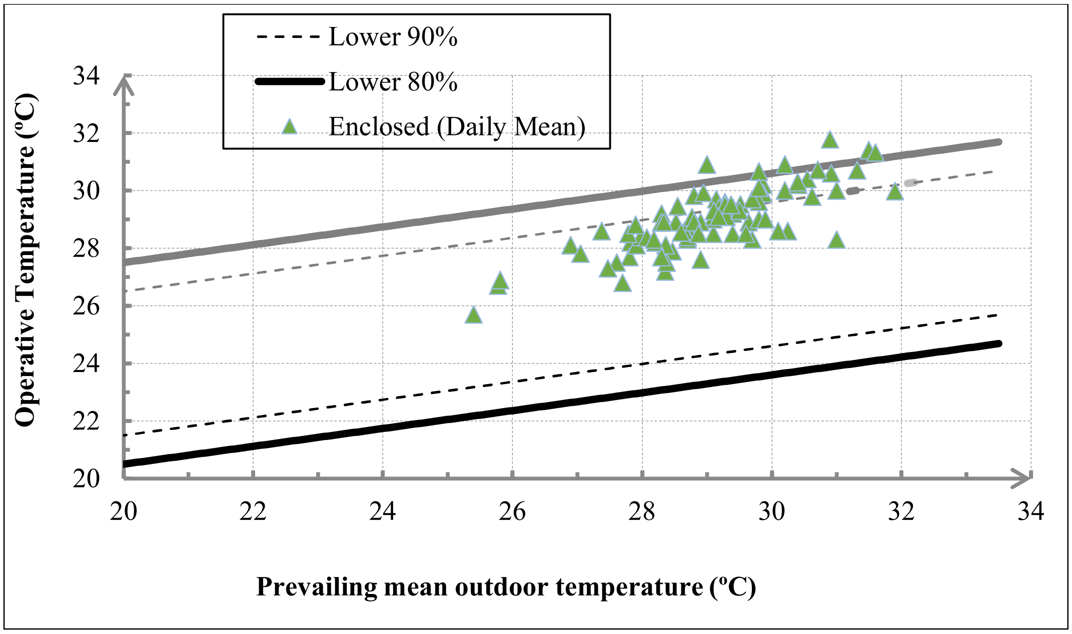
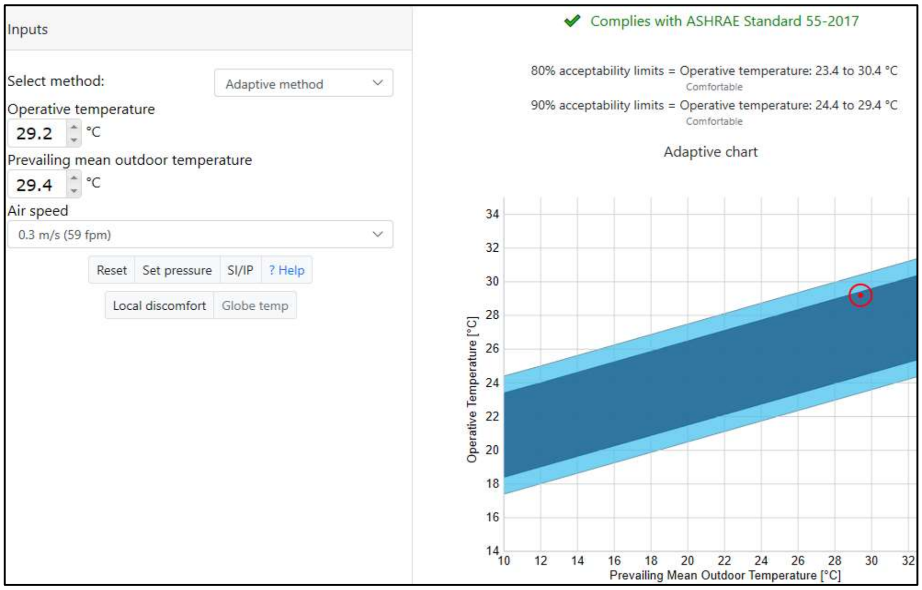


Figure 9: Indoor operative temperature plotted against the prevailing mean outdoor temperature
Source: Fieldwork, 2015



Inputs

Select method: Adaptive method

Operative temperature 29.2 °C

Prevailing mean outdoor temperature 29.4 °C

Air speed 0.3 m/s (59 fpm)

✔ Complies with ASHRAE Standard 55-2017

80% acceptability limits = Operative temperature: 23.4 to 30.4 °C
Comfortable

90% acceptability limits = Operative temperature: 24.4 to 29.4 °C
Comfortable

Figure 10: Analysis of combined enclosed walled classroom with air velocity of 0.3m/s using CBE thermal comfort tool

Source: Fieldwork, 2015

CONCLUSION

This study focused on assessing and comparing the thermal performance of two typical classroom types predominantly found in south-eastern Nigeria. These two classroom types have a significant difference in their building envelope. Results of the data analysis showed that the two classroom types comply with the ASHRAE standard 55 adaptive comfort model. This indicates that the thermal behaviour of these two classroom types was capable of providing a comfortable thermal environment without the use of active ventilators. However, the thermal performance in the *short wall* classroom-type was found to be significantly better than that of the *enclosed wall* classroom-type. The reason may be linked to a higher percentage of wall openings of the *short wall* classrooms which allowed more air into the classrooms. Cross ventilation is one of the best and cheapest strategies for improving indoor thermal comfort in warm and humid climates. Allowing enough air to enter indoors through building envelopes helps to remove excess heat accumulated indoors, thereby minimizing discomfort. Thus, to ensure thermal comfort in an indoor environment, and, at the same time, reduce the energy demand, passive strategies and adequate envelope treatment are required with more openings on the walls. There is a need for more research on a passive cooling design strategy that will help to promote a higher degree of thermal comfort in the hot and humid climate and completely do away with the need for air conditioning systems.

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