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An Investigation of Thermal Comfort in Classrooms in the Tropical Savanna Climate

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ABSTRACT

Studying the thermal environment in classrooms is essential due to its impact on students' health, teaching, learning, and productivity. In the Nigerian context, there is a general lack of thermal comfort studies, and none specifically relate to secondary school settings. This study aims to investigate students' perceptions of the indoor thermal environment and to determine the optimum temperature in naturally ventilated classrooms in the tropical savanna climate. Field investigations were conducted in free-running classrooms in Abuja to evaluate occupants' thermal comfort and perceptions. The study involves 901 pupils from 21 classrooms. Data were obtained through physical measurements of thermal comfort variables and a questionnaire survey on occupants' perceptions of the indoor thermal environment. The objective assessment indicated that 86% of the classrooms were inconsistent with the ASHRAE standard–55. Although 60% of the pupils were satisfied with their thermal environment, 78% preferred a cooler than neutral temperature. The result revealed a comfort temperature of 28.9 ^{o}C. The results extend the literature on thermal comfort in classrooms to the tropical savannah climate of the west African sub-region, which has received little attention in earlier research. The findings provide foundation data for developing a comfort standard for classrooms in the zone.

1. Introduction

Educational facilities aim to offer ideal learning environments for students and teachers [1]. As a result, classrooms should be built with climate responsiveness in mind [2] while also being structured to enhance concentration and the learning process. The thermal environment significantly impacts students' well-being and productivity [3-5], as students devote a substantial portion of their day to school. Thus, studying the relationships between classroom characteristics and comfort is crucial, especially for children exposed to an unfavourable indoor thermal environment [6,7].

There are several models for measuring thermal comfort in school buildings. However, the ones most often used are "Fanger's rational" and "adaptive models" [1,8]. The first performs better in air-

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conditioned buildings where occupants cannot react to changing conditions [5,7]. The second model works better in Naturally Ventilated (NV) structures and fits with the adaptive model [7,9]. de Dear [10] described the adaptive technique as "an architectural approach that is person-environment specific" and the rational method as "engineered models of a deterministic character."

When designing classrooms, it is essential to consider students' thermal preferences because the thermal perception of children and adults is not always the same [11]. Even though the climate, season, and mode of operation may be the same at the secondary level of education, studies have shown that thermal sensations and neutral temperatures are not always the same [12]. This can be a unique challenge when setting the right temperature for the student's comfort [5]. Given the complexity of these situations, there are no standards for thermal comfort in school buildings. Existing guidelines like ISO 7730 [13], ASHRAE–55 [14], and EN 16798–1 do not consider students' and teachers' different needs and preferences.

The thermal comfort of pupils in schools around the globe has been the focus of numerous research investigations. These investigations examined the thermal comfort of classrooms in temperate climates such as the UK, Denmark, and the Netherlands [15–17]; Mediterranean climates such as those in Italy, Portugal, and Cyprus [2,6,18,19] and subtropical climates such as those in Taiwan, Australia, and China [20,21]. Over this decade, several studies in naturally ventilated classrooms in the tropics have also been conducted [7,20,22–27]. These investigations demonstrated that students quickly adapted to naturally ventilated classes and found comfort levels between 24 and 31 degrees Celsius [5].

In the Nigerian context, there is a general absence of research on thermal comfort in Nigerian cities, in contrast to other countries with similar population sizes [27]. On the third of July 2022, a general bibliometric search in Google Scholar, Scopus, Science Direct, Web of Science, and SAGE journals, with the term "Thermal Comfort and Nigeria," and then, thermal comfort and major Nigerian cities of Lagos, Bauchi, Kaduna, Kano, Abuja, Ibadan, Enugu, Akure, and Port-Harcourt, yielded only 81 documents. According to these searches, only eleven (11) of these documents relate to school settings, and none specifically relate to secondary school settings. This is potentially a critical gap and a driving force for this research.

Abuja is a compelling location for this study, Nigeria's most urban and new capital city. It is one of the fastest-growing African cities, with an urbanization rate of 8.3% per annum [28]. Its population growth puts much pressure on schools and energy demand. Its location in Nigeria's geographical centre provides a transitional tropical climatic setting that is neither too hot (like in the semi-arid region) nor too humid (as experienced in Nigeria's coastal area).

This study would help extend the knowledge frontier on thermal comfort to the west African tropical savannah climate, which has received little attention in the past. The data will also help create a comfort standard that will assist in designing energy-efficient, naturally ventilated classrooms in the area.

The goals of this research include

i. To measure the indoor thermal environment of classrooms in Abuja and to determine whether the conditions comply with Standard–55
ii. To analyze students' perceptions of the indoor thermal condition of the classrooms
iii. To determine the optimal classroom temperature based on Abuja's climate

2. Methodology
2.1 Abuja Location and Climate

Abuja and other nearby settlements comprise the Nigerian Federal Capital Territory (FCT). It is situated in Nigeria's north-central region, between latitudes 9^o 03' and 9^o 07'N and longitudes 7^o 26' and 7^o 39'E. Its area is roughly 1,994 km2. The Köppen Climate Classification subtype for Abuja is Tropical Savanna (AW). It has two distinct weather seasons: hot, dry, and warm, humid. A brief interval known as harmattan occurs between the two seasons, typically from early December to February [29]. Except for the harmattan period, the region's temperature is usually high for most of the year. The daytime air temperature ranges from 26 to 36 degrees Celsius, with a low night-time temperature of 20 to 24 degrees Celsius. Table 1 provides an overview of Abuja's monthly climatic data.

Table 1
An overview of Abuja's monthly climatic statistics

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Max. Temperature	33.6	34.9	35.5	33.8	30.6	28.2	26.8	26.2	27.6	29.1	32	33.2
Avg. Temperature	27	28.6	29.6	28.6	26.5	24.5	23.4	22.9	23.6	24.7	26.4	26.7
Min. Temperature	20.5	22.3	23	24	23	21.7	20.9	20.7	20.8	21.3	21.1	20.4
Humidity (%)	26	29	38	57	73	82	85	87	85	80	51	29
Rainfall (mm)	2	6	20	57	138	205	269	326	290	144	11	1
Rainy days	1	1	3	7	14	17	21	21	20	15	2	0
Avg. sun hours	10.3	10.3	10	8.3	6.1	4.5		3.9	4.6	6.3	9.9	10.3

2.2 The Investigated School and Classroom

Government Secondary School Garki, Abuja, serves as the case study institution. The coordinates are 9° 03' 61.704 N and 7° 48' 28.797 E. It is located in Area 10 of Garki, Abuja, on Kam Salam Street, off Mashood Abiola Road. The junior secondary and senior secondary divisions make up the school. This survey is focused on the secondary portion, which opened its doors in 1987. This component consists of an administrative block, a laboratory section, a library, and classroom blocks. A covered walkway on the eastern side connects the three classroom blocks, which are placed in a straight line. The one-story classroom blocks accommodate roughly 1,200 students. Figure 1 shows a graphic view of the case study.

According to Torres-Rodríguez *et al*., [30], Chernousov and Chan [31] and Zomorodian *et al*., [12], a building's indoor thermal condition is influenced by the construction characteristics of the building, including the building's building materials and thermal envelope properties [32]. Classrooms in the study school are constructed of a solid ground floor made of mass concrete 150 mm thick, laid 300–mm above the hardcore. The floor is finished with a 50–mm cement-sand screed. The walls are generally made up of 225–mm sandcrete hollow blocks, plastered on either side with 25 mm of cement-sand mortar. Each classroom has a 900 x 2100 mm steel casement door that opens to a 3000 mm lobby in the front of the building. Windows are of the projected type, framed with steel, with an infilled glass panel. Roof structural members are typically seasoned timber covered with a 0.55–mm corrugated long-span aluminum sheet.

Fig. 1. Shows the pictorial views of the case study school

2.3 Data Collection

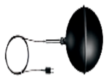
Two cross-sectional field studies were conducted: the first on March 12 and 13, 2020 (dry season), and the second on June 15 and 16, 2021 (rainy/wet season). Data for this study was obtained through physical measurements and a survey method, which was done concurrently. The survey was conducted in 21 classrooms, ten (10) in the dry period and eleven (11) during the wet season, with a different group of students in each classroom for each season. The survey was conducted with 901 respondents, comprising 894 students and seven teachers.

2.3.1 Indoor environmental parameters

Four atmospheric variables, air velocity, globe temperature, humidity, and ambient air temperature, were evaluated concurrently while the questionnaire survey was administered. The instrument consists of a Testo Turbulence probe for measuring air velocity. Testo 605i probes were utilized to assess the air temperature and humidity, and a 150-mm globe thermometer was employed to determine the globe's temperature. The instruments' measuring range, precision, and resolution are specified in Table 2. Following the criteria for instrumentation and procedures, measurements and instruments were classified as Class II.

All indoor climate measurements were made at 1.1 m above the ground [33] following UNI EN ISO 7726 guidelines and at 3 points in each classroom. Depending on how occupants were spread, a Testo 440 comfort kit with probes for temperature, humidity, air speed, and globe temperature was placed at a mid-position in the classroom, while a Testo 605i with sensors for temperature and humidity was set at two (2) other different stations in the room. All the instruments were newly calibrated to ascertain the performance and accuracy of each device. Environmental parameters were measured over 40 minutes, but the first 15 minutes were discarded (for the instrument to attain its resolution) [6,14]. The parameters were measured every 10 s and averaged at 3-minute intervals. The ASHRAE Standard–55 was used to compute the "mean radiant temperature (T_{mrt})" and the "operating temperature (T_{op})".

Table 2
Instruments' measuring range, accuracy, and resolution

S/N	The name of the instrument. /Sensor	Diagrams	Measurement	Measuring range	Accuracy	Resolution
1	Testo 440 Comfort Kit		Air velocity and IAQ instruments	-40–150 °C	± 0.3 °C	0.1 °C
2	Testo 605i		Humidity and temp.	0–100% & 20–60 °C	±1.8% RH ±0.5 °C	0.1% RH 0.1% °C
3	Testo Globe thermometer		Globe temperature	10–120 °C	Class 1	0.1% °C
4	Testo Turbulence probe		Air Velocity	0–5m/s 0–50 °C	±0.03 m/s ±0.5 °C	0.01 m/s 0.1 °C
5.	Testo 174 H datalogger		Humidity and temp.	0–100%-20–70°C &	±3% RH &. ±0.5°C	0.1% RH & 0.1 °C

2.3.2 Respondent survey

The study questionnaire has questions drawn under three sections: demographics, thermal comfort, and clothing checklist. The demographic survey examined the respondents' physical information, including their gender, age, approximate height, approximate weight, and length of time in Abuja. Thermal comfort was evaluated using

i. The 7–point ASHRAE thermal sensation scale, "(hot = + 3; warm = + 2; slightly warm = + 1; neutral = 0; slightly cool = - 1; cool = - 2; cold = - 3)".

ii. 2–point thermal acceptability scale; "(acceptable = 1; unacceptable = 2)"

iii. 3–points McIntyre thermal preference scale; "(cooler = -1; no change = 0; and warmer= +1)"

The clothing checklist requests the respondents to check off the clothing items that matched the clothes they were dressed in at the time of the survey according to the ASHRAE standard checklist [12]. The clothing insulation (clo) for each representative occupant was found by summing up the different values listed for each piece of clothing in the collection. The anticipated representative metabolic rate for every student in the classroom is 1.0 MET, which indicates the rate for leisure activities [34].

3. Results and Discussion

3.1 Sample Characteristics

The study was conducted at Government Secondary School (GSS) in Garki, Abuja. Nine hundred and ten (910) respondents (after the removal of invalid data) participated in the campaign. Table 3 displays the respondents' background and statistical summary. There were more female participants (59.2%) than male participants (40.8%). Primary data on the samples' length of residence in Abuja indicated that approximately 74% of the respondents have resided in Abuja for more than five years. Most respondents were therefore assumed to have fully acclimatized to the local climate.

Table 3
Respondents' background and statistical summary

		Total = 1448 Freq.	Percent	Total %	Statistics	
Gender	Male	368	40.8%	100%		
	Female	533	59.2%			
Age (Years)	12–14	142	15.8%	100%	Mean	16.19
	15–17	612	67.9%		Std. Dev.	2.80
	18–20	131	14.5%		Min.	12
	>20	16	1.8%		Max.	60
Height (cm)	135–149	31	3.4%	100%	Mean	163.63
	150–164	414	45.9%		Std. Dev.	8.78
	165–179	416	46.2%		Min.	140
	>179	40	4.4%		Max.	195
Weight (Kg)	32–47	250	27.7%	100%	Mean	55.55
	48–63	501	55.6%		Std. Dev.	9.78
	64–77	130	14.4%		Mini.	32
	>77	20	2.2%		Maxi.	95
Length of Residence in Abuja (years)	< 5	235	26.1%	100%	Mean	10.61
	6–10	191	21.2%		Std. Dev.	5.42
	11–15	298	33.1%		Min.	1
	>15	177	19.6%		Max.	46

3.2 Clothing Variable

The research population's average value for insulation from clothing is 0.60 clo and varied from 0.36 to 1.10. Table 4 shows the seasonal variations among the respondents' clothing insulation. During the rainy season, participants wore 0.06 clo more clothing than during the dry season. On warm days, students dressed in less clothing often undid one or two buttons from the top of their shirts. On such days, students who wore full sleeves often rolled up their sleeves. This behavior may be related to seasonal adaptation to high ambient temperatures. Other thermal comfort surveys have noted similar occupant behavior [35–37].

Table 4
Summary statistics of Clothing Insulation Value (clo)

Group	Statistics	Dry season	Rainy season	Both season
Clothing Insulation Value (clo)	N	443	458	901
	Mean	0.57	0.63	0.60
	Std. Dev.	0.07	0.13	0.11
	Min.	0.44	0.36	0.36
	Max.	0.79	1.10	1.10

3.3 Indoor Climate

Table 5 provides the summary statistics for the indoor climatic measurements. The average indoor air velocity was only 0.08 m/s. Although fans were seen in every classroom, they were rarely used during the interviews, partly due to low temperatures in the rainy season and sometimes due to fans being in disrepair or power outages. The relative humidity, on average, was 53%. The mean radiant temperature (T_{mrt}) was roughly 0.5 °C warmer than the globe temperature (T_g) of 31.2 °C and three-quarters (3/4) degrees more than the mean operative temperature (T_{op}) of 31 oC. The air temperature (T_a) ranged between 26.5 and 34.3 °C over the entire period, with a mean of 30.48 °C.

ISO 7730 [13] recommended ranges for air temperature and relative humidity are 23 to 26 degrees Celsius and 30 to 70 percent, respectively. The results of this study indicated that the temperature in the classrooms surpassed the upper limits, and the humidity exceeded the lower and upper limits of the sedentary activity standard. However, the average air velocity of 0.13 m/s was within the limits of 0.20 m/s for passive activity.

Based on ASHRAE Standard 55 [14] guidelines that recommend temperatures between 19 and 28 degrees Celsius (67-82 degrees Fahrenheit) with no established lower humidity limits for thermal comfort, 18 (86%) out of the 21 studied classrooms were outside the acceptable thresholds of the comfort range.

Table 2
Indoor climatic measurement summary statistics

	N	Minimum	Maximum	Mean	Std. Dev.
Air Temperature (°C)	901	26.5	34.3	30.48	2.01
Airspeed (m/s)	901	0.08	0.47	0.16	0.10
Relative humidity (%)	901	14.7	76.0	53.05	19.88
Globe Temperature (°C)	901	27.0	35.1	31.22	2.08
Mean Radiant Temperature (°C)	901	27.3	35.5	31.75	2.19
Operative Temperature (°C)	901	26.90	34.90	31.08	2.05

3.4 Students' Thermal Perception

The best way to respond to inquiries about thermal perception as it relates to comfort and satisfaction with the indoor environment is to combine subjective scales. The ASHRAE thermal sensation scale is the most helpful in indicating one's total thermal condition. However, it cannot tell how satisfied the subject is with that state. Instead, this relationship is implicitly inferred, and the traditional assumptions have been:

i. that "neutral" thermal sensation denotes the ideal conditions, and
ii. Comfort, or acceptability, indicates the "three central categories of the thermal sensation scale (slightly cool, neutral, and slightly warm)." This assumption implies that thermal sensations outside these three primary categories are undesirable or uncomfortable.

The direct acceptability question allows us to determine whether the physical conditions and related thermal sensations are appropriate. Another scale, the McIntyre preference scale, asks the participant to indicate whether they would prefer to "feel warmer, unchanged, or cooler," which allows for a more direct assessment of ideal conditions.

The comfort zone is thermal settings that are "acceptable to at least 80% of the occupants.". Currently, Standard 55 uses the temperatures related to the main three thermal sensation categories in which 80% or more of the occupants will vote to set its comfort zone boundaries of acceptance.

3.4.1 Thermal sensation

Table 6 displays the statistical summary of thermal perception. For ambient temperature measurements between 26.5 °C and 34.3 °C., the mean TSV was 0.91, and it is in the slightly warm region of the thermal comfort zone. For a thermal environment to be deemed acceptable, 80% of the dwellers must vote for the "3 central categories (-1, 0, 1)". When direct measurement of the students' counts on the sensation scale for the "3 central categories" is calculated, Figure 2 shows that only 59.4% of the population falls within the "3 central categories (-1, 0, 1)". Therefore, the students' votes for an acceptable classroom thermal setting fell short of the ASHRAE Standard–55 criterion of 80 percent.

Table 6
Thermal Perception Statistical Summary

	N	Min.	Max.	Mean	Std. Dev.
TSV	901	-3	3	0.91	1.38
Thermal Preference Vote	901	-1	+1	-0.69	0.63
Thermal Acceptance Vote	901	1	2	1.40	0.49
General Comfort Votes	901	-3	+3	0.27	2.06

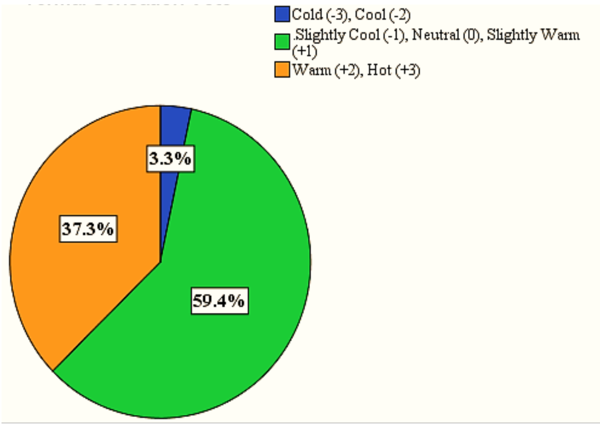


Fig. 2. Pie chart showing the frequency of thermal sensation Votes

3.4.2 Thermal acceptability

Indoor conditions in naturally ventilated structures depend on the weather. It is, therefore, more crucial to maintain a comfortable temperature range than to keep the environment at a constant neutral temperature [36]. According to Standard–55, an appropriate thermal setting must satisfy at least 80 percent of the inhabitants. There are numerous ways to assess conformity with Standard–55's 80 percent thermal acceptability requirement [38]. The conventional and most popular approach is an indirect measure that equates satisfaction (or acceptability) with the" 3 center categories of the seven-point thermal sensation scale (-1, 0, +1)", as shown in figure 2. With this approach, it is estimated that 59.4% of occupants are comfortable with their thermal environment.

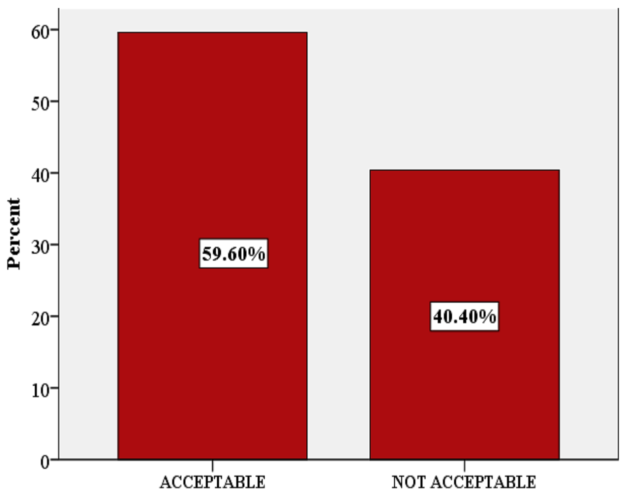


Fig. 3. Thermal Acceptance Vote

The second approach employs a current situation and a direct query.: "Are the conditions in the classroom acceptable to you right now?" Using this method, 59.6% of occupants found the conditions acceptable in Figure 3. In the two approaches used for the thermal acceptability assessment (59.4 and 59.6%), the votes fell below the 80% acceptability benchmark stipulated by Standard–55. Therefore, the students are not comfortable in the classrooms.

This finding is contrary to the result of Mishra and Ramgopal [35] in tropical classrooms in India, where students' responses to the thermal acceptability question yielded about 80% acceptability for indoor classroom temperatures varying from 22.1 to 31.5 °C operative temperature.

3.4.3 Thermal preference

A mean Thermal Preference Vote (TPV) of -0.69 indicates students' preference for being cooler (Table 6). Figure 4 displays the findings of the respondents' subjective thermal preferences. Approximately 77.8% of the respondents preferred it to be cooler, 13.1% did not require a change, and 9.1% desired a warmer environment. The preference of most respondents to want a cooler condition in this study is consistent with the general tendency of people from warm climates to prefer cool conditions [39].

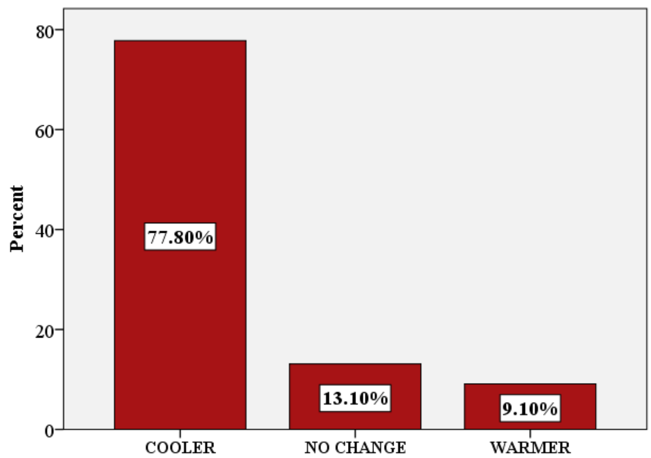


Fig. 1. Thermal Preference Vote

Table 3
Crosstabulation of thermal sensation and thermal preference votes

			Thermal Preference			
			Cooler	No Change	Warmer	Total
Thermal Sensation Vote	-2, -3	Count	2	0	28	30
		% of Total	0.2%	0.0%	3.1%	3.3%
	-1,0, +1	Count	373	117	45	535
		% of Total	41.4%	13.0%	5.0%	59.4%
	+2, +3	Count	326	1	9	336
		% of Total	36.2%	0.1%	1.0%	37.3%
Total		Count	701	118	82	901
		% of Total	77.8%	13.1%	9.1%	100.0%

Crosstabulation of thermal sensation and preference scales suggests that the best or preferred thermal condition is not usually the neutral thermal sensation. This was obvious when 373 (41.4%) votes of the students who were feeling near neutral thermal sensations "(slightly cool, neutral, and slightly warm)" out of 535 (59.4) votes still wanted to feel cooler, as shown in the highlighted portion of Table 7. The neutral temperature may not always be ideal, as approximately 70% of subjects who felt near neutral preferred to be cooler. This agrees with other scholars' views [40,41].

3.5 Optimal Classroom Temperature

3.5.1 Neutral temperature

The neutral temperature is an additional metric for assessing thermal comfort. According to Humphreys *et al.* [8], it is the temperature at which most survey participants select the neutral (0) response on the ASHRAE scale. The neutral temperature is determined by performing a regular linear regression with the T_{op} as the independent variable and the mTSV as the dependent variable [42,43]. The regression equation that results is

$$mTSV = 0.4Top - 11.56 \qquad ; R2= 0.94 \qquad p < 0.001 \qquad (1)$$

From Eq. (1), a neutral temperature is attained by substituting the value of zero (0) for mTSV. The equations produced 28.9 °C as the neutral operative temperature. The graph of the plots is shown in Figure 5.

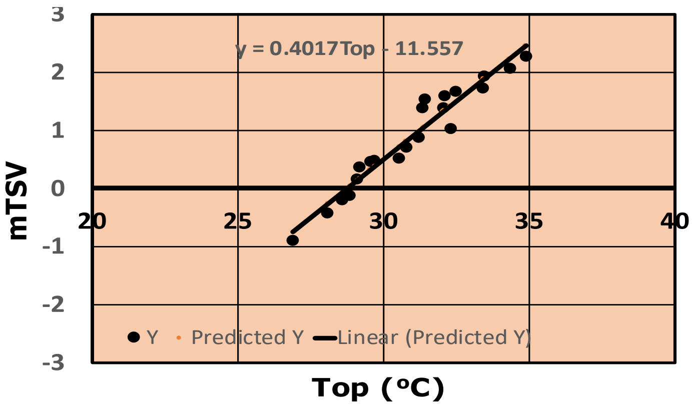


Fig. 5. shows the regression plots for mTSV and T_{op}

3.5.2 Comfort temperature range

The thermal acceptability limits are the range of appropriate or comfortable indoor temperatures for a portion of the population that the sample represents. These limits, centered on the neutral temperature, can be found using the linear regression model. This research established the thermal comfort range using the ASHRAE adaptive model, which set 80%, or -0.85TSV+0.85 comfort zone. The thermal comfort range can be calculated by substituting ±0.85 for mTSV in Eq. (1). The comfort range for the classrooms is 26.8 – 31.0 °C.

3.6 Comparison of Findings with Previous Studies

The neutral temperature found in this survey (28.9 °C operative temperature) is comparable to the readings recorded in some studies conducted in naturally ventilated tropical school classrooms: 28.8 °C for Wong and Khoo [44], 29.2 °C for Liang [45], 28.5 °C for Hamzah *et al*., [42], 29 °C for Mishra and Ramgopal [36], and 28.4°C for Hussein *et al*., [46].

The comfort temperature range of 26.8–31.0 °C for this investigation is also consistent with the findings of other studies conducted in naturally ventilated school buildings in tropical regions. For non-air-conditioned classrooms in Malaysia, Hussein *et al*., [46] found a "comfort temperature range" of 26°C to 30.7 °C. In a parallel development, Mishra and Ramgopal [36] also found a "comfort temperature range" of 22.1 to 31.5 °C for students' thermal comfort in the Indian Institute of Technology Kharagpur NV classrooms.

There is a pervasive paucity of thermal comfort studies in Nigerian secondary schools. Recent research conducted by Munonye and Ji [7] in Nigeria's warm and humid Imo state primary schools revealed that "combined open-space classrooms" produced a neutral temperature of 28.8 °C with a comfort range of 25.2-32.3 °C, whereas "combined enclosed-plan classrooms" produced a neutral temperature of 28.1 °C with a comfort temperature range of 25.2-30.5 °C. In contrast, Ogbonna and Harris [47] discovered a comfort temperature of 26.3 °C and a comfort range of 24.9 °C to 27.7 °C in Jos, Nigeria, which is lower than this study's findings. Jos' climate is responsible for the disparity. Jos City's temperature ranges from 24 to 32 degrees °C, whereas the study area's daily air temperature ranges from 26 to 36 °C.

4. Conclusion

This study's most significant contribution is that students in naturally ventilated classrooms in Abuja are comfortable in conditions outside the ASHRAE standard-55 comfort zone. ASHRAE standard 55 recommended a temperature comfort range of 26 to 28 °C for summertime. However, the students were comfortable at temperatures up to 3K above the Standard's upper threshold. Students' exhibition of greater thermal tolerance in the study area saves the time and effort invested in establishing classroom comfort zone conditions. This opportunity allows schools to cut their long-term energy costs by having well-designed NV classrooms with improved passive strategies. Other conclusions drawn from the study are:

The indoor air temperature ranging from 26.5 – 34.3 °C and relative humidity of 15%–76% for this study is inconsistent with the ASHRAE standard–55 and the ISO EN7730 standard for sedentary activity. Evaluation of indoor parameters in the classrooms indicates that only 14% of the classrooms met the ASHRAE Standard 55 comfort requirement. Students' thermal perception, however, showed that 60% were comfortable with their thermal environment.

For this study, the neutral temperature is not ideal, as approximately 70% of subjects who felt near neutral preferred it to be cooler. This finding implies that most tropical students want to feel significantly colder than neutrality and that, as a result, neutrality-based standards may not be appropriate.

This study's findings have practical consequences for building services engineers, architects, and building industry stakeholders [48]. It can be used to design new classrooms and assess the comfort temperature of existing buildings. It may also serve as foundation data for classroom thermal comfort and related studies in the climatic zone.

The study has many strengths and substantially contributes to existing knowledge. However, it has some limitations that can be addressed in future studies. First, only one school's classrooms were studied. Secondly, air-conditioned classrooms were not considered. Future studies should be conducted in air-conditioned classrooms. The survey on NV classrooms should be expanded to cover classrooms in other regional climatic zones to establish a more extensive database of acceptable temperature ranges and adaptive opportunities in Nigeria.

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