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Determining the Thermal Stress of Primary School Children in the Warm and Humid Climate of Imo State

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Abstract: ***Most studies on thermal comfort in schools dealt with the general comfort temperature of the occupants. There is a paucity of specific information about heat and cold stress experienced by students during the time they were in school. Considering these, a field study was carried out in some selected months during the rainy and dry seasons of 2018 to investigate if heat stress and cold stress exist in naturally ventilated classrooms of government primary schools in Imo State. Responses from 330 children, in the age group between 7 and 12 years, were subjectively and objectively collected. Results indicate that the subjects, apart from experiencing heat stress, also experienced cold stress, both occurring in14.8% of the periods the surveys were carried out. In 62.5% of this period, the subjects expressed heat stress while cold stress was experienced in 37.5%. While January experienced the coldest cold stress with a thermal sensation of - 1.50, February recorded the warmest thermal sensation (1.60). Though January was specifically identified as a delicate month for the children because of the high fluctuations in indoor temperatures experienced during this month, however, February reported the highest period of thermal stress (28.0%). From the results, it is important that children need to dress properly according to temperature to avoid catching a cold or getting exposed to thermal stress during the lesson hours. Architects need to factor in all this information when designing primary school buildings in tropical climates.***

Keywords: Architect; Cold stress; Heat stress; Schools; Temperature

1. Introduction

People living in tropical climates are concerned about overheated indoor spaces exacerbated by climate change. These overheated indoor spaces impact more vulnerable populations such as children [1]. In thermal comfort studies, schools are getting more attention because students spend a long time in classrooms under various indoor environmental conditions. If exposed to high indoor temperatures, within the occupied time, they may be uncomfortable. Exposing children to high indoor temperatures can impact their health and affect their learning and problem - solving ability [2, 3]. It was also found that adequate learning conditions improve students' performance by as much as 30% [4]. The frequency of heat waves has increased in recent times, and people who can afford air - conditioning systems use them to reduce this impact. This artificial method of providing thermal comfort is becoming popular in buildings in Nigeria across the whole month of the year. The disadvantages in the use of air - conditioning systems to provide thermal comfort are their high cost of operation and the carbon monoxide (CO_2) they deposit into the atmosphere that causes climate change.

In the tropics, most of the buildings are naturally ventilated (NV), and people resort to various forms of adaptive actions to be thermally comfortable. ASHRAE Standard 55 defined thermal comfort as that condition of mind that expresses satisfaction with the thermal environment. In a simple term, it is a state in which a person is satisfied with the temperature of the environment or a state in which a person does not complain about the temperature. The predicted mean votes (PMV) model, the actual mean votes (AMV) model, and the adaptive thermal comfort (ATC) model are the various models developed to predict thermal comfort in an environment. The AMV and the ATC are usually used to predict occupants' comfort in naturally ventilated buildings. Classrooms are places where people from different socioeconomic backgrounds gather. Therefore, identifying the thermal conditions in educational buildings is important because of the effects of poor indoor environment on peoples' health. Previous thermal comfort studies in tropical climates focused on determining heat stress periods and there is limited information about the existence of cold stress periods. The study will attempt to fill this gap. This study aims to determine the periods primary schoolchildren in Imo State are thermally uncomfortable based on ASHRAE comfort requirements.

2. Review of Literature

Countries, where thermal comfort studies have been mostly carried out, are Taiwan, China, Japan, Italy, the United Kingdom, and the USA. [5]. Because social background, traditional way of life, culture, buildings, and climates are distinct from one geographical place to another, comfort study done in a geographical area may not be generalized to apply to a different geographical area [6, 7, 8]. For now, the number of thermal comfort studies conducted in school buildings is not comparable to those conducted in offices [9]. Fanger stated that the factors influencing the condition of thermal comfort can be divided into two main parts: four environmental factors (air temperature, mean radiant temperature, air velocity, and relative humidity) and two personal factors (metabolic rate and clothing insulation) [10].

According to the adaptive comfort model, people do adapt to the temperature they are more accustomed to or to the temperature prevailing more in their environment. For example, Elsherif et al, [11] studied subjects in naturally ventilated classrooms in Khartoum Sudan, and found thatthe internal comfort temperature of 34.12°C was acceptable. Adaji et al [12] found that subjects in low - income residential buildings in Abuja can prefer a temperature of 29.4°. Azari & Hariri [13] found the indoor temperature of 29.9°C acceptable in a survey conducted in Sekolah Malaysia. Mishra &Ramgopal [6] found 31.5°C, as the upper limit, acceptable in classrooms located in Kharagpur, India. Vi et al [14] conducted fieldwork and observed that schoolchildren can accept a temperature of 33.0°C in Minh city of Vietnam. Other examples are the fieldworks of Munonye and Ji [15], Jindal [16], Tari Ahmed [17], Liang, et al [18], and a host of other works where the occupants also accepted high indoor temperatures. An important piece of information is that the acceptable mean indoor temperatures in these studies were found to be close to the mean outdoor temperatures. The adaptive comfort model posits that there is a relationship between the outdoor temperature and the indoor temperature. This relationship influences people's perception of thermal comfort. People who stay indoors in a free - running building, do adapt to the external temperature around the building, mediated through its walls and operable windows, and roofs [19]. Thus, the adaptive comfort model is often used by thermal comfort researchers to determine the thermal perceptions of building occupants in NV buildings. These buildings are mostly found in tropical regions.

3. Material and Methods

3.1 Data collection

A field study was conducted in six public primary school classrooms randomly selected from the three senatorial zones in Imo State. The investigated classrooms were naturally ventilated (NV). The number of occupants in each classroom ranged from 25 to 30. Each classroom measured approximately 6.8 meters by 9.4 meters. The survey was conducted in January, February, April, May June, and October. Three months were randomly selected from each of the two seasons (rainy season and dry season). In each of the surveyed classrooms, the indoor and the outdoor environmental parameters were collected using Tiny Tag Data Loggers. Kestrel 3000 Pocket Wind Meter measured the indoor air velocity. For the subjective data collection, ASHRAE Standardized questionnaire was adopted, with minor modifications to suit the age and the background of the subjects (Table 1). The questionnaire was distributed and filled in at 9.00 am and at 1.00 pm as the data loggers were taking the environmental measurements. During these periods, the students were reading or writing and most of them entered their classrooms about an hour before the questionnaires were administered. At this time, their metabolic rate was assumed to have settled and reached the ASHRAE recommended sedentary level of approximately 1.3 met [20]. Another condition for ASHRAE adaptive comfort model to be used is that the prevailing mean outdoor temperatures should not be above 33.5°C or below 10.0°C [16].

Figure 1: Outdoor conditions of the surveyed buildings

Figure 2: Students filling the questionnaire

Table 1: ASHRAE 7 - point thermal sensation scale

ASHRAE Thermal Sensation Scale	**- 3**	**- 2**	**- 1**	**0**	**+1**	**+2**	**+3**
	colder	cooler	a bit colder	okay	a bit warmer	warmer	hotter

3.2 Method of analysis

Data collected from the fieldwork were transferred to Excel Spreadsheets, organized, and statistically analyzed into tabulation and regression graphs. In NV buildings, there is a relationship between the indoor temperature and the outdoor temperature. To assess thermal comfort, operative temperature (Top) can be used. Top can be defined as the average of the mean radiant temperature and ambient temperature, weighted by the heat transfer coefficients for radiation and convection [20]. This can be calculated using Equation 1, for building occupants that are not exposed to direct sunlight, have near sedentary physical activity levels, and are present in an enclosed air speed below 0.2m/s [20].

$$T_{op} = \frac{1}{2}T_a + \frac{1}{2}T_r$$

where:

T_{op} = operative temperature

T_r = mean radiant temperature

T_a = air temperature **(1)**

The comfortable and uncomfortable periods during these months were determined by applying the ASHRAE Adaptive comfort model. The model sets the comfort zone within - 0.85 to +0.85 thermal sensation votes at 80% acceptability criterion [20].

4. Results and Discussion

The prevailing mean outdoor temperature was below 33.5°C and above 10.0°C for the months the fieldwork was carried out. Standard (ASHRAE) 55 does not cover the prevailing mean outdoor temperatures above 33.5°C or below 10.0°C [16]. Having satisfied this requirement, the adaptive comfort model was therefore adopted to analyze the data collected from the fieldwork. From the data, an insignificant difference between air temperature and mean radiant temperature was observed (Table 2). As a result, the operative temperature was adopted for the analysis of this work. The mean indoor temperatures for the months the surveys were conducted ranged from 28.1°C to 29.5°C, while the mean outdoor relative humidity ranged from 62.8% to 73.6% (Table 2). Higher values of mean indoor operative temperatures were recorded during the dry season (Jan, Feb, and Apr) compared to the rainy season months (May, June, and Oct). From the regression analysis of the mean indoor temperature against the mean thermal sensation, positive correlations were obtained as shown in Figures 3 to 8. In order words, as the temperature was on the increase, the subjects expressed warmer thermal sensations. This implies that temperature influenced the thermal sensation of the subjects. In addition, as the mean indoor operative temperature and relative humidity differed from month to month, so also the neutral temperature, comfort range, and sensitivity to temperature change differed. The findings from this work indicate that the thermal perception of the students was influenced by the environmental variables they encountered daily during school hours. Generally, the subjects accepted higher indoor temperatures during the rainy season months compared to the dry season months. Also, they could accept cooler temperatures during the rainy season compared to the dry season. The result is consistent with the higher comfort bandwidth experienced in the rainy season months compared to the dry season months (Table 2). The result suggests that the subjects were more thermally comfortable within a higher range of indoor temperatures during the rainy season months. In addition, heat stress and cold stress were experienced in 14.8% of the period the surveys were conducted in all the months combined. Heat stress was recorded in 62.5% of this period while cold stress was recorded in 37.5% of this time.

Furthermore, there was no month the thermal perception of the subjects was the same. Figures 3 - 8 show the results of the regression analysis of the mean indoor operative temperature against the mean thermal sensation for the various months the survey was carried out. The regression equation, shown on the graph (Figure 3), for the month of January, produced a neutral temperature of 28.1°C with a comfort range of 25.4 – 30.8°C for January.

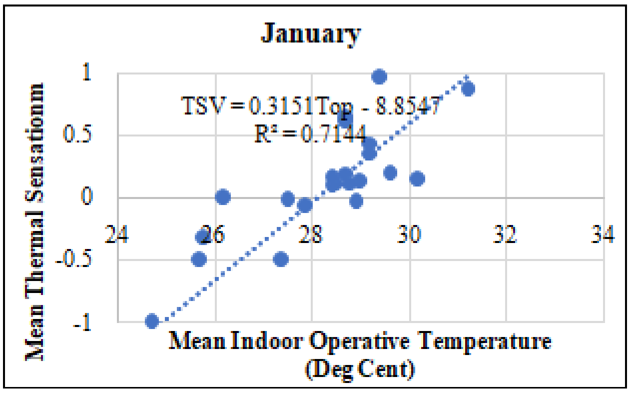

Figure 3

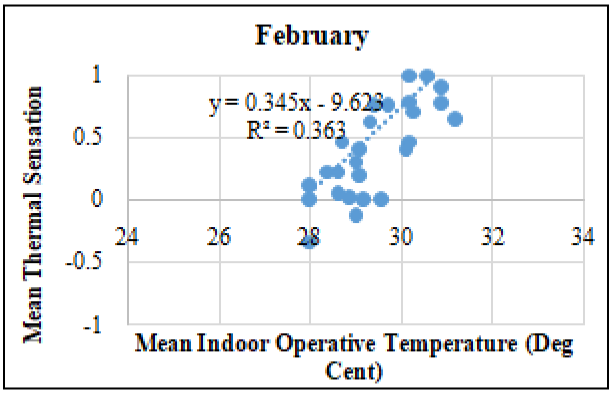

Figure 4

Regression of Top vs TSV (Mean)

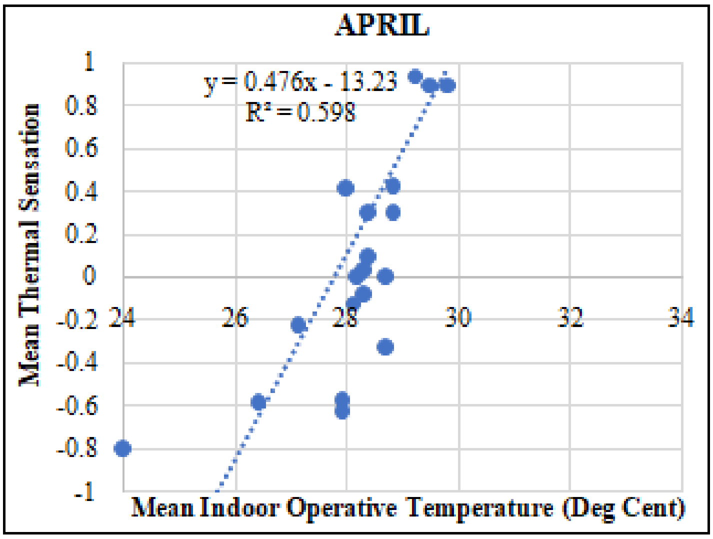

Figure 5

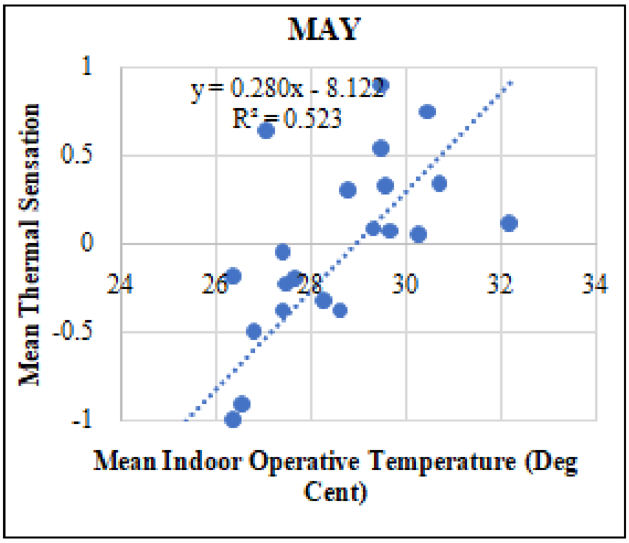

Figure 6

Regression of Top vs TSV (Mean)

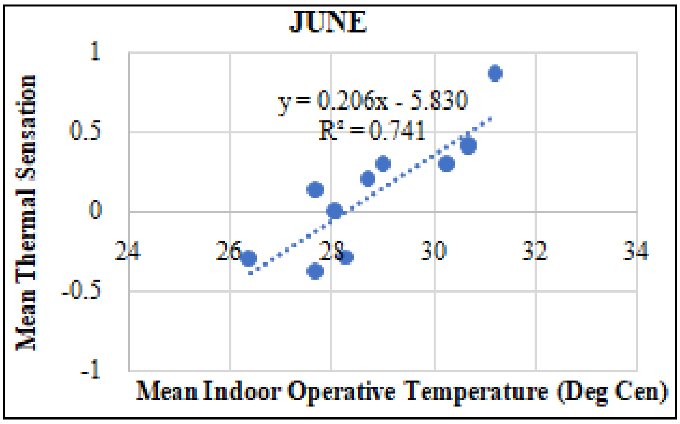

Figure 7

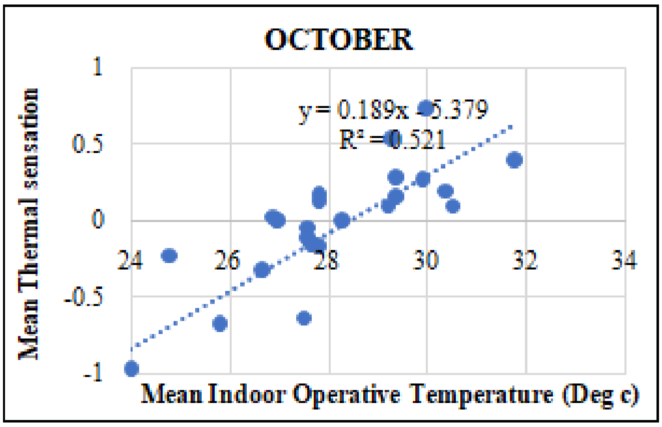

Figure 8

Regression of Top vs TSV (Mean)

Furthermore, high sensitivity was expressed by the subjects in January. As summarized in Table 2, for every 1.4°C change in indoor operative temperature, the thermal sensation of the subjects shifted by one (1) full scale on the ASHRAE 7 - point thermal sensation scale. That is an indication that the subjects found it difficult to adapt to the changes in the indoor operative temperatures in January. A check on the thermal sensation of the subjects (Table 3) clearly explained the reason for the high sensitivity to temperatures. There were high fluctuations in thermal sensation within the period the survey was conducted in January. For example, the thermal perception in January ranged from as cold as - 1.5 to as warm as 1.17, making it difficult for the subjects to adjust and adapt to temperature fluctuations. Harmattan is attributed as the cause of this fluctuation. The effect of the harmattan season, which is usually high in the month of January, contributed to the high fluctuations in temperature in January. Harmattan season, brought over by the northeasterly trade wind which blows from the Sahara desert over West Africa, is predominantly associated with cold wind and wide fluctuations in temperature. This effect of harmattan helped to lower the mean indoor operative temperature in January, known for reporting some warm days. Some high temperatures were recorded on some days while other days low temperatures were recorded. For example in January, high temperatures in values 29.9°C, 29.1°C, and 29.5°C were recorded on the 22nd, 23rd, and 30th, respectively January. While in the same month low temperatures in values 26.0°C, 24.4°C, and 26.8°C were recorded on the 18th, 19th, and the 25th, respectively.

The finding in January is that subjects may sometimes feel cold and may prefer warmer temperatures. The result suggests that rather than feeling only heat stress in January (the days that the survey was carried out) the subjects also felt cold stress. The usual understanding is that subjects in tropical climates always feel warm and would always prefer colder temperatures. The month of January is a delicate month for the children in terms of swings in thermal perception, which could change at short notice.

Table 2: Measured thermal variables in the classrooms at occupied school hours during the surveyed months of 2018.

Month	Mean Air Temp (^oC)	Mean Rad Temp (^oC)	Mean Indoor RH (%)	Mean Neutral Temp (^oC)	Mean TSV	Comfort Range (^oC)	Upper Limit (^oC)	Sensitivity	Bandwidth (^oC)
Jan	28.4	28.3	62.8	28.1	.05	25.4 - 30.8	30.8	1.4	5.4
Feb	29.5	29.5	66.1	27.8	.59	25.4 - 30.3	30.3	2.7	4.9
Apr	28.3	28.3	68.9	27.9	.11	25.9 - 29.5	29.5	1.6	3.6
May	28.3	28.4	73.6	28.9	- .19	25.9 - 31.9	31.9	1.9	6.0
Jun	28.2	28.1	70.1	28.2	- .12	24.3 - 32.5	32.5	1.3	8.2
Oct	28.1	28.3	70.2	28.5	- .19	24.0 - 32.9	32.9	1.9	8.9

For February, the subjects expressed warmth thermal sensation 100% of the period the survey was conducted. February is usually one of the warmest months of the year in the survey area. This assertion is consistent with the highest mean indoor operative temperature (29.5^{o}C) obtained in February (Table 2). This is also reflected in the mean thermal sensation vote which is the highest during the survey period. The subjects felt warm and would prefer a temperature of approximately 1.7^{o}C lower than the mean value that prevailed in that month to be thermally comfortable. The subjects also recorded the highest thermal sensation (1.6) for the whole period the survey was conducted (Table 3). Furthermore, Table 3 shows that the heat stress for February occurred 28.0% of the time the survey was conducted which is the highest for thesix months the surveys were carried out. The heat stress period was the time the comfort temperature was outside the comfort zone (±0.85) of the 7 - point ASHRAE thermal sensation scale. These days are indicated in Table 3.

Table 3: Daily Mean Thermal sensation results of the children According to Month

Date	**Mean Thermal Sensation Votes**					
	Jan 15th - 31st	**Feb** 5th – 28st	**April** 2nd – 27th	**May** 1th – 25th	**June** 6th – 29st	**Oct** 8th – 31st
1				.20		
2			- .38	.07		
3			- .51	.21		
4			- .62	.13		
5		.30	**1.5^H**	Sat		
6		.20	.36	Sun	- 0.28	
7		.70	Sat	.09	- 0.06	
8		**1.0^H**	Sun	.20	- 0.05	.45
9		**1.3^H**	**- 1.1^C**	.14	Sat	.20
10		Sat	- .41	.05	Sun	.05
11		Sun	.25	.07	**1.09^H**	- .12
12		.72	.11	Sat	.33	- .30
13		.74	.46	Sun	.29	Sat
14		**.88^H**	Sat	.2	.50	Sun
15	.05	**.90^H**	Sun	.16	.05	.44
16	.10	**1.60^H**	.02	.19	Sat	**- .88^C**
17	**- 1.50^C**	Sat	.67	**- .91^C**	Sun	- .02
18	- .16	Sun	**.92^H**	- .39	.60	- .18
19	- .19	.44	.55	Sat	- .19	.02
20	Sat	.75	.24	Sun	**1.5^H**	Sat
21	Sun	.25	Sat	- .14	.45	Sun
22	.23	.39	Sun	.30	.20	.65
23	.21	.23	.21	.10	Sat	.07
24	**- .86^C**	Sat	.43	- .42	Sun	.14
25	- .54	Sun	.66	**- 1.07^C**	- .54	.11
26	- .45	.25	.25		.58	.25
27	Sat	.05	.07		.29	Sat
28	Sun	.33			.05	Sun
29	.55				.58	.37
30	.43				Sat	.58
31	**1.17^H**					.38
Heat/Cold Stress	**11%**	**28%**	**16%**	**11%**	**10%**	**6%**

Limit value (ASHRAE - 55); - 0.85<PMV<+0.85 Heat Stress^{H}Cold Stress ^{C}

The mean indoor operative temperature, mean indoor relative humidity, and the mean thermal sensation within the occupied school hours in all the classrooms combined for April were 28.3^{o}C, 68.9%, and.11, respectively. These results were obtained at the mean indoor air velocity of 0.18m/s and with 1.60 as the sensitivity of the students to temperature changes. Figure 5 shows the results of the regression analysis of the mean indoor operative temperature against the mean thermal sensation votes for April. The regression equation, shown on the graph (TSV = 0.4769Top – 13.236) produced a neutral temperature of 27.9^{o}C and a comfort range of 25.9^{o}C – 29.5^{o}C. April and May reported the same mean indoor operative temperature but different thermal perceptions. For example, while the subjects in

April indicated a warm thermal sensation and would prefer to be cooler, in May they indicated a cold thermal sensation and would prefer to be warmer (Table 2). Furthermore, while the subjects can accept 31.9°C in May they could only accept temperatures of up to 29.5°C in April. The results show that having the same mean indoor temperature does not connote having the same thermal perception.

The months of May and January exhibited similar behavior in the thermal perception of the subjects. However, the mean indoor operative temperature in January was slightly higher than that of April by 0.1°C, which was not significant. But at almost the same mean indoor temperature the thermal perception differed significantly. Continuous rainfall was witnessed in May, resulting in cold environments. The cold environment influenced the thermal perception even at high temperatures. The thermal perception in June and October was almost the same, as shown in Table 2. Also, the mean indoor operative temperature, the indoor relative humidity, the comfort range, and bandwidth do not differ. However, the percentage of subjects who were thermally comfortable vary between the two months (June and October).

5. Conclusion

This study is part of a comprehensive investigation of the thermal perception of primary school children in Imo State Nigeria. The study focused on determining the periods schoolchildren experience uncomfortable thermal conditions. Results from the fieldwork showed that apart from heat stress experienced by the subjects, they also experienced cold stress. Heat stress and cold stress were generally experienced in 14.8% of the period the surveys were carried out in all the months combined. In 62.5% of this period, the subjects experienced heat stress while cold stress was experienced in 37.5%. The month of January was observed to be the most delicate month for the children because of the high fluctuations in indoor temperature which resulted in a wide range of thermal perceptions. From the results, the children need to dress properly according to temperature to avoid catching a cold or getting exposed to thermal stress during the lesson hours. Architects need to factor in all this information when designing primary school buildings in tropical climates. Future work is recommended for more fieldwork on the thermal perception of school children according to month.

Declaration of competing interest

The author declares that there is no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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