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INVESTIGATING THE COMFORT TEMPERATURE FOR SCHOOL CHILDREN IN A WARM AND HUMID CLIMATE OF IMO STATE, NIGERIA

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Abstract

Thermal conditions in classrooms influence the physical and social development and the overall well-being of a student's life. Understanding the relationship between thermal conditions in classrooms and the perception of the thermal environments by the students will help in providing sustainable classroom blocks. This paper presents the results of a study relating to thermal comfort in three selected naturally-ventilated classroom schools located in the warm and humid climate of Imo State, Nigeria. The aim was to determine the perception of the thermal environment by young children aged 7-12 years in these classroom spaces. The investigation was carried out during the rainy and dry seasons where the environmental parameters in the surveyed classrooms were measured, together with simultaneous subjective assessment of the subjects through the use of questionnaires. Regression analysis was applied between the mean thermal responses of the children and the mean operative temperatures to determine their optimum temperature, the preferred temperature, and their comfort range. Results indicate that the subjects accepted the indoor thermal environments beyond the range specified by the International standards such as ASHRAE and ISO. For the combined classrooms all season, the optimum temperature obtained for the young children was 28.8oC with a preferred temperature of 27.4 oC and comfort range of 25.8-31.6oC. The findings in this paper may add value to the thermal comfort data base and also provide useful input in the provision of classroom blocks that are sustainable.

Keywords: children, classrooms, optimum temperature, sustainability, thermal comfort.

INTRODUCTION

Thermal comfort is important in classrooms because it can improve the overall-wellbeing of the students who use the spaces for class lessons. Thermal comfort is one of the components of Indoor Environmental Quality (IEQ), and is rated by most scholars as the number one component that gives building occupants the most concern to comfortable living, especially people living in the warmer climates. A good indoor environment can improve the academic performance of students (Almeida, de Freitas & Delgado, 2015), and decreases the likelihood of school children dropping out of school (Godfrey, Osher, Williams, Wolf, Berg, Torrente & Aber, 2012). Thermal comfort in buildings can be achieved using two methods; artificial and natural methods. Artificial method involves the use of active ventilators such as an air-conditioning system. Using this method means energy consumption for which the building sector contributes 19-50%, with the likely outcome of rising to 60% in future (López-Pérez, Flores-Prieto & Ríos-Rojas, 2019). A large proportion of this energy is used for thermal comfort. This artificial method of thermal comfort is becoming popular in private primary schools in Nigeria. There is a high probability of this trend spreading to public schools in the near future, meaning more energy use and more CO2 emission. Carbon in the atmosphere can destabilize the ecological balance, rendering the environment unsustainable. The natural method of providing thermal comfort is through 'adaptation'. In the context of thermal comfort, adaptation may involve all the processes people pass through in order to become thermally comfortable in the environment they found themselves. This process comprises three adaptive behaviours; behavioural (clothing change), physiological (acclimatization) as well as psychological (expectation). Adaptive thermal comfort posits that building occupants will take some voluntary actions, such as removing or putting extra clothing, posture and activity changes in order to maintain thermal comfort. Allowing building occupants to adapt to indoor temperatures they are accustomed to, on a daily basis, may create some significant offsets in temperature between the artificial and natural methods of providing thermal comfort, resulting to energy savings.

There exists a close relationship between thermal comfort and buildings' architectural and constructional characteristics, such as layout, external shading and thermal mass of the materials used in their construction. (Zomorodian, Tahsildoost & Hafezi, 2016; Akingbade , 2004; Alozie, Odim & Alozie , 2015). When these features are properly designed, they can provide the desired thermal comfort to building occupants. However, architects are shying away from this primary responsibility of providing good designs that encourage maximum use of natural ventilation. The current craze in the use of airconditioning systems to provide thermal comfort in some private primary schools in Nigeria may be linked to poor designs. The renovation of most of these old primary schools to new 'standards' are observed to negate the benefits of taking the good advantage of natural ventilation.

Considering the above context, the importance of providing a comfortable indoor environment for learning that considers an option of reduced energy use is important. Also, considering the importance of comfort requirements in classrooms and the fast growing number of schools built in Imo State, Nigeria this study aims at determining the thermal comfort perception of primary school children (aged 7-12 years) who engage in class lessons in naturally ventilated classrooms located in the warm and humid climate of Imo State. Adaptation to the indoor thermal conditions in these classrooms will be an important consideration in this exploration.

The aim of this study is to determine the thermal perception of primary school children, ages 7-12 years, who conduct their class lessons in naturally ventilated classrooms located in the warm and humid climate of Imo State, Nigeria. Their thermal perception is determined using three methods;

1) Determining optimum temperature
2) Determinung preferred temperature
3) Determining comfort range

CONCEPTUAL FRAMEWORK

Two popular models are used to determine thermal comfort. They are the heat balance model and the adaptive comfort model. The first model uses the Predicted Mean Votes (PMV) and the Percentage of People Dissatsified (PPD) as indices to determine the comfort levels of building occupants. This is a laboratory study based on the theory of heat balance between the human body that involved experiments in a controlled chamber in which the participants were all adults and also Europeans. This model is not suited for naturally ventilated buildings. In addition, because the model was based on adults, using it may not accurately reflect the thermal sensations and preferences of school children (de Dear, Kim, Candido & Deuble, 2015; Teli, Jentsch & James, 2012; ter Mors, Hensen, Loomas & Boerstra, 2011).

The second approach, the adaptive model, was proposed to encourage low energy after the oil-shock in the 70s. The adaptive thermal comfort supporters are of the opinion that factors beyond fundamental physics and physiology play an important role in building occupants' expectations and thermal preferences. It further postulates that people tend to adapt naturally to the changing surrounding environment. Thus, the adaptive approach to thermal comfort hinges on the argument that building occupants normally take some voluntary actions (such as removing clothings or putting on extra ones and change in posture or activity) to achieve and maintain the desired thermal comfort. This was succiintly put by Humphreys, Nicol and Roaf (2016 p.34); '*People like other animals, have been adapted too, and where fuel was scarce and warmth needed, they largely controlled their comfort behaviourally-adaptively'.* Furthermore, the adaptive responses to the large variations in indoor temperatures in different climates and cultures ensure that the human race could survive in all the wide variety of conditions (Nicol & Roaf, 2017). Reports from the various studies in naturally ventilated classrooms in the tropical climates indicate that building occupants were comfortable at the temperatures they are more accustomed to. Nicol, Raja, Allaudin and Jamy (1999) observed that the Pakistani office workers were comfortable at the temperature of 31^{o}C. Karyono nd Delyuzir (2004) found subjects in Indonesia comfortable at neutral temperature of 24.9 ^{o}C. Subjects in Brazil were found comfortable at range of temperatures between 27.9 to 29.3 ^{o}C. Different comfort temperatures were also observed in studies conducted in naturally ventilated buildings located in Nigeria. Efeoma and Uduku (2014) found a neutral temperature of 28.8^{o}C for the subjects in an office setting in Enugu. Akande and Adebamowo (2010) investigated comfort temperature of building occupants in Bauch and found a neutral temperature of 28.4^{o}C. Ogbonna and Harris (2008) conducted comfort study in Jos and observed comfort temperature of 26.2^{o}C. Okafor, Udochukwu, Nwankwo and Nwokocha (2016) evaluated comfort temperature in Okigwe and observed neutral temperatures of 28.8 ^{o}C and 29.4^{o}C for the traditional building and contemporary building, respectively.These examples show that people tend to adapt at the temperatures they are more accustomed to.

Furthermore, apart from people adapting to temperatures they are used to, various field works reinforced the belief that thermal environmental conditions found unacceptable by users of space in airconditioned buildings were found acceptable in naturally ventilated buildings. For example, a study conducted in a hot and humid climate in Egypt to determine the thermal perception of primary school children in naturally ventilated classrooms found them thermally comfortable at temperatures between the range of 25.5 to 29.5^{o}C (Abdeen, Ali, Abel-Rahman and Ookawara, 2014). Wong and Khoo (2012) conducted study in naturally ventilated classrooms in Singapore and found the users of the indoor spaces comfortable at temperatutes in the range of 27.1 to 29.3

^oC. Mishra and Ramgopal (2015) observed 29.0 ^oC and 26.8 ^oC as neutral temperature and preferred temperature, respectively in a study conducted in naturally ventilated classrooms in India. These are few examples of many thermal comfort studies conducted in primary schools in naturally ventilated classrooms in the tropics where the subjects found high temperatures acceptable. These high temperatures are often found unacceptable in buildings where the occupants are more used to airconditioning systems. These buildings the occupants find comfortable at high temperatures often take advantage of natural ventilation.

METHODOLOGY

The study area

The study area, Imo State, is located in the South East of Nigeria and categorized according to the climatic classification of Koppen- Geinger in the group of tropical (Azadeh, Fergus, Mark & Chryssa, 2017). The State is located between latitude 4 ° 45′N, 7° 15′N, longitude 6 ° 50′E, and 7° 25′E, and represents one of the five South Eastern states in Nigeria. Imo State is bounded on the East by Abia State, on the South by Rivers State, and on the West by Anambra State. There are twenty-seven (27) Local Government Areas that make up the state and three (3) geo-political zones otherwise known as senatorial zones. They are Imo West (Orlu), Central (Owerri) and East (Okigwe). The state lies in the rain forest zone of the warm humid tropics characterised by high temperatures and high relative humidity for most periods of the year. Mean annual rainfall ranges from 2500 to over 4000 mm, with mean maximum temperature of about 30^oC.

Study buildings and Data collection

This study is based on a large experimental campaign survey carried out during the rainy season and dry season in 6 naturally ventilated primary school classrooms. A school was selected from each of the three senatorial zones that constitute Imo State. Shown in Figure 1 is school A from Imo West zone. The two surveyed classrooms, A_{OP} and A_{EN}, measure 144m^2 and 80m^2, respectively. Shown in Figure 2 is school B from Imo central (Owerri zone). The two surveyed classrooms measure 80m^2 (B_{EN}) and 360m^2 (B_{OP}). Also shown in Figure 3 is school C. This school is located in Imo East (Okigwe) and measures 80m^2 (C_{EN}) an0d 384m^2 (C_{OP}).

Figure 1: Sketch of the floor plan of school A

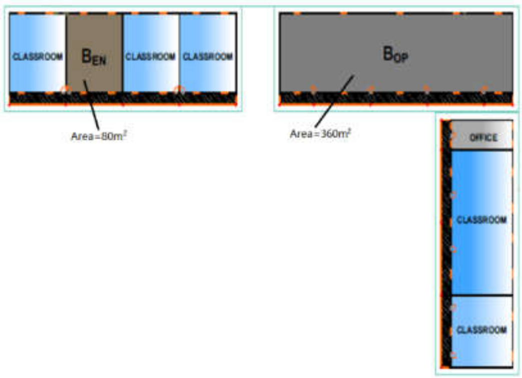

Figure 2: Sketch of the floor plan of school B

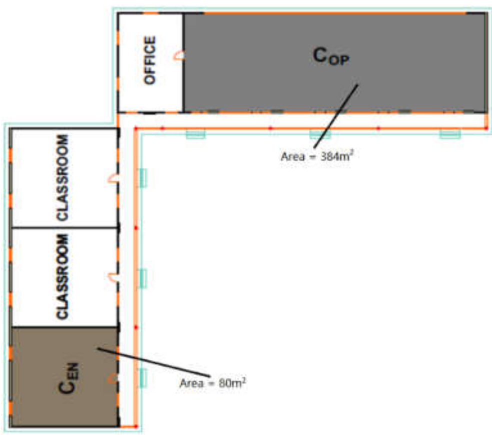

Figure 3: Shows the floor plan of school C

Field work included the measurement of objective parameters: indoor air temperature, indoor relative humidity, outdoor temperature and indoor air velocity. Tinytag ultra plus 2 (TGU-4500) data logger measured the indoor air temperature and indoor RH, while Tinytag plus 2 (TGP-4017) data logger measured the outdoor temperature. The instruments used for the survey met the prescriptions of ASHRAE 55 (ASHRAE 2017) and ISO 7730 (ISO 2005) Standards. ASHRAE Standard 55 (2017) and ISO 7730 (2005) specifies heights of 1.1, 0.6 and 0.1m, above the floor level, for taking the indoor environmental variables. The data loggers were calibrated to automatically collect data every 5 minutes. Kestrel 3000 pocket wind meter was used to take spot measurements of air velocity inside the surveyed classrooms. The indoor measuring instrument was placed at the center of each of the surveyed classrooms approximately 0.9 meters above the floor level. The technical characteristics of the measuring instruments are shown in Table 1.

Table 1: 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 +85°C	±0.01°C	±0.3%
	Indoor relative humidity	0% to 100%	±0.3%.	±1.8% RH
Tinytag Plus 2 (TGP-4017) loggers	Outdoor Temperature	25 to +85 °C	±0.01°C	-
Kestrel 3000 Pocket wind meter	Air velocity	0.30 to 40.0m/s	-	±1.66%

Source: Fieldwork, 2016

To ascertain the correct temperatures produced as desirable by the occupants, participants were asked to regularly complete short comfort vote surveys on the ASHRAE 7-point thermal sensation (TSENS). The McIntyre 3-point preference scale was adopted to determine whether they would prefer to feel 'warmer' or 'cooler', or whether they want 'no change' (okay). Table 2 provides further detail.

Table 2: Rating scales used in thermal comfort

ASHRAE Thermal Sensation	-3 (cold)	-2 (cool)	-1 (a bit cold)	0 (okay)	+1 (a bit warm)	+2 (warm)	+3 (hot)
McIntyre Thermal Preference	Cooler		okay			Warmer	

Source: Fieldwork, 2017

RESULTS AND DISCUSSION

General characteristics of the sample

Table 3 shows that the sample constitutes returned responses from 7050 valid returned questionnaires drawn from 330 primary school children aged 7-12 years in rainy season and dry season. In each classroom the sampled children were in the same age group and were homogeneous in cultural background and heterogenous in social status. The survey was conducted approximately 164 days; rainy season 64 days and dry season 100 days. Each day two surveys were conducted, morning and afternoon. All the classrooms in the study area were naturally ventilated and none had any active ventilator such as air conditioning system or fan. The subjects were repeatedly survey twice a day in the morning and afternoon hours in both seasons.

Table 3: Summary of survey period for the 6 classrooms from 3 schools during both rainy and dry seasons

Classroom Type	Approx. Num. of Pupils	Survey Date	Season	Administered Questionnaire			
				Expected Number	Actual Collected	Valid Response	Invalid Response
A_{OP}	25	Oct 12-24 (9days)	Rainy	450	380	370	10
A_{OP}	25	Feb 6-28(17 days)	Dry	850	745	713	32
A_{EN}	30	Oct 12-24 (9days)	Rainy	540	420	411	9
A_{EN}	30	Feb 6-28(17 days)	Dry	850	740	708	32
B_{OP}	25	Oct 25-Nov 3(8days)	Rainy	400	343	330	13
B_{OP}	25	April 2-27(20days)	Dry	1,000	885	817	68
B_{EN}	30	Oct 25-Nov 3(8days)	Rainy	480	415	404	11
B_{EN}	30	April 2-27(20days)	Dry	1,200	961	880	81
C_{OP}	25	May 9-29(15days)	Rainy	750	620	595	25
C_{OP}	25	Jan 15-31(13days)	Dry	650	520	508	12
C_{EN}	30	May 9-29(15 days)	Rainy	900	785	716	69
C_{EN}	30	Jan 15-31 (13 days)	Dry	780	610	598	12
Total	330	164 days		8850	7424	7050 (95%)	374(5%)

Source: Fieldwork, 2017

Furthermore, in some days during the survey the number of children in some classrooms were as small as 20 or as large as 35. A set of 158, representing 47.9% of the children participated in the dry season survey, while 172 children, representing 52.1%, participated in rainy season survey. Further detail shows that the number of female participants was more (58%) compared to the male (42%) during both seasons. According to season, female constituted 55.1% and 61.0% for rainy season and dry season, respectively, against 44.9% and 59.0% for rainy season and dry season respectively for men. Most of the participating children (56.0%) were within the age range 9-10 years, with 9 years as the mean age. Of all the participants that were surveyed, none was less than 7 years or more than 12 years. Majority of them (96%) were born in the study area (Imo state) and have lived in the state throughout their life.

Table 4: Respondents' sample size

		Total (n=330)		Dry season (n=158)		Rainy season (n=172)	
		Sample size	Percentage	Sample size	Percentage	Sample size	Percentage
Gender	Male	138	42.0%	71	44.9%	67	59.0%
	Female	192	58.0%	87	55.1%	105	61.0%
Age (years)	<7	0	0%	0	0%	0	0%
	7-8	26	8.0%	11	6%	15	9%
	9-10	185	56.0%	96	56%	89	56%
	11-12	119	36.0%	63	37%	56	35%
	>12	0	0%	0	0%	0	0%

Source: Fieldwork, 2017

Measured thermal variables

Table 5 gives detail of statistical summary of the minimum, maximum, mean, standard deviation and coefficient variation of the measured indoor and outdoor thermal variables in the surveyed classrooms at occupied school hour time that spanned from 7.30 am to 2.45pm. As shown in Table 5, the indoor temperature extracted from the dataloggers for all the combined classrooms in both seasons fall within the range 22.5-35.6°C The studied children experienced a mean indoor temperature of 29.1°C and SD (1.7).

The outdoor temperature for all 6 classrooms averaged 29.6°C during the same survey period falling within the range 23.0-37.4°C with SD (1.7). The relative humidity varies from 24.0 to 94.2% with a mean value of 71.2% and standard deviation of 12.4. Spots checks of the airflow in the classrooms show that the maximum air velocity in the combined classrooms all season was 0.30m/s, with a mean value of 0.19m/s.

Table 5: Mean, standard deviation, minimum and maximum values of the main environmental parameters of the 6 school classrooms over the survey period all seasons.

Classroom	All Open	All Enclosed	Combined Open and Enclosed
Operative Temperature (^0C) Mean S.D. Min Max	* 28.9 1.6 22.5 35.6*	* 29.3 1.5 22.9 35.1*	* 29.1 1.7 22.5 35.6*
Outdoor Temperature (^0C) Mean S.D. Min Max	* 29.6 1.7 23.0 37.4*	* 29.6 1.7 23.0 37.4*	* 29.6 1.7 23.0 37.4*

Relative Humidity (%)			
Mean	*71.8*	*70.8*	*71.2*
S.D.	*13.1*	*11.8*	*12.4*
Min	*24.0*	*27.4*	*24.0*
Max	*94.2*	*93.5*	*94.2*
Air velocity (m/s)			
Mean	*0.19*	*0.14*	*0.19*
S.D.	*-*	*-*	*-*
Min	*-*	*-*	*-*
Max	*0.30*	*0.28*	*0.30*

Source: Fieldwork, 2017

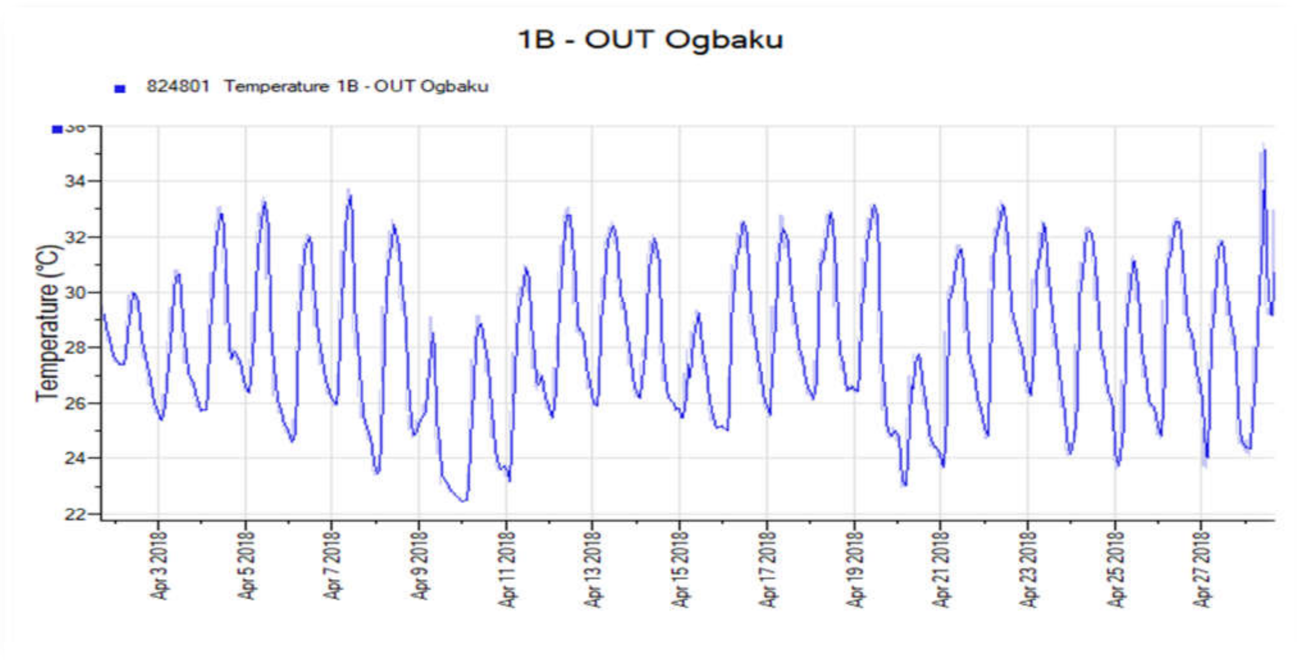

Figure 4: Sample of graphical presentation of temperature from data logger

Source: Fieldwork, 2017

Optimum temperature

Figure 5 shows the scatter plot and the regression of the mean indoor operative temperature (Top) upon the mean thermal sensation votes (TSV_{mean}). The linear regression between the dependent variable (TSV) and its independent variable Top is presented in equation (1). The real strength of the relationship between temperature and TSV is the value of *p,* and this value of *p* is similar whether binning method is used in temperature or not (Haddad, 2016). As can be seen in the graph, the linear regression model can explain 52% of the relationship between the mean Thermal Sensation Votes (TSV_{mean}) and the mean indoor operative temperature. The percentage of the explanation of the relationship is not very high; however, with $p < 0.001$ obtained from the correlation analysis, the relationship is statistically significant. The neutral temperature, or optimum temperature, corresponds to TSENS value equal 0 on the seven-point ASHRAE scale when applied to analysis of TSV=0.29x-8.33 for the combined classrooms all seasons, produced a neutral temperature of 28.8°C. This temperature is the ideal comfort temperature of the studied children in the combined classrooms all seasons. The optimum temperature can also be obtained from the graph in Figure 5 where the intersection of regression line with neutral (okay or '0') thermal sensation gives neutral temperature of the studied population.

$$TSV = 0.29T_{OP}\ 8.33 \qquad (1)$$

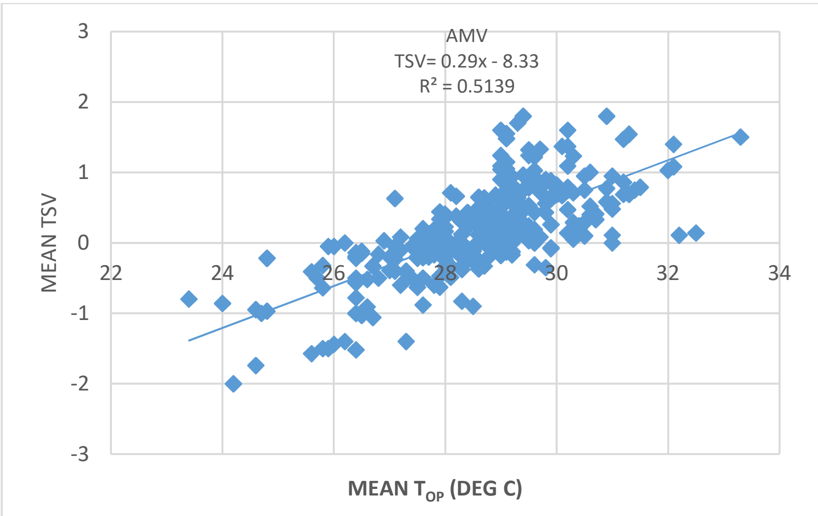

Figure 5: Bivariate Scatter plot of mean thermal sensation votes against weighted Indoor operative temperature in combined classrooms all season.

Source: Fieldwork, 2017

Preferred temperature

The thermal preference of the studied children illustrated in Figure 6 shows that in the combined classrooms all seasons, 50% (half of the entire children) would prefer to be cooler than what the existing indoor thermal condition presents. 37% of the entire class would rather prefer the thermal condition to remain in the condition they found it, while 13% would prefer a condition that is warmer. McIntyre (1980) in his studies found out that people of warm climates may prefer what they call a 'slightly cool' environment and, on the contrary, people of cold climates may prefer what they call a 'slightly warm' environment.

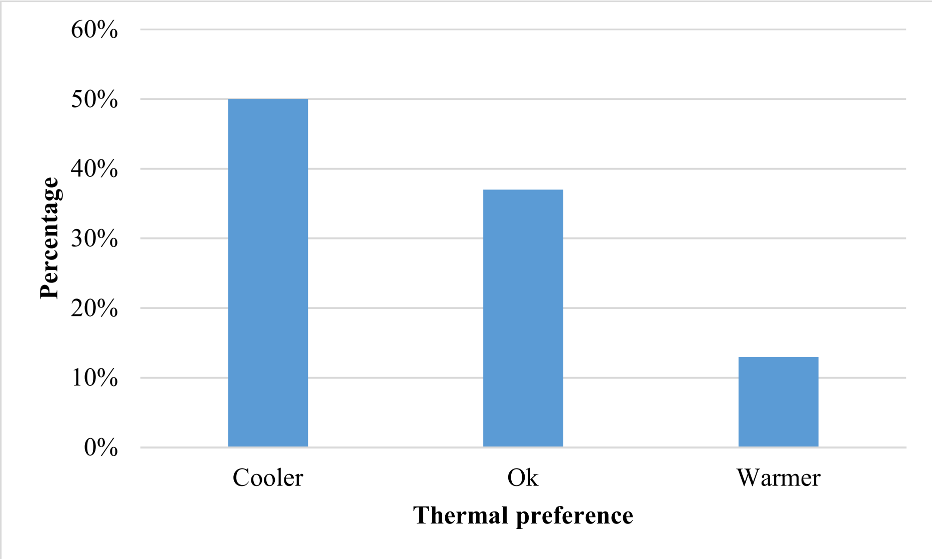

Figure 6: Distribution of subjects' thermal preference votes

Source: Fieldwork, 2017

Based on the thermal preference of the school children on the McIntyre thermal preference scale, their preferred temperature was obtained through linear regression analysis of the votes of the children who wanted to be 'cooler' and those who wanted to be 'warmer' against the operative temperature, binned at 1°C interval (with the range from 24.5°C to 32.5°C). The result of the regression produced a preferred temperature. This temperature is where the intersection of the percentage of students who wanted to be 'warmer' and those who wanted to be 'cooler' meets. As was done in several studies in classrooms (Haddad, Osmond & King, 2016; de Dear et al, 2015), the young children's preferred temperature was obtained from the intersection of the two fitted lines, 'want cooler' and; want warmer'. As illustrated in Figure 7, the two fitted lines intersected at a preferred operative temperature of 27.4°C. The preferred temperature is lower than the neutral temperature produced in this study by 1.4°C, meaning that the sampled subjects preferred, on average, sensations cooler than neutral. According to Humphreys and Hancock (2007), when field surveys have been analysed, differences between the 'preferred temperature' and the 'neutral temperature' have been frequently been found, and the difference may be as much as three degrees, but generally it is much smaller.

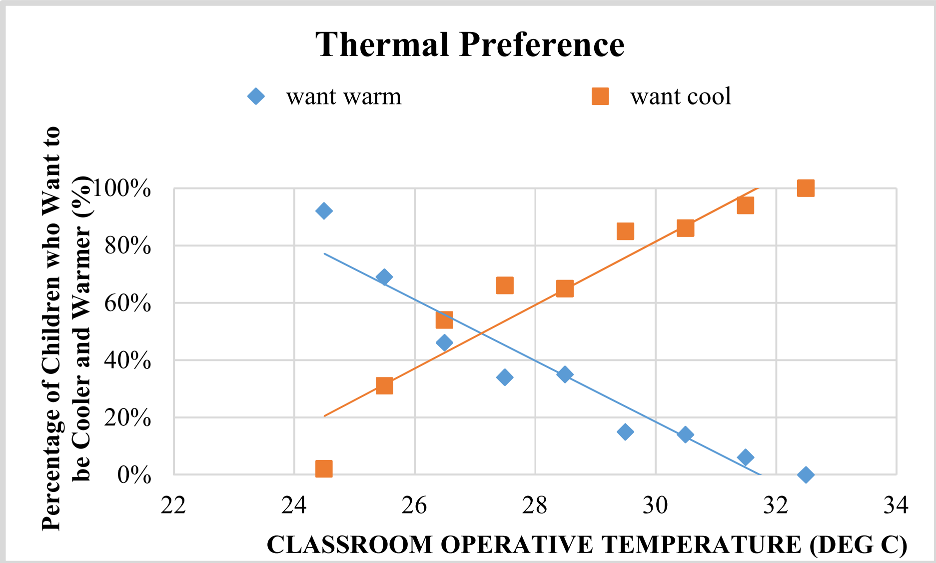

Figure 8: Linear regression models for thermal preferred temperature

Source: Fieldwork, 2017

Comfort range

The comfort range of the young children can be determined using thermal comfort indices such as the Predicted Mean Votes (PMV) established by Fanger (2002) or the adaptive method established by de Dear and Brager (2002). In this study, the ASHRAE adaptive Model that sets 80% comfortable zone, -0.85≤TSV≤+0.85 (de Dear RJ, et al, 2015) was adopted to determine the thermal comfort range. In this study, the mean thermal sensation votes were regressed against the indoor operative temperatures (T_{OP}) using the excel package. The reason for adopting the adaptive model in this study was earlier discussed in this work. The acceptable range of temperature was determined from the linear equation based on thermal sensation in the range of (*-0.85≤TSV≤+0.85)* for 80% acceptable indoor thermal condition. This was used as the primary consideration.. Based on the regression equation, $TSV=0.29T_{op}-8.33$, a comfort range of 25.8-31.6°C was calculated for the combined classrooms all seasons.

CONCLUSION

This study on acceptable range of temperature by the children indicated that the children accepted warmer conditions than the one predicted by ASHRAE adaptive comfort model. The comfort temperature range recommended by the standard (for summer) is between 21-28°C (James and Christopher, 2012). The upper limit of the acceptable range of temperature in the combined classrooms all seasons was by 3.6°C warmer than the upper limit of the Standard. These results suggested that the studied children in the study area have higher tolerance to indoor thermal conditions than the standard suggested. This is because most of the subjects accepted the existing thermal conditions in the classrooms which exceeded the comfort range recommended by ASHRAE Standard 55 for summer time. For the primary school children in the study area to be thermally comfortable, there is no need to use air-conditioning systems. However, architects should endeavour to design classroom blocks that can take full advantage of natural ventilation of indoor spaces.

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