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Determining the Adaptive Thermal Comfort and Preference Votes of Children in Public Primary Schools in the Hot Semi-Arid Climatic Zone of Nigeria.

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Abstract:
Provisions for thermal comfort is important to childrens' performance and health. The lack of good environmental comfort can greatly affect the learning capacity of pupils. An inherent research concern is that current thermal comfort approaches are predicated on the adult subjects. However, there is no certainty on the effect of these approaches towards children. This study is a research survey with experimental measurements using Kestrel 5500 indoor climate tracker on the effects of thermal comfort on the learning capacity of children. It adopted a cross-sectional approach using graphic questionnaires for data collection. The graphic comfort scale sought the pupils to make a subjective voting of their thermal sensations when they were in their classroom environment using the adapted ASHRAE thermal sensation 5 points scale. Concomitantly, measurements were taken with instruments with the records of Mclntyre preference 3 points scale. The result shows that a combined thermal discomfort percentage of about 68.86% (45.92% warm and 22.94% hot) of the students found the environment was not thermally satisfactory at a mean air velocity of 0.53m/s, air temperature of 35.38ºC, radiant temperature of 37.33ºC and relative humidity of 35.60%. The preference votes of the classes portray a clear preference of 62.30% of the pupils, requested for cooler environment at a mean air velocity of 0.53m/s, air temperature of 35.38ºC, radiant temperature of 37.33ºC and relative humidity of 35.60%. Consequently, the classroom environment is not thermally comfortable for the pupils. The research recommends that there is the inescapable need for further studies on the use of building materials, opening types and right orientation in construction that will bring down the temperature in the Hot Semiarid climatic zone of Nigeria that will ultimately enhance pupils learning environment.

Keywords: Thermal; Comfort; Votes; Preference; Adaptive; Children; Hot semiarid

1. Introduction

Thermal comfort is defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation" [1, 2]. One of the fundamental functions of buildings is to provide safe and healthy indoor environment [3]. For the fortunate it also provides comfort and aesthetic delight. The challenge of designing comfortable buildings today requires a different approach in a world where fossil fuels are becoming ever scarcer and more exorbitant and the climate more severe. Over 70% of global greenhouse gas emissions accounts from the construction and operation of buildings [4]. Buildings are exposed to high solar radiation throughout the whole year and a large portion of the end-use energy in buildings is dedicated to maintaining thermal comfort in tropical climates. Therefore, a growing international consensus now calls for passive and low-energy structures. Ventilation using free, natural energy should be preferred and mechanical condition only used when the climate demands it [5].

With the rapid growth in the number of public primary school buildings in Nigeria, 62,406 in 2014 as published by Universal Basic Education Commission [6], provisions for comfort are critical to students' performance and well-being. An inherent concern is that current thermal comfort models are based on studies with adult subjects, mostly in the temperate regions and mainly in institutional buildings. There is no assurance however that these models apply to children [7]. As had been widely demonstrated a comfortable environment enhances productivity for workers and equally the absence of a good environmental comfort can greatly influence the learning capacity of students. [8-10].

However, thermal comfort is based on thermal adaptation of individual occupant which is correlated to factors such as geographic location and climate [11]. Comfort is a climate and culture specific phenomenon and different nations are developing their own unique comfort standards. South Africa, Egypt and Ghana are inclined towards that. Nigeria should follow suit by developing its unique standard to meet the climatic, social, cultural and economic realities of its local environmental conditions. [7, 12, 13, 32]. This study is an effort towards that direction.

Three significant aspects of sustainability research are integrated in school buildings: building performance, energy consumption and indoor environmental quality. Thermal comfort falls under the indoor environmental quality research. Thermal comfort studies have largely concentrated on adults, and typically compare measurement of physical environmental factors with qualitative assessments to ascertain the relationships between thermal sensation, preference and acceptability. Thermal comfort studies on children even in the advanced world, have not been carried out extensively so far [14]. It is concluded that the research on this field especially in primary school buildings has to be initiated across the world in different climatic conditions [13, 14].

There is therefore paucity of knowledge about thermal comfort models of children across the globe. Overall, warm temperatures tend to reduce performance, while colder temperatures reduce manual dexterity [15]. The results of the studies summarized by Wargocki *et al.* [16] suggests that increased classroom temperatures may have negative effects on the performance of schoolwork by children.

The indoor environment in classrooms can have a large effect on comfort, health and learning performances [17]. The recent review article of Zahra *et al.* [18] reveals that several papers on the topic were published from 1969 to 2015, but these are mainly based in Europe.

Every region has got its own identity in terms of culture, climate and buildings. For this reason, according to Fergus *et al.* [19] researchers should be encouraged to see the intricacies associated with the comfort situation of the place they dwell in. This is especially critical in Nigeria where most primary schools are not connected with electricity and even where it exists fans are not allowed by the primary school regulatory body Universal Basic Education Commission [20]. The Minimum Standards section 5 sub section 11 under services stipulates that ventilation in classrooms should be purely by natural means and not ceiling fans.

Kwong *et al.* [21] identified rooms with a slightly low temperature leads to more effective learning. As elevated classroom temperatures tend to reduce performance of students, Nigeria could be worse hit, where in some areas mean temperatures are up to 40^{O}C and had once risen to an extreme 47.2^{O}C in Sokoto [22]. Knowing the temperatures people are experiencing in their area and the limits which residents can tolerate is a first step to proffer passive solutions to reduce discomfort [23]. By allowing the occupants to lengthen the non-heating and cooling period, applying passive design strategies can decrease the energy consumption and enhance indoor comfort conditions [24].

This study, therefore, builds upon previous thermal comfort works that had focused mostly on offices [25] residences [23] and industrial [10] environments by filling the gap and now focusing not only on classroom environment but on children's thermal comfort which is at variance with that of adults [7, 12, 13, 19, 26, 32] and whose dearth in research is glaring in the developing countries as Nigeria.

The aim of this research is to appraise the environmental and physiological parameters of children in public primary schools as it relates to classrooms with a view to determining the adaptive thermal comfort and preference votes in the hot semiarid climatic zone of Nigeria. There are three objectives can be derived from the aim of the study include; To examine the current levels of the environmental (temperature, relative humidity, radiant temperature, air velocity) parameters of thermal comfort in the classrooms of public primary schools in the hot semiarid climatic zone of Nigeria.; To examine the current levels of physiological (metabolic rate and clothing) parameters of thermal comfort in the classrooms of public primary schools in the hot semiarid climatic zone of Nigeria.; To determine the thermal comfort votes and preferences of children in public primary schools in the hot semiarid climatic zone of Nigeria.

2. Materials and Methods

The study is a survey research with experimental measurements. By studying a sample of that population, survey research provides a numeric or quantitative description of attitudes, trends or opinions of a population. It adopts a cross-sectional approach using questionnaires or structured interviews for data collection with the intent of generalizing from a sample to the population [27].Various comfort scales sought the pupils to make a subjective voting of their thermal sensations while in their present classroom environment using the adapted but graphical ASHRAE thermal sensation scale and concomitantly taking measurements with instruments. The Mclntyre preference scale was used and the graphic scale for children were equally applied.

Table 1 - Research method schedule

Sn	Study	Issues for Investigation	Research and Statistical Analysis Methods
1	Current levels of thermal comfort parameters	• Environmental parameters • Physiological parameters	Field survey and interpreting gathered data using descriptive statistics
2	Assessment of environmental variables for air temperature, radiant temperature, relative humidity, air velocity	• Air temperature • Air velocity • Radiant temperature • Relative humidity	• Percentiles • Flow charts
3	Assessment of physiological variables for clothing insulation and metabolic rate	• Clothing insulation • Metabolic rate/activity level	Calculations from standard tables
4	Assessment of thermal comfort sensation votes	• Hot • Warm • Neutral • Cool • Cold	Five levels adapted comfort sensation votes graphical scale
5	Determination of the preference votes	• Prefer cooler • Prefer no change • Prefer warmer	Three levels Mcantyle preference scale

A detailed outline of the step by step of the research schedule undertaken in carrying out the research is given on Table 1 where objectives are correlated with the specific issues for investigation and the analysis methods.

2.1 Population of the study

The hot semiarid climatic zone in Nigeria consists of the northernmost parts of Yobe, Jigawa, Katsina, Kano, Zamfara and Sokoto states. Regional locations were randomly selected to represent the Eastern, Central and Western respectively, of the hot semiarid climatic zone of Nigeria for this study, Figure 1. All the selected regions within the hot semi arid climatic zone, fall about the same latitude 12^{0}30’N.

Figure 1. Map on study area

2.1.1 Sample size

Hair *et al.* [28] and Kamran [29] both advanced that for multivariate methods, the desired level is between 15 to 20 observations for each variable. This implies that for multivariate studies, the number of variables will be multiplied by 15 to 20 to obtain the sample size. Therefore, for this study, there are 5 variables that are multiplied by 20 giving a total sample size of 100 classrooms and 4000 pupils, the units of analyses. However, in order to improve the representativeness of the samples, an increase to 192 classrooms and consequently 7680 pupil responses were adopted for a 40 pupil classroom size.

2.1.2 Sampling technique and schools that meet UBEC standard

The multistage purposive sampling technique is a commonly used probability sampling method. According to Levy [30], multistage sampling can be described as sampling plans where at each stage the sampling is carried out in stages using smaller and smaller sampling units, Table 2. The samples are precisely part of the population of the study area. UBEC standards of not more than 40 pupils in class, adequate circulation and classrooms ventilated naturally were considered.

In view of the above 84, 84 and 24 totaling 192 classrooms were sampled, pro rata, from each of East, Central and West spread of the hot semi-arid climatic zone respectively, Table 2. This gives us a total sample size of 192 classrooms and 7680 pupil responses for an average class of 40 pupils.

Table 2 - Sampling technique

Location in the Hot Semi Arid Climatic Zone	**Percentage of School Population in the Zone**	**First Sampling Frame**	**Final Sample Size Classes**	**Final Sample Size Pupils**
East	37.5%	14 Schools = 84 Classes	84	3360
Central	37.5%	14 Schools = 84 Classes	84	3360
West	25%	4 Schools = 24 Classes	24	960
	100%	**32 Schools = 192 Classes**	**192**	**7680**

2.2 Instruments for data collection and method of administration

2.2.1 Checklist

The checklist consists of tabulated lists of possibilities that could be encountered in the schools. This relates to metabolic rate, clothing types, architectural features obtainable and others to include unforeseen scenario.

2.2.2 Experimental measurements

To measure the environmental factors Kestrel 5500 multi-purpose indoor climate tracker with a stand, Plate 1 in Figure 2 was utilized to measure the climate conditions. The multi-purpose Kestrel 5500 is ideal because it measures air velocity, temperature and relative humidity with sensory accuracy of 0.3m/s, 0.30ºC and 1.6% respectively [31].

Figure 2. Plate 1 - Kestrel 5500 Multivariable climate tracker

2.2.3 Questionnaire

For the thermal votes and responses from pupils a 5 category thermal sensation scale with graphics and the Mclntyre Preference Scales, Tables 3 and 4 and Figure 2.

Table 3 - 5-point adapted scale for children

Descriptor	**Number**
How Are You Feeling Right Now?	
Hot	+2
Warm	+1
Neutral	0
Cool	-1
Cold	-2

Source: (Adapted from ASHRAE,2010)

Table 4 - McIntyre 3-point preference vote (Humphrey,2016)

Descriptor	**Number**
I Will Prefer To Be / I Wish To Be	
Warmer	-1
Neutral	0
Cooler	+1

2.2.3.1 Visual graphic scale for children's thermal sensation vote

In addition to words, facial expression with sketches can be a good option to describe children's thermal sensation. It uses a visual communication technique, "graphic scale" Figure 3, as the most easily understandable and appropriate research tool in field studies especially for children. Children in all age groups prefer using faces as the measurement tool [14].

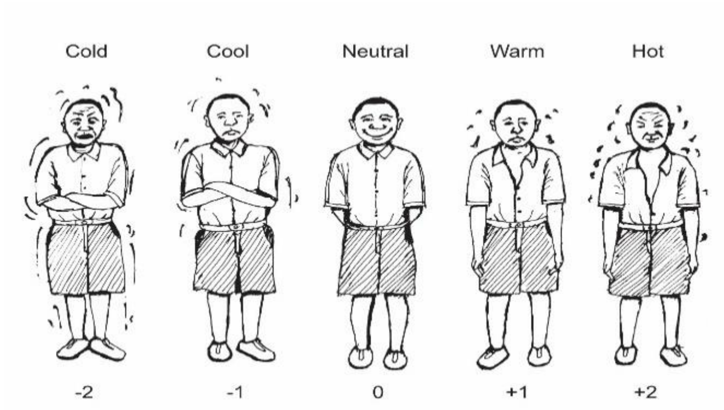

Figure 3. Visual graphic scale for children's thermal sensation vote (Author, 2023)

2.2.4 Experimental set up and method of administration

The researcher concomitantly while taking readings from the instruments, moves from subject to subject asking for their comfort votes and preferences. The indoor microclimate was taken at a point in the centre of the room and at a number of points distributed around the classroom.

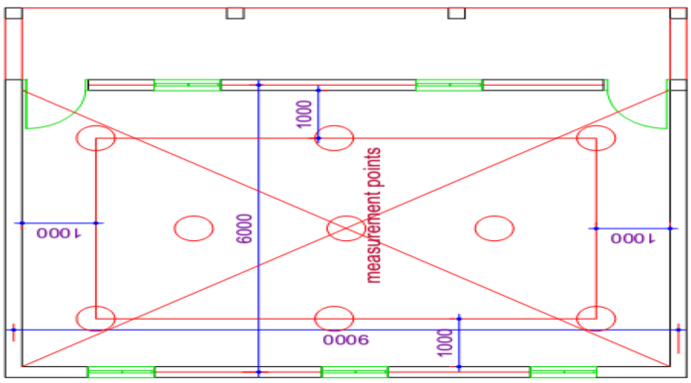

Figure 4. Experimental measurement set up points

Physical measurements were taken close, but not too close, to the subjects. In all cases the instrument was at least 1000mm away from subjects or surfaces in order to avoid any radiant effect on the instrument, Figure 4. The vertical height at which the instrument was placed is representative of the student's experience consequently measurements for a seated student was measured at a vertical height of about 600mm above the floor level [19].

3.0 Results and Discussion

All measurements were recorded strictly during school hours. The environmental and physiological parameters were recorded and the basic details for each of the classrooms is as given on Tables 5 and 6 respectively. The parameters were recorded for each class of an average of 40 pupils which is the UBEC standard classroom size to avoid overcrowding that could influence the comfort votes, adequate circulation and classrooms ventilated naturally were considered.

3.1 Environmental (temperature, relative humidity, radiant temperature, air velocity) parameters in the classrooms of public primary schools in the hot semiarid climatic zone of Nigeria.

The mean air temperature was at 35.38^{o}C, this is way above the acceptable comfort range of 24.3^{0}C to 29.3 ^{0}C and 30% to 65% humidity for thermal comfort [2] and is in consonance with the findings of earlier studies by Humphrey [5] and others.

Table 5 - Environmental variables

Variable	Min.	Max.	Mean for All Classes	Standard
Air Velocity m/s	0.30	1.20	0.53	0.3-1.0
Air Temperature °C	26.70	42.50	35.38	24-29
Radiant Temp. °C	26.00	40.80	37.33	24-29
Rel. Humidity %	13.30	73.10	35.60	30-65

3.2 Physiological parameters in the classrooms of public primary schools in the hot semiarid climatic zone of Nigeria

Research objective II is the determination of the physiological parameters. Clothing and metabolic rates are the two physiological determinants of thermal comfort. Clothing reduces the body's heat loss and is classified according to its insulation value. The unit used for measuring clothing's insulation is the Clo unit. The Clo measurement is designed such that a naked person has a Clo value of 0.0 and someone wearing a typical business suit has a Clo value of 1.0. The Clo value is calculated by simply adding the individual Clo values of garments together if the person's dress and the Clo values for the individual garments are known as shown on Table 6.

Table 6 - Clothing insulation table (culled from ASHRAE 55, 2017)

Male		**Female**	
Cloth Type	**Clo.Value**	**Cloth Type**	**Clo.Value**
Short sleeve shirt	0.19	Short sleeve blouse	0.19
Long sleeve shirt		Long sleeve blouse	
Vest		Vest	
Panties	0.03	Panties	0.03
Cardigan		Cardigan	
Trousers	0.25	Trousers	0.25
Short knicker		Hijab	0.53
Cap	0.04	Headgear	0.04
Slippers		Slippers	
Socks		Socks	
Sandal	0.02	Sandal	0.02
Others		Others	
	0.53 Clo.		**1.06 Clo.**

The metabolism is the amount of energy released by the body and is dependent on the amount of muscular activity being carried out. Metabolism is at its lowest while sleeping at 0.8 Met, sitting 1.2 Met, walking 1.9 Met, domestic work 2.9 Met and is at its highest during sporting activities, where 10 Met could be attained.

It is to be noted that the study was carried out in schools having the same Clo value at 0.53 Clo for male and 1.06 Clo for female as students wear the same school uniform and the same Met value of 1.2 Met for students seated and writing in the classrooms. This is clearly explicably because the pupils were wearing fairly same type of school uniforms and undertaking the same activity that yields same metabolic rate. The Clo and Met values are obtainable from ASHRAE, 2017 tables depicting different garments and activities respectively with their corresponding values.

3.3 Findings from: Comfort and preference votes of children in primary schools classrooms

Research objective III aims at the determination of comfort and preference votes which have different measurement scales, the comfort has a five scale levels while the preference has a three level measurement scale.

3.3.1 Comfort sensation vote

The result on Figure 5 shows that a combined discomfort percentage of about 68.86% (45.92% warm + 22.94% hot) of the students find the environment not thermally satisfactory at a mean air velocity of 0.53m/s, air temperature of 35.38°C, radiant temperature of 37.33°C and relative humidity of 35.60%.

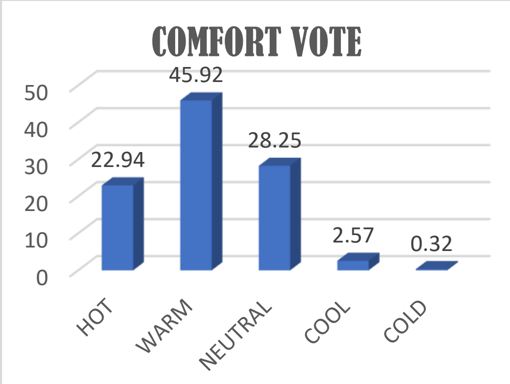

Figure 5. Summary of comfort votes

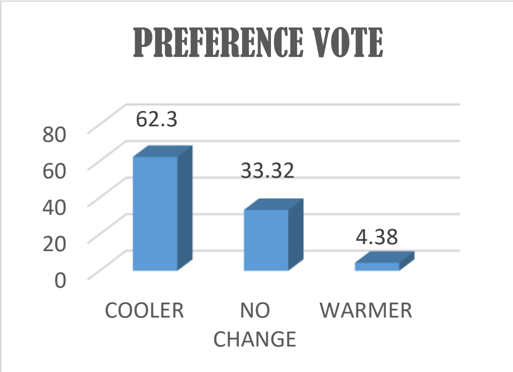

Figure 6. Summary of preference votes

3.3.2 Preference vote

The preference votes of the classes as shown in Figure 6 portrays a clear preference by about 62.3% of the pupils for cooler environment at that time at a mean air velocity of 0.53m/s, air temperature of 35.38ºC, radiant temperature of 37.33ºC and relative humidity of 35.60%.

Table 7 - Relating objectives to findings

Objective	Measurements	Instrument	Findings
Objective i	Determining the current levels of the environmental parameters	Kestrel 550 indoor climate tracker	Air Temperature at 35.38^{0}C Radiant Temperature at 37.33^{0}C Air Velocity at 0.53 m/s Relative Humidity at 35.6%
Objective ii	Determining the current levels of physiological parameters	Calculations	Metabolic Rate at 1.2 Met Clothing Insulation at 0.53 Clo. and 1.06 Clo. for male and female respectively
Objective iii	Determine the comfort & preference votes.	Graphical scale	68.86% of pupils voted for a combined warm (45.92%) and hot (22.94%) uncomfortable thermal sensation.62.30% of the pupils voted for cooler environment on the preference scale. Consequently, the existing classroom environment does not meet the children's thermal comfort requirements.

The results of this study is consonance with previous studies by [12, 15-17, 32] that increased classroom temperatures especially in tropical naturally ventilated classrooms was not thermally conducive and may have negative effects on the performance of schoolwork by children.

4. Conclusion

The thrust of this study was to appraise the classroom environment so as to determine the learning environment, thermally, of children in the classes of the hot semi-arid climatic zones of Nigeria, which will ultimately enhance learning assimilation as hot environments are impediments to learning as copiously stated in literature review. This is further exacerbated by the non-usage of fans in the classrooms as instructed by UBEC the primary school administrative commission in Nigeria. The first objective was to determine the current levels of the four environmental determinants of thermal comfort air temperature, radiant temperature, air velocity, and relative humidity. These were measured from the field and the single most important determinant, temperature, was at 35.38 0C which is way above the acceptable comfort level given in standards. The second objective was to determine the physiological determinants of thermal comfort, clothing insulation and the metabolic rate. The duo were found to be the same with the Met. value of 1.2 Met for pupils seated while writing and Clo values of 0.53 Clo and 1.06 Clo for males and females respectively. The third objective was to determine the comfort and preference votes of pupils in the classrooms in the zone. The thermal vote shows that 68.86% of pupils voted for a combined warm (45.92%) and hot (22.94%) uncomfortable thermal sensations and 62.30% of the pupils voted for cooler environment on the preference scale. Therefore showing that the classroom environment does not meet the children's thermal satisfaction as shown on Table 7.

The research recommends that there is the inescapable need for further studies on the use of appropriate building materials, opening types and right orientation in construction that will bring down the temperature for efficient learning in the hot semiarid climate of Nigeria. The results of this study shows a new thermal comfort data on field experiments that can be used by researchers and policy makers when dealing with schools in the hot semiarid climate. This is a guide for future provision of new classrooms and retrofitting of existing public facilities for public classrooms in Nigeria that will ultimately enhance pupils learning environment.

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Conflict of Interest

The authors declare no conflict of interest.

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