The Effect of Indoor Air Temperature on Thermal Comfort of Pupils in Naturally Ventilated Public Primary Schools in Abuja, Nigeria.

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Abstract

The effect of indoor air temperature on the thermal comfort of a sample of pupils from 6 naturally ventilated primary schools in Abuja, Nigeria has been reported in this paper. The schools are from the 6 districts of Abuja, approximately 207 primary six pupils aged 9-12 were used as samples. The study involved series of field surveys in which the thermal comfort of the samples was evaluated at two different temperature levels of 25.4 and 37.5 ^{0}C. Also, during the field experiments there was spot measurements of some indoor environmental variables. The field experiments were conducted in early March 2017(dry season), March corresponds to one of the peak months with the highest out door air temperatures in Nigeria. The data (thermal sensation votes) from the field experiments were analysed using descriptive analysis of the Predicted Percentage Dissatisfied (PPD) and the t-test. Results from the descriptive PPD analysis and t-tests showed that the indoor air of temperature of 37.5^{0}C affected the thermal comfort of the samples. In sum, result from this study shows that high indoor air temperature in classrooms can be detrimental to the thermal comfort of children that are presumed to be acclimatised to the tropical climate of Nigeria. The practical implication of the results from this study is that, the current naturally ventilated classrooms procured for Universal Basic Education (UBE) programme in Nigeria cannot moderate the indoor air temperature to suit the thermal of comfort of school children, particularly in areas with similar climate as Abuja, Nigeria. The results, limitations and key contributions from this study has been discussed.

Keywords: Thermal comfort; effect; pupils; indoor air temperature, Universal Basic Education (UBE).

1. Introduction

Air temperature refers to the temperature of air surrounding an occupant in a space (Parson, 2003; ASHRAE 55, 2010). Amongst the six environmental factors that affects the thermal comfort of humans indoors, air temperature is the most critical (CIBSE, 2006; Auliciems and Szokolay, 2007). This suggests the need for school buildings e.g. classrooms to have the appropriate indoor air temperatures that will promote the thermal comfort and learning of pupils. Generally, results from early and recent research conducted in schools, offices and climatic chambers indicates that the thermal comfort of humans indoors can deteriorate at relatively high and low indoor air temperatures (Humphreys, 1977;Lan et al., 2010; Cui et al., 2013;Le et al., 2017;Bluyssen et al., 2018; Jiang et al., 2018; Porras-Salazar et al., 2018).

Specifically, when it comes to schools which is the focus of this study, the negative effect of indoor air temperature on the thermal comfort of children has been reported over several decades as shown by the results of some studies summarised in Table1. Nevertheless, it is acknowledged in this paper that indoor air temperature does not only affect the thermal comfort of humans but also the health and performance of tasks (Wargocki and Wyon ,2007; Haverinen-Shaughnessy and Shaughnessy , 2015). However, for the sake of scope, this paper will focus mainly on the relationship between indoor air temperature and thermal comfort of pupils.

Since most of the findings of the authors summarised in Table 1 shows that elevated indoor air temperature can be detrimental to the thermal comfort of pupils, it is therefore necessary to investigate whether the naturally ventilated classrooms provided by the Universal Basic Education (UBE) can sustain the thermal comfort of school pupils. UBE is an educational programme in Nigeria. Since the establishment of the programme in 2004, thousands of similarly designed classrooms and schools have been constructed across the country, the classrooms

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in these schools usually depend on natural ventilation irrespective of the tropical climate of Nigeria. Nigeria is a tropical country. Tropical countries are characterised by high out door air temperatures during most periods of the year (McGregor and Nieuwolt, 1998).

In addition to research in Table 1 , it is worth to mention that some previous research have focused on the thermal comfort conditions in residential and office buildings in Nigeria (Ogbona and Haris, 2007; Akande & Adebamowo, 2010; Adaji et al., 2017; Jimoh & Demenongu-Demshakwa, 2020).

Table 1. Studies showing the effect of indoor air temperature on thermal comfort of pupils

Reference	Country	Part of the Findings
(Humphreys, 1977)	United Kingdom	Feeling of warmth is positively related to thermal discomfort
(Sonne et al., 2006)	United States of America	Temperature is the most chronic problem in school amongst in comparison to IAQ, humidity, light, noise, odour and mould
(Zeiler & Boxem, 2009)	Netherland	They concluded that thermal comfort should be given much priority in schools
Continuation of Table 1		
(Teli et al., 2011)	United Kingdom	Complaints about high indoor air temperatures during non-heating season was reported
(Teli et al., 2012)	United Kingdom	Operative temperature could be positively related to feelings of tiredness
(De Guili et al., 2014)	Italy	Complaints about elevated indoor air temperature during summer was reported the pupils.
(Le *et al.*, 2017)	Vietnam	The findings show that Vietnamese children could tolerate high air temperatures up till 32.8^{0}C
(Jiang et al., 2018)	China	''The temperature variation affected not only thermal comfort, but also pupil's well-being''
(Bluyssen et al., (2018)	Netherland	Pupils identified temperature as part of the variables that affect their comfort in classrooms
(Porras-Salazar *et al.*, 2018)	Costa Rica	About 60% of the samples were thermally dissatisfied with elevated classroom temperature

2. Method

2.1 Geographic context of the study

This study was conducted in the Federal Capital Territory of Nigeria, Abuja (FCT). Abuja is located at the central part of Nigeria (Figure 1). The FCT is made up of 6 districts, the districts are: Abaji, Abuja municipal, Bwari, Gwagwalada, Kuje, and Kwali (Figure 2). Furthermore, Abuja is characterised by relatively high outdoor air temperatures most times of the year. Outdoor air temperatures in Abuja could read above 40^{0}C in the month of March (one of the peak months) and above 30^{0}C most times of the year ^{0}C (Field work data from Nigerian Metrological Agency office Abuja, 2017).

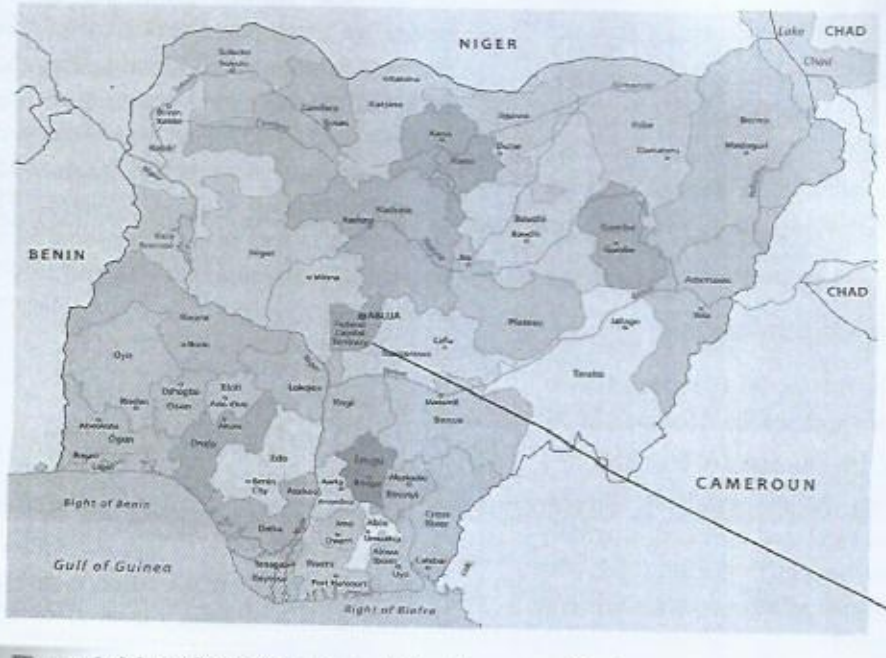

Figure 1: Map of Nigeria. Source: https://www.worldatlas.com/maps/nigeria

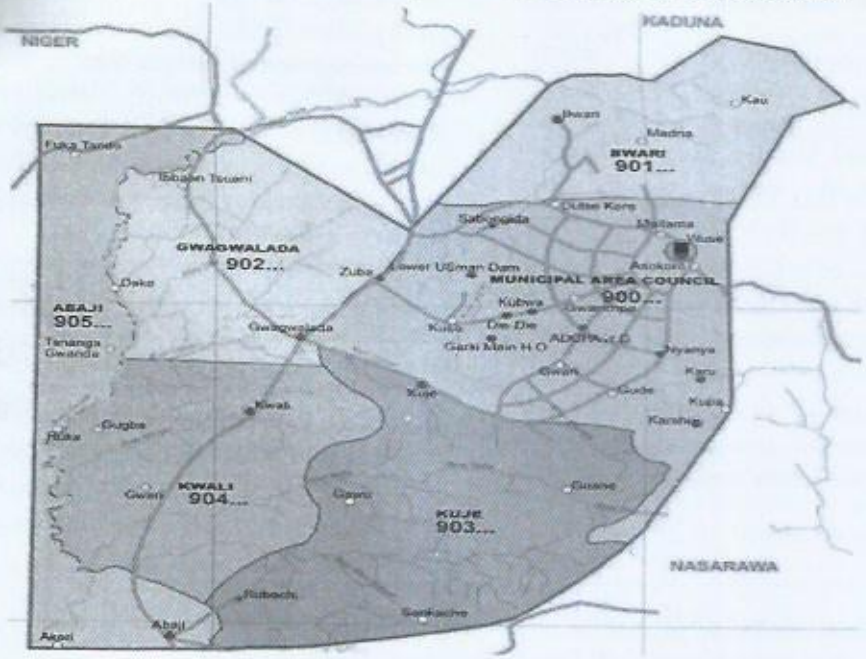

Figure 2: Federal Capital Territory, Abuja and the 6 local districts
Source: https://www.bing.com/search?q=map+of+ NIGERIA++showing+Abuja

2.2

The schools, samples and sample size

For the selection of schools, 6 public primary schools were randomly selected to participate in the field surveys. The schools are from the 6 districts of Abuja, Federal Capital City of Nigeria (Figure 2). In short, one school from each of the districts earlier mentioned in 2.1was randomly selected to participate in the field surveys in this study. The rationale for selecting 6 schools for this study was informed by the fact that, public primary schools in FCT Abuja have

similar design features and curriculum, as well, the pupils usually put on similar uniforms.

As regard samples and sample size: 207 pupils participated in the field surveys from the 6 schools, they are existing members of primary 6 as at the time of the field surveys. Furthermore, the samples were put through the aim and protocols of the field surveys prior to the start of the field surveys.

2.3 Description of the physical features of a typical classroom

A typical classroom in the school is rectangular in shape (7x8 M) with an approximate floor area of 56 M^2, and a height of 3.0 M. The walls of the classroom are built with 225mm hollow sandcrete blocks, plastered with cement/sand and finished internally with a bright colour (cream). Additionally, the classrooms usually depend on natural ventilation and daylighting all year round.

2.4 The design of the study

Field surveys were conducted in Early March 2017(hot dry season) in six public schools within the six districts of Abuja. This means one field survey was conducted in a school. March corresponds to one of the months with the highest outdoor air temperatures in Nigeria. At each field survey, samples were requested to evaluate their thermal comfort and thermal preference at two different indoor air temperature levels of 25.4 and 37.5 ^{0}C during their normal school work. This means at each field survey, the participants were requested to evaluate their thermal comfort and thermal preference during morning lesson (09.00 – 10.00am) and afternoon lessons (12.30-13.30pm). The average indoor temperature in the classrooms during morning lessons and afternoon lessons are 25.4 and 37.5^{0}C respectively.

2.5 Measurements

2.5.1 Physical measurements.

The Exitech 445815 thermo/hygrometer was used to measure the air temperatures and humidity levels in the classrooms at the field surveys. The instrument measures indoor air temperature in the range of -10 to + 60^{0}C, with an accuracy level of +- 1^{0}C; humidity range 10-99% The measurements were taken from a height of 1.1m above the floor levels (Feriadi & Wong, 2004; Zeiler & Boxem, 2009). Furthermore, the *clo* and activity levels used in this study were estimated from ASHRAE (2004). The *clo* was estimated to be 0.56 for girls and boys as shown in Table 2 and the activity level 1.0 met. This met value (1.0) corresponds to persons that are seated, reading and writing ASHRAE (2004).

Table 2. Clothing insulation (clo)value of the samples as estimated from ASHRAE (2004).

Boys	**clo values**	**Girls clothing**	**clo values**
Men's brief	0.04	Bra	0.01
Long sleeve /short sleeve shirt	0.20	Panties	0.03
Trousers	0.15	Under wear	0.02
Shoes	0.15	Long skirt	0.15
Socks	0.02	Sandals	0.02
----------	----------	Long-sleeved shirt dress	0.33
Total	0.56	----------	0.56

2.5.2 Measurement of thermal comfort and thermal preference

The thermal comfort of the participants at the field surveys were evaluated via the thermal sensation voting scale adopted from ASHRAE (2004), Table 3. The thermal sensation voting scale mentioned here was presented on a questionnaire. Also, the questionnaire requested the samples to indicate their thermal preference (Table 4). Lastly, the questionnaire requested the samples to document some of their personal characteristics (Age, sex, health status, mood, and state of hunger during the survey).

Table 3. The 7 point ASHRAE (2004) thermal sensation voting scale used measure thermal comfort

*Please mark X in **one** of the boxes below on how hot or cold you feel right now with respect to the air temperature in the classroom.*

Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
-3	-2	-1	0	+1	+2	+3

Table 4. The thermal preference scale

Kindly indicate your thermal preference with respect to the indoor air temperature in the classroom right now. Mark X in a box below as your response.

Want Warmer	No change	Want cooler

3. Statistical Analysis

SPSS version 24 was utilised in carrying out the statiscal analysis in this present study. The significance level was put at 0.05(De Vaus, 2002; Field *et al.*, 2012).Descriptive analysis of Predicted Percentage Dissatisfied (PPD) and the dependent sample t-test were utilised in analysing and reporting the data from the field surveys in this present study.

4. Results

4.1 The schools, sample size and some personal characteristics of the samples

The distribution of schools and samples size utilised for the field surveys this study is presented in Table 6. The samples consist of 57% boys and 43% girls. The samples were of ages 9-12 years. The samples were dressed in *clo* value of approximately 0.56 clo. 0.56 *Clo* is considered to be light dressing (ASHRAE 2004). The met value of the samples is 1.0, this value corresponds to persons seating, reading and writing (ASHRAE 2004). Furthermore, analysis of the questionnaire used for the field surveys indicated that none of the samples was sick, hungry, physically challenged and sad during the field surveys.

Table 5. The schools and sample size

Code name for schools **(location)**	Sample per school **(number of samples used for statistical analysis due to missing data)**
School 1**(Abaji)**	43 **(37)**
School 2**(Abuja municipal)**	32 **(32)**
School 3**(Bwari)**	28 **(28)**
School 4**(Gwagwalada)**	36 **(34)**
School 5**(Kuje)**	33 **(32)**
School 6**(Kwali)**	35 **(29)**
Total	207**(192)**

Table 6. The environmental conditions in the classrooms

Environmental condition	Field surveys at low air indoor temperature(0.9.00-10am)	Field surveys at high indoor air temperature (12.30-13.30pm)
Indoor air temperature	25.4^{0}C	37.5^{0}C
Relative humidity	62%	35%

4.2 Thermal comfort (See Table 3 for the thermal sensation voting scale)

For a space to be thermally comfortable, 80% of the votes the persons in that space are expected to be in the range of **+1, 0 and -1** on the ASHRAE 2004 thermal sensation voting scale.By extension, this suggest that when more than 20% of persons in a space are voting outside the range of **+1, 0 and -1,** they are thermally dissatisfied (thermal uncomfortable) in that space.

In view of the background from ASHRAE (2004) put above, results from the descriptive analysis of thermal sensation votes from the field surveys are presented in Table 8. In sum, the results in Table 8 shows that about 93% of the samples were thermally satisfied when their thermal comfort was measured at indoor air temperature of 25.4^{0}C, this is because 93% of the thermal sensation votes of the samples is within the range of 0 and -1.This result suggest that the samples used for the field surveys in this study were thermally comfortable at indoor air temperature of 25.4 ^{0}C. In contrast, results in Table 8 shows that 89 % of the samples were thermally dissatisfied when their thermal comfort was measured at 37.5^{0}C, this is because most (89%) of the thermal sensation votes of the samples falls within +2 and +3. In short, this result shows that the samples used for the field surveys were thermally uncomfortable at 37.5^{0}C.

Table 7. Result of Predicted percentage dissatisfied (PPD)

Thermal sensation voting scale	Predicted percentage dissatisfied (PPD) at 25.4	Predicted percentage dissatisfied (PPD) at 37.5
+3 hot	0	67
+2 warm	0	22
+1sligthly warm	0	11
0 neutral	62	0
-1slightly cool	31	0
-2 cool	6	0
-3 cold	1	0

Furthermore, an analysis of the thermal sensation votes was conducted using the dependent sample t-test. The dependent sample t-test was used to compare the mean of the thermal sensation votes at 25.4 and 37.5^{0}C. The result of the dependent sample t-test showed that there is a significant difference between the mean of the thermal sensation votes of the samples, the mean of the thermal sensation votes used to measure the thermal comfort of the sample at 25.4^{0}C is M =0.36 and at 37.5^{0}C is M = 2.6 , p=0.00. This result shows that in comparison to the indoor air temperature 25.4^{0}C, the indoor air temperature of 37.5^{0}C significantly affected the thermal comfort of the samples used for the field surveys in this study.

Again, an independent sample t-test was conducted. The independent sample t-test was used to compare the mean of the thermal sensation votes of boys (samples) with that of girls (samples) at the two temperature (25.4 and 37.5^{0}C) levels used for the field surveys. The results shows that there is no significant the difference between the mean of the thermal sensation votes of boys and girls. The result of the independent sample t-test reported here indicates that the effect of indoor air temperature on thermal comfort of children is not dependent on Gender.

Overall, the results presented in this subsection shows that relatively high indoor air temperature of 37.5^{0}C can affect the thermal comfort of school children in naturally ventilated public schools in Federal Capital Territory of Nigeria. Also, the results of this study shows that indoor air temperature of 25.4^{0}C can be thermally suitable for children. Lastly, the results from this study suggests that there is no gender difference when it comes to the effect of indoor air temperature on the thermal comfort of children, provided that the children put on clothing with similar insulation values and are performing the same task in the same space at the same time.

4.4 Thermal preference

Descriptive analysis of thermal preference votes of the samples is presented in the next paragraph of this subsection.

As regards thermal preference, about 90% of the samples indicated that the indoor air temperature in the classroom should not be cooler or warmer when their thermal comfort was measured at 25.4^{0}C. In contrast, about 94% indicated that they will prefer that the indoor air temperature in the classroom to be cooler when their thermal comfort was measured at indoor air temperature of 37.5^{0}C. In sum, the result here suggests the samples (pupils) would prefer cooler air temperatures in classroom.

5. Discussion

Statistical evidence (PPD and dependent t-test) result in this present study shows that indoor air temperature of 37.5 ^{0}C (high temp) was significantly detrimental to the thermal comfort of the samples. This result implies that as the indoor air temperature in the classrooms used for the field surveys increased from 25.4^{0}C (low temp) to 37.5 ^{0}C (high temp) , the thermal sensation of the samples from the 6 schools also significantly increased from the state of being thermally comfortable to uncomfortable. From the results in this study, it clear that pupils will prefer relatively cooler indoor air temperatures for carrying out academic tasks in classrooms. Again, results from the field surveys in this study can be reliable, this is primarily because there was control for the effect of some extraneous variables that concerns the personal characteristics of the samples. For example, the age of the samples were similar, none of the samples was sad, sick and hungry and the samples wore the appropriate clothing insulation values (0.5clo) that corresponds with warm seasons. Since, public primary schools in Nigeria have similar design features, the results obtained in this study can be applicable to other naturally ventilated public schools in Nigeria, particularly in places with similar climate as Abuja.

Furthermore, results from the field surveys in this present study suggest that there is no significant difference in the thermal comfort of children as a result of gender. This result suggests that, there is likely not be a significant difference in the thermal comfort and preference of the children due to gender. The finding concerning gender reported from the analysis in this study resonates the findings from the research of some authors (Fanger 1973; Wong et al. 2009; Hwang & Chen, 2009; Liu et al. 2011), their results shows that there is no significant difference in thermal comfort of males and females' due physiological differences. By extension, the practical implication of the results from this study is that, the naturally ventilated classrooms procured for public schools cannot sustain the thermal comfort of pupils during hot season in Nigeria. Thus, there is a dire need for designers of public schools in Nigeria to identify passive and active strategies of providing thermal comfort for naturally ventilated schools across the country.

Another practical implication of the results from this study is that, the indoor air temperature in the naturally ventilated classrooms in Abuja could read much higher than the 18-24^{0}C suggested by World Health Organisation (WHO), this organisation according to Ormandy & Ezratty (2012) recommends 18-24^{0}C indoors for the thermal comfort of humans indoors.

Lastly, the negative effect of high indoor air temperature observed and documented in this study strengthens the findings from previous research of some authors (Humphreys, 1977; Lan et al., 2011; Cui et al., 2013).Their research shows that high indoor air temperature is positively related to thermal discomfort. The key limitations of this study is that, the samples (schools) used for this study is relatively small, this is in comparison to the number of public schools in the six districts of Abuja.

6. Conclusions

The effect of indoor air temperature on the thermal comfort of pupils in the tropical climate of Abuja has been conducted, the conclusions are highlighted below.

- Indoor air temperature in naturally ventilated schools in Abuja could read up to 37.5 ^{0}C during the peak of hot seasons, this can in turn affect he thermal comfort of school children.
- There is a positive correlation between high indoor air temperature and thermal discomfort
- Children cannot tolerate high indoor air temperature in the range of 37.5 ^{0}C
- The thermal comfort of children is not dependent on gender.
- The current design features of naturally ventilated public schools in Nigeria may not be able to moderate the indoor air temperature to suit the thermal comfort of school children during hot season. This is particularly naturally ventilated schools in similar climate as Abuja

7. References

ASHRAE (2004) '9-11', *Standard 55-2004*. Available at: http://www.almas-hvac.ir/fh/download/ASHRAE_Thermal_Comfort_Standard.pdf (Accessed: 19/10/2018) .

Adaji,M & Watkins, R & Adler, G . (2017) Indoor Thermal Comfort of Residential Buildings in the Hot-Humid Climate of Nigeria during the dry season. In: Passive Low Energy Architecture (PLEA) Conference, 3-5 July 2017, Edinburgh, Scotland.

Ademola, O. J.& Demenongu-Demshakwa, J.(2020) Establishing Indoor Comfort Temperature (Neutral Temperature) in Naturally Ventilated (NV) Office Buildings in Jos, Available at: https://www.researchgate.net/search.Search.html?type=publication&query

Akande, O. K., & Adebamowo, M. A. (2010). Indoor Thermal Comfort for Residential Buildings in Hot-Dry Climate in Nigeria. In Proceedings of International Conference on Adapting to Change: New Thinking on Comfort. Cumberland Lodge, Windsor, United Kingdom.

Bluyssen, P.M., Zhang, D., Kurvers, S., Overtoom, M. & Ortiz-Sanchez, M. (2018) 'Self-reported health and comfort of school children in 54 classrooms of 21 Dutch school buildings', *Building and Environment*, 138, pp. 106-123.

Creswell, J.W. (2012) 'Educational research', *Planning, conducting, and evaluating quantitative and qualitative research.*

De Vaus, D. (2002) *Analyzing social science data: 50 key problems in data analysis*. Sage.

Feriadi, H. & Wong, N.H. (2004) 'Thermal comfort for naturally ventilated houses in Indonesia', *Energy and Buildings*, 36(7), pp. 614-626.

Field, A., Miles, J. & Field, Z. (2012) *Discovering statistics using R*. Sage publications.

Haverinen-Shaughnessy, U. & Shaughnessy, R.J. (2015) 'Effects of classroom ventilation rate and temperature on students' test scores', *PloS one*, 10(8), p. e0136165.

Humphreys, M. (1977) 'A study of the thermal comfort of primary school children in summer', *Building and Environment*, 12(4), pp. 231-239.

Jiang, J., Wang, D., Liu, Y., Xu, Y. & Liu, J. (2018) 'A study on pupils' learning performance and thermal comfort of primary schools in

China', *Building and Environment*, 134, pp. 102-113.

Kevan, S.M. & Howes, J.D. (1980) 'Climatic conditions in classrooms', *Educational Review*, 32(3), pp. 281-292.

Le, T.H.V., Gillott, M.C. and Rodrigues, L.T. (2017) 'Children thermal comfort in primary schools in Ho Chi Minh City in Vietnam'. Available at: http://eprints.nottingham.ac.uk/id/eprint/44185(Accesses 20/2/22)

McGregor, G.R. & Nieuwolt, S. (1998) *Tropical climatology: an introduction to the climates of the low latitudes*. John Wiley & Sons Ltd.

Ogbonna, A.C., & Harris, D.J. (2007). Thermal comfort in Sub-Saharan Africa: Field research report in Jos, Nigeria. School of the Built Environment Heriot Watt University. Retrieved from https://www.sciencedirect.com .

Ormandy, D. & Ezratty, V. (2012) '116-121', Health & thermal comfort: From WHO guidance to housing strategies.

Porras-Salazar, J.A., Wyon, D.P., Piderit-Moreno, B., Contreras-Espinoza, S. and Wargocki, P. (2018) 'Reducing classroom temperature in a tropical climate improved the thermal comfort and the performance of elementary school pupils', *Indoor air*.

Teli, D., Jentsch, M. F., James, P. A. B. & Bahaj, A. S. (2011). Overheating risk evaluation of school classrooms. World Renewable Energy Congress. Linköping, Sweden, 8-13 May.

Research, 13(2), pp. 193-220.

Wargocki, P. & Wyon, D.P. (2007) 'The effects of moderately raised classroom temperatures and classroom ventilation rate on the performance of schoolwork by children (RP-1257)', *Hvac&R Research*, 13(2), pp. 193-220.

Zeiler, W. & Boxem, G. (2009) 'Effects of thermal activated building systems in schools on thermal comfort in winter', *Building and Environment*, 44(11), pp. 2308-2317.