Thermal Comfort Assessment of Primary School Children in a Warm and Humid Climate

A case study of Imo State, Nigeria

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Declaration

I declare that the research contained in this thesis was carried out by me. It has not been previously submitted to this institution or any other institution for the award of a degree of any other qualification.

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Abstract

Thermal comfort study in buildings gained unprecedented momentum in recent times because of the concern over climate change. The increasing temperature caused by climate change is likely impacting the comfort and the health of building occupants, especially in a primary school setting where young children engage in-class lessons for an extended period. This thesis presents the results of the perception of the thermal environment by primary schoolchildren (aged 7-12 years), and that of their teachers and the thermal performance of the classrooms they use for class lessons.

Fieldwork that involved the collection of objective and subjective data were carried out in six naturally ventilated classroom buildings that have two different architectural features. The studied subjects in the survey area (Imo State) represented a variety of users in a similar climatic context in Nigeria. The fieldwork covered two seasons associated with the study area; the rainy season and the dry season, during which the subjects were repeatedly surveyed twice a day. Structured comfort questionnaires were adopted to collect approximately 7050 valid copies of responses from 330 schoolchildren and 44 of their teachers at the same time data loggers were collecting indoor and outdoor environmental parameters. The data from the fieldwork were stored in a spreadsheet of Microsoft Excel and analysed using both descriptive and inferential statistical techniques.

Results show that at the prevailing indoor air velocity, not all the surveyed classroom spaces met the specifications of the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 55-2017 comfort zone, adopting an 80% acceptability criterion as the primary consideration. Higher compliance was reported in the ‘open-space’ classrooms compared to the ‘enclosed-plan’ classrooms. The calculated comfort temperature of the schoolchildren is 28.8^{o}C, at an observed mean indoor operative temperature of 29.1^{o}C for the combined classrooms. Result also shows that the schoolchildren are comfortable in the operative temperature range of between 25.8^{o}C and 31.6^{o}C within 80% ASHRAE comfort zone with a greater majority of them voting comfortable at the temperature range of between 26.0^{o}C and 28.0^{o}C. The result of the comparison of the Predicted Mean Votes (PMV) and the Actual Mean Votes (AMV) shows that the PMV overpredicts the students’ thermal sensation, and underestimates the neutral temperature by 3.5K. The result further suggests that the schoolchildren in the warm and humid climate in Nigeria can tolerate high temperatures in naturally ventilated classrooms. Another important finding is that though the children generally prefer a cooler indoor environment, the result reveals that it is not always all the time that people in the warm and humid environment prefer a cooler environment. Furthermore, the comparison of the thermal perception of the schoolchildren and their teachers indicates that their teachers perceived the indoor classroom warmer than their students feel and are more sensitive to temperature changes than their students. The paper concludes that schoolchildren can accept high indoor temperatures and still become comfortable and may not need air-conditioning systems. This creates an opportunity for potential energy savings in primary schools in a warm and humid environment. The findings from this work are important information for researchers in the built environment, service engineers, and architects, and may help to discourage high energy use in Heating, Ventilation, and Air-conditioning (HVAC) systems in primary schools in the warm and humid climate in Nigeria. The study recommends extending future work to private schools and other schools in other climatic regions in Nigeria for comprehensive information about the comfort perception of primary schoolchildren.

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List of Symbols and Abbreviations

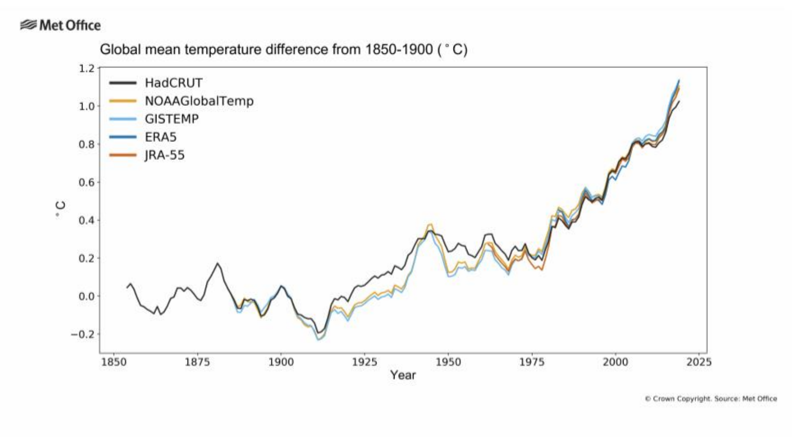
EN	Enclosed
ET^*	Effective Temperature
HVAC	Heating, Ventilation and Air-Conditioning
I_{cl}	Thermal Insulation Value of Clothing for a Combination of Garments
ISO	International Organization for Standardization
K	Ambient Operative Temperature
Km/h	Kilometre per hour
L	Thermal Load of the Body
M	Metabolic heat production
MET	Metabolic Equivalent
MM	Mixed-Mode
NV	Naturally-Ventilated
OP	Open
PM	Post Meridiem' (After Midday)
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied
RMR	Resting Metabolic Rate
SCATs	Smart Controls and Thermal Comfort
SET^*	Standard Effective Temperature
SD	Standard Deviation
T_{comf}	Comfort temperature
T_{lim}	Limits of acceptable temperatures
T_n	Neutral temperature
T_{od}	Daily mean outdoor temperature
T_{op}	Operative temperature
T_{out}	Outdoor temperature
$T_{pma(out)}$	Prevailing mean outdoor temperature
T_{rm}	Exponentially weighted running mean outdoor temperature
TSV	Thermal sensation vote
W/m^2	Watts per m^2 body surface

1 Chapter 1: Introduction

1.1 Introduction

Research interest in ‘ thermal comfort’ is motivated by concerns over climate change-induced problems which are already causing devastating effects on human beings and the environment. The changes in the global average temperature are already causing changes in sea levels, precipitation, drought, wind patterns, and indoor temperature. The news of the vast iceberg the size of Wales, in the UK, that broke out from an ice shelf in Antarctica in 2017 and the frequent occurrences of hurricanes are pointers to the consequences of increased global temperature. The impact of climate change particularly becomes more severe in the underdeveloped and developing countries (Small & Nicholis, 2003), and Africa has been identified as one of the most vulnerable continents to climate change (Hope Sr, 2009). It was projected that the temperatures in Africa are likely to rise faster than the global average during the 21st century (Joshi, Hawkins, Sutton, Lowe, & Frame, 2011; Ademakinwa & Rodrigues, 2017). Globally, at the 48th session of the International Panel on Climate Change (IPCC), the organization was alarmed at the rate of increase in global temperature (Masson-Delmotte, 2018). What is worrisome is that since the middle of the 20th century, most of the warming has been attributed to human-induced increase of atmospheric greenhouse gas (Change, 2014). The World Metrological Organisation (WMO) in a press release informed the United Nations Secretary-General’s Climate Action Summit, that 2015-2019 witnessed a continuous increase in carbon dioxide (Co_2) levels and other reference key greenhouse gases in the atmosphere to new records, with Co_2 growth rates nearly 20% higher than the previous five years (2010-2015). The report further added that 2015 to 2019 ‘is set to’ be the warmest five years and to become the deadliest metrological hazard caused by heatwaves affecting all continents. Buildings are contributors to the greenhouse gas emissions and the occupants are at the mercy of this growing heatwaves (Vellei, Herrera, Fosas, & Natarajan, 2017).

Buildings may have a great impact and influence on the natural environment. Approximately 90% of people spend about 90% of their daily time inside buildings (Dimoudi & Tompa, 2008), be it residential, commercial, industrial, religious, or educational buildings. Children in particular spend long periods of time in classrooms (Haddad et al, 2012).



Five-year running average of global temperature anomalies (relative to pre-industrial) from 1854 to 2019 for five data sets: HadCRUT.4.6.0.0, NOAAGlobalTemp v5, GISTEMP v4, ERA5, and JRA-55. Data for 2019 to June

Figure 1.1: Global mean temperature difference 1850-1900
(Source: Pinardi et al., 2019)

According to Sarbu & Pacurar (2015), the indoor environmental quality in classrooms these students stay impacts on their health and affects their learning and problem-solving ability. Godfrey et al., (2012) argue that improving the quality of the learning environment can improve attendance, decrease the likelihood of dropping out of school and reduces antisocial and unhealthy behaviours. It was also found that adequate learning conditions improve student’s performance as much as 30% (Almeida, de Freitas, & Delgado, 2015). Some international bodies, such as International Standard Organization (ISO) and American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) recommend some acceptable range of indoor temperatures in buildings. These International organizations suggest that the current comfort standard based on adults Iso, (2005) and ASHRAE, (2017), could be applicable for children in classroom situations.

However, some thermal comfort researchers doubt the applicability of the comfort standard produced from surveys on adults on children. Various studies have shown that the temperature of thermal comfort for young children may differ from that of adults (ter Mors, Hensen, Loomans, & Boerstra, 2011; Teli, Jentsch, & James, 2012; Teli, James, & Jentsch, 2013; de Dear, Kim, Candido, & Deuble, 2015; Wang et al., 2017; Trebilcock, Soto-Munoz, Yanez, & Figueroa-San Martin, 2017; Nam, Yang, Lee, Park, & Sohn, 2015). Some researchers further suggest that adopting and generalizing the current thermal comfort standard, adopted from adults, for children, may give wrong feedbacks as to what the actual thermal comfort conditions of children are (Zomorodian, Tahsildoost, & Hafezi, 2016; Montazami, Gaterell, Nicol, Lumley, & Thoua, 2017; Mishra & Ramgopal, 2015; Pinardi et al., 2019). Apart from the lack of consensus on whether to apply the current standard on children or not, these international organizations, are yet to properly define and assess thermal comfort in school buildings (Singh et al., 2018). Singh et al, however, added that these international organizations have properly defined thermal comfort in residential, office and commercial buildings. But in schools, student's density is generally higher than in offices and residential buildings. Furthermore, de Dear et al.,(2015), Shamila Haddad, Osmond, & King, (2017) added that studies conducted in different classrooms are not providing the indoor thermal conditions and IAQ for which they are designed. de Dear et al. (2015) further posited that these are classrooms where children spend one-third of the day inside. To provide a comfortable environment in classrooms, one would require to know the actual thermal comfort perception of the occupants. For now, the number of thermal comfort studies conducted in school buildings is not comparable to those conducted in offices (Ricciardi & Buratti, 2018). The review article by Zomorodian et al., (2016) reveals that only 48 papers on the topic (school building) were published from 1969 to 2015, and were mainly based in Europe. However, there has been an increase in comfort study in schools in recent time but the focus remains in schools located in the western world.

Also, the quality of infrastructure and the learning environment likely have a strong influence on academic standards in schools (Ayeni & Adelabu, 2012). Despite the benefits of a good learning environment for children, it is not uncommon that infrastructure in Nigerian public schools is dilapidated and inadequate to provide quality education service delivery (Asiabaka & Mbakwem, 2008). It is also not rare to see cases of 100 children per teacher (Akindele, 2014; Benson, 2016) or schoolchildren sitting under trees outside the school building because of inadequate classrooms or overheated indoor spaces. The continuous rise in the global temperature may have some adverse effect on the health of these children exposed to overheated indoor and outdoor spaces. Children exposed to very high temperatures may experience a greater risk of mental disorder, infectious diseases, allergic diseases, and respiratory diseases (Zhiwel et al 2012). There is a need to provide a good learning environment that is thermally comfortable. However, the provision of this sustainable thermal comfort indoors will demand a deeper understanding of the climate, users, site, and, materials (Adebamowo & Olusanya, 2012).

Apart from providing comfortable indoor thermal conditions in classrooms, it is also important to consider buildings in terms of their energy consumption and sustainability (Nicol & Humphreys, 2002). Providing the needed thermal comfort in buildings using active ventilators means more 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). The main use of this energy in buildings is for Heating, Ventilation & Air-conditioning which can be up to 40-50% (Bastide, Lauret, Garde, & Boyer, 2006). Precisely, a large proportion of this energy is used for thermal comfort in buildings (Yang, Yan, & Lam, 2014). The building sector alone contributes 30% of yearly greenhouse gas emissions in both developed and developing nations (UNEP). In the United Kingdom, an increase in temperature by 1^{o}C causes an increase in energy consumption by about 10% (Humphreys & Hancock, 2007). On the local scene, Nigeria is the 44th emitter of CO_2 in the list of over 200 countries in the world (Cosmas, Chitedze, & Mourad, 2019). Added with the growing dependence of classrooms on technology comes increasing energy consumption associated with both the operation and maintenance of buildings (Huang, Hamza, Lan, & Zahi, 2016; Nicol & Humphreys, 2002; Yau & Chew, 2014; Singh et al, 2018). Using the air-conditioning system to achieve thermal comfort has become popular in private schools in Nigeria and there is a likelihood it may spread to public schools. This use of air-conditioning system leads to a high level of energy consumption and negative impact on the environment. To eliminate or reduce the short and long-term risks and hazards of climate change on humans and property, the United Nations Framework Convention on Climate Change (UNFCC) came out with some strategies narrowed to two objectives.

Mitigation and adaptation are the main objectives of UNFCC in combating climate change. The mitigation approach involves a human intervention to limit the sources of gases, while adaptation is defined as ‘the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities’ (IPCC, 2014). To drive a reduction in greenhouse gas emission (GHG) that causes climate change, many countries adopted benchmarking processes that require calculations of building energy demand. Measures such as the Energy Performance of Building Directive (EPBD) in Europe requires member states to develop calculation methodologies to allow building energy demand to be determined (European Union, 2010). Denmark was one of the earliest countries to adopt energy efficiency regulations in the building code. The United States of America (USA) pioneered energy efficiency regulations in 1975 and was followed by South Korea and Japan and later India in 2007 (Ezema, 2015; Evans, et al, 2017). In Nigeria, the Federal Ministry of Urban Development is gearing towards approving the country’s National Building Code. Furthermore, to realize sustainable development in the building sector towards minimizing climate change and the consequences, professionals in the construction industry added their voice to the need to rapidly and significantly reduce global carbon emissions in support of a minimum 80% cut in carbon dioxide (CO_2) emissions by 2050.

However, solutions to climate change may not solely be technical problems requiring technical solutions; rather it is more to do with human behaviour and how building occupants respond to the larger environment (Cândido, de Dear, Lamberts, & Bittencourt, 2010). Indeed, there is a growing concern that we have already passed an early 'tipping point' where the most aggressive global movements to reduce carbon emissions can do little to avoid a significant shift in the global climate system (Dave *et al.*, 2012). As a result, mitigation alone cannot be a solution to climate change, and there is a need to think of adapting as the climate changes (Eckstein, Künzel, Schäfer, & Winges, 2019). Adaptation and mitigation have a complementary role to play to ensure that while people seek for comfortable thermal indoor conditions, these are achieved with less energy use. Hence, the importance of adapting buildings and their users to climate parameters with lower energy consumption is imperative.

In the tropical climates, most of the buildings are naturally ventilated, and there may be a relationship between the adaptation of the occupants to the local environment and the local temperatures they experience daily. Various researchers suggest that taking advantage of these naturally ventilated buildings that encourage adaptation to a wider range of indoor thermal conditions is beneficial. Maintenance of narrow temperature range (as found in air-conditioned buildings) requires significant energy inputs, and these static environments do not necessarily result in appreciable higher levels of occupant satisfaction (Arens *et al.*, 2009). This focus is re-awakening an interest in natural ventilation (de Dear & Brager, 2002; Toftum, 2004; Zhang *et al.*, 2007). Furthermore, some other researchers suggest that naturally ventilated buildings can significantly reduce greenhouse gas emissions and become more energy efficient.

A naturally ventilated building may use less energy in a warmer climate as no air-conditioning system may be used, but a building with high casual heat gains and a full air-conditioning system may require much more energy in a warmer climate (Williams *et al.*, 2011). The adaptive model is recognized in the developed countries, leading to its inclusion in both the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) and the European Committee for Standardization. Some other countries that have developed their model for adaptive thermal comfort are China (Carlucci, Bai, de Dear, & Yang, 2018) and India (Manu *et al.*, 2014). Other countries are also in the race to develop an adaptive thermal comfort model applicable to their locality.

A research problem is an issue or concern that needs to be addressed, for example, a void in the literature, conflict in research results or topics that have been neglected such as a need to lift up the voice of marginalized participants (Creswell J. 2014). Motivated by this statement and linking it to children (vulnerable group) who spend a good number of hours in classrooms engaging in-class activities, this study did a critical and relevant literature review and pilot study as they concern comfort-related matters in classrooms. The outcome directed a need to investigate the thermal comfort requirements of children aged 7-12 years in Nigeria whom their opinions have not been sought regarding their thermal conditions in their classrooms. We live in a world where parents, especially those from developing countries, make most decisions for their children thinking that they are unable to make decisions that affect their lives. Allowing these children to make their thermal condition decision themselves was indeed challenging but fulfilling. Accepting this challenge was also motivation by the United Nations (UN) convention of 1989 that reflected in Article 12 the Rights of children to participate, say and have their opinions considered on what affects their lives. If one wants to know how people feel in a particular situation, there is no better way to find out than to go and ask them (Nicol, Humphreys, & Roaf, 2012), by the method of fieldwork. However, while attempting to get the subjective responses of these young children and their teachers, it is also important to understand the indoor thermal conditions they use for class lessons. The buildings and the rooms the subjects inhabit are almost as important to the survey as the human subjects themselves (Nicol et al., 2012).

1.2 Research Rationale

Young children coming out fresh from their homes in quest of education are exposed to different indoor classroom environments. The indoor environments in classrooms are vital for pupils' perception, health, and performance, especially thermal comfort (Jiang, Wang, Liu, Xu, & Liu, 2018), considering that schoolchildren spend up to one-third of the day inside classrooms (Bluyssen, 2014). At this level of education, children are exposed to become an integral part of the society and to adapt to situations out of the home. Children are shaped by their physical, social and emotional changes throughout their childhood. Because they are more vulnerable than adults to environmental pollutants (Suk, Murray, & Avakian, 2003), they could be negatively impacted by climate change-induced problems, such as heat stress and other environmental problems. There are various literature reports about the relationship between high temperature and health issues. Exposure to high temperatures can cause health problems such as an increased risk of heatstroke, respiratory and cardiovascular hospitalizations and deaths (Anderson et al., 2013; Hoshiko, English, Smith, & Trent, 2010). The United Nations Convention on the Rights of the Child (UNCRC) commits all signatory states to protect the right of every child, to ensure they are safe and operate in healthy environments. Also, the African Charter on the Rights and Welfare of the Child (ACRWC) recognizes that a child's safety and healthy development depends on care about health, physical, mental, moral and social development

Lighting, noise, air quality, and thermal comfort are some of the components of Indoor Environmental Quality (IEQ) that may worry building occupants. A pilot study carried out in a higher institution to evaluate and rate these components rated thermal comfort above other IEQ components, as the number one component that gives them the most concern. The higher institution where this pilot study was carried out is in Anambra State, Nigeria. Nigeria is boarded on the North, East, and West by Niger, Cameroon, and the Benin Republic, respectively (Nwilo & Badejo, 2006). Nigeria is located in West Africa just north of the equator. This makes it experience tropical climate which is characterized by hot and wet conditions associated with the movement of inter-tropical convergence zone both North and South of the equator. In Nigeria, primary education is provided for children whose ages are between 6 and 12 years. The primary schools can be owned by the government, individuals or, religious organizations. In the survey conducted by Griffitts on user satisfaction in buildings with passive features, he observed that having the 'right temperature' was one of the things people considered most important about a building (Nicol et al., 2012). Furthermore, a panel of judges rated different components of IEQ and observed that thermal comfort was more important compared to indoor air quality and considerably more important compared to acoustic and virtual comfort (Albatici, n.d.). The summary of the ranking of indoor environmental quality components from some studies is shown in Figure 1.2.

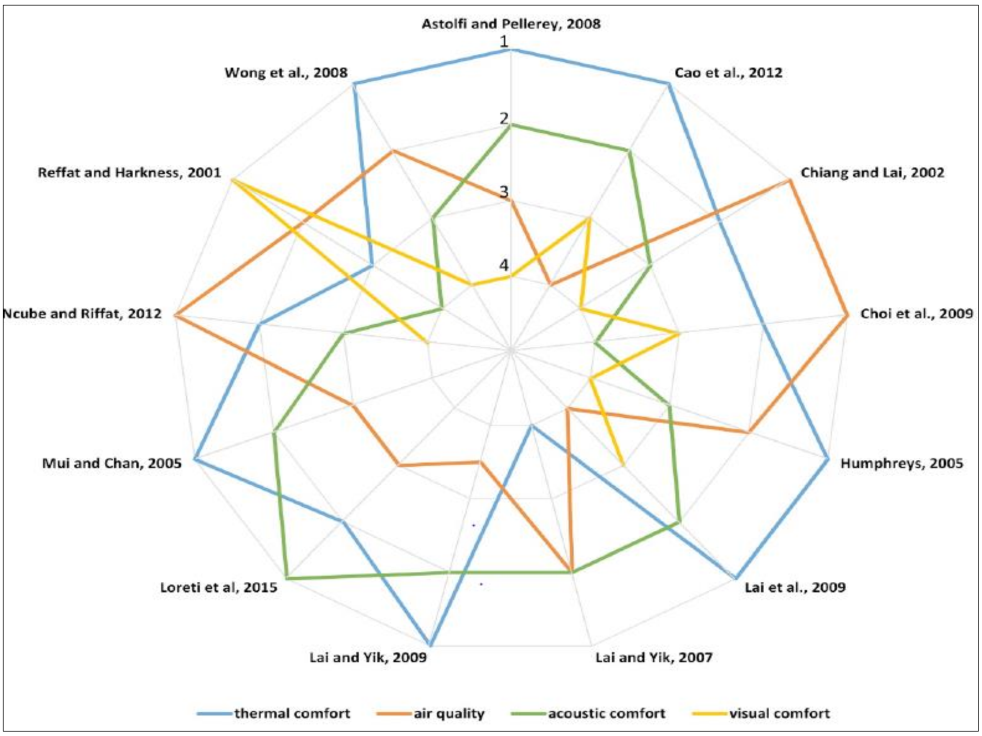


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Figure 1.2: Summary of the ranking of indoor environmental quality components (rank 2 = higher importance, rank 4 =minor importance. Adapted from Albatici, n.d.)

ASHRAE Standard 55 suggests that the recommendations of its standard (based on fieldwork with adults) could also apply to children in classroom situations (Shamila Haddad, 2016). The standard suggests that the acceptable range of indoor temperatures of children and adults is assumed to be the same. However, most thermal comfort researchers are doubting if this assertion is true. They argue that since no child was involved in Fanger's initial heat-balance thermal comfort research that produced the Predicted Mean Votes (PMV) (adopted in the standard), it is not certain if findings from field studies in offices or universities or climate chamber experiments (where only adults were used) will accurately reflect the thermal sensation and preferences of schoolchildren (Teli et al., 2012; Teli et al., 2013; de Dear et al., 2015). This is because the metabolic rate and the activity levels vary between the two groups, and it may likely affect their thermal perception (Zomorodian et al., 2016; Jiang, Wang, Liu, Xu, & Liu, 2018). Compared with adults, children have a lower sweat rate in all environmental conditions (Falk & Dotan, 2008). Furthermore, the difference in physical and physiology between children and adults, including differences in surface-area-to-mass ratio, blood volume per body surface area, sweating rate, metabolism, body temperature, and circulation (Falk, 1998), may also influence their thermal perception. These are some of the reasons some thermal comfort researchers raised some doubts about the applicability of the existing thermal comfort standards and guidelines, such as ISO 7730, EN 15251, and ASHRAE 55, on children (Trebilcock et al., 2017). In addition, the likely dominance of controls in classrooms may also influence the thermal perception of the occupants. In primary schools, the teachers, (adults), are believed to control the internal environment by opening the windows, doors, and putting on fans when they wish to do so (Auliciems, 1975; Humphreys, 1977; ter Mors, et al., 2011; De Giuli et al., 2012). According to Humphreys, Nicol, & Raja, (2007), the opportunity to control an environment affects the thermal perception of the occupants, making those who do not have control over the environment to bear to the uncomfortable indoor conditions. The daily school schedule of children that includes a lot of outdoor playing may also influence their thermal perception (Teli et al., 2012). Children likely have a different comfort temperature from that of adults (Korsavi & Montazami, 2020). Thus, a different comfort criterion might be required to achieve thermal comfort for children Mishra & Ramgopal, (2013), Zomorodian et al., (2016), especially for those within the age range 7-11 years (Mendell & Heath, 2005;Wargocki & Wyon, 2007).

The above reasons prompted various research studies across the globe to determine the thermal comfort temperature of children and to compare the findings with that of adults so that appropriate comfort standards for children can be produced in the nearest future. Meanwhile, some pieces of empirical data about the thermal comfort perception of schoolchildren are available from studies done in Europe, America and Asia, (Nicol, 2004; Montazami & Nicol, 2013), but in Africa this information is limited. The results from fieldwork in these continents may not apply to African countries. This is because, as 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 (Yao, Li, & Liu, 2009; Indraganti, 2010; Nicol et al., 2012; Mishra & Ramgopal, 2015). Trebilcock et al. (2017) confirmed this argument, in the recent finding from a field study, of a correlation between thermal comfort temperature and socioeconomic backgrounds of the participants. The comfort models specific to an area should be developed based on the indoor and outdoor temperature, relative humidity, and clothing pattern of people of the region. It is important to evaluate the comfort requirements of people worldwide, particularly, in tropical regions that lack comprehensive standards (Nicol, 2004; Toe & Kubota, 2011).

However, in Nigeria, researchers such as Odim, (2008), Ogbonna & Harris, (2008), Akande & Adebamowo, (2010), Uzuegbunam, (2011), Adunola & Ajibola, (2012), Abiodun, (2014), Ahadzie, Ankrah, Efeoma, & Uduku, (2014), Ahadzie et al., (2014), Alozie & Alozie, (n.d.), Adunola & Ajibola, (2016), Adaji, Watkins, & Adler, (2017), Efeoma, (2017) and a host of others have evaluated thermal comfort conditions in indoor spaces using field surveys. Thermal comfort studies of building occupants done in naturally ventilated buildings in the warm and humid section of Nigeria reported neutral temperatures between the range 23-32^{o}C with comfort range from 18-33^{o}C. However, these studies focused on residential buildings, offices and hostel blocks, and the participants used in the evaluation were all adults. In a tropical country like Nigeria, for example, there is a dearth of thermal comfort studies in schools, and at present, there is a lack of information on the comfort temperature of children in the country.

Comfort is not only a function of human physiology but also involves the nature of the buildings (Shove, Chappells, Lutzenhiser, & Hackett, 2008). Kwong, Adam, & Sahari, (2014) reviewed some thermal comfort studies and noted the importance of thermal comfort evaluation towards energy conservation improvement in tropical buildings and found that the present work on thermal comfort for tropical buildings is still scanty. Because of climate change and energy consumption in buildings, the design of buildings and their services extend beyond the comfort requirements of building occupants. Buildings are not seen as a function of just the physical and physiological state of the human body. Buildings are also seen as a function of the ways they are heated and ventilated, the opportunities they afford for its inhabitants to control it, the form(s) of energy inhabitants use to fit the building to their needs (Nicol & Stevenson, 2013). Nicol and Stevenson further asked the question: How can comfortable working and living conditions be maintained for the majority in such a world, especially, with the rising cost of living, corresponding to an increase in fuel poverty, with the added uncertainty of climate change?. Addressing the thermal performance of buildings may provide inputs that may guide in addressing this question.

The intending study area, Nigeria has a tropical climate with a population of about 180 million people with 43% of this population within the age range of 0 -14 years (Mundi, 2018). Most of this age range is made up of primary schoolchildren who are susceptible to a climate change-induced problems such as heat stress. As far back as 2008 there was a total of 21,294,518 enrolments of primary school pupils and 54,434 primary schools in Nigeria (Akindele, 2014). Furthermore, findings from the Universal Basic Education Rapid Response Survey showed that out of 332,408 classrooms in Nigeria only 140,134 (i.e. 42%) were in good condition. The poor conditions of the primary school infrastructure in the country, coupled with the exponential growth in the population of the primary schoolchildren have led to high demand for more classrooms. To meet up with these demands, the various stakeholders in the educational sector are calling for the upgrade of the failing infrastructure. Nigerian government addressed the issue of dilapidated and inadequate primary school buildings and decided to embark on massive renovation and construction of new ones. Many new classroom blocks are being constructed or renovated. The renovation of older bocks, that previously had no windows and doors, include the installation of windows, doors and, the addition of more blocks on them to form complete enclosure between the inside and the outside. However, in some schools, some of these older blocks are just renovated but still left in the original form with no windows and doors. There are various literature reports of classrooms that leave the users in poor thermal conditions probably because the design and the construction of such classrooms did not consider the climate of the locality.

However, providing inner spaces that are thermally acceptable to the occupants becomes a big challenge to designers because of the lack of thermal comfort guidelines applicable in the Nigerian context. According to Sangowawa et al (2016)., the building industry in Nigeria has had to rely extensively on the international guidelines, such as the British Standard Code and the American Uniform Building Code which were principally developed for use in developed western countries. Nigeria, despite being the most populous country in Africa and the seventh in the world, has neither standard energy efficiency code for buildings nor thermal comfort standards (Adebamowo & Olusanya, 2012). In the Nigerian building code currently under review, thermal comfort is reflected in the draft copy. However, only residential buildings and office buildings are being considered in the current revision.

Children in public schools (state) in Nigeria come from different socio-economic backgrounds unlike those in private schools. Their class lessons take place in naturally ventilated buildings and as such provide good settings for studying the applicability of ASHRAE adaptive comfort. It is not likely that residential spaces will be more suitable to use in determining their comfort temperature because of the limited number of occupancy and the non-diversification of the socio-economic group. The primary school buildings in use in Nigeria have different architectural characteristics, which may prop up some variables that may likely influence occupant’s thermal comfort perception for good or for bad. The architecture of a building contributes to the indoor thermal comfort of occupants and the building type influences thermal comfort (Frontczak & Wargocki, 2011). Furthermore, people transiting from one building to another one may experience variations in thermal perceptions even when such buildings are in the same geographical or climatic areas. For example, Efeoma, (2017) reported a neutral temperature of 28.8°C in a study with adults in an office setting while Okafor (2017) reported a lower neutral temperature in residential traditional buildings with adults. Both studies were conducted in the same locality, not far away from one another.

This study was justified by literature reviews and the pilot study conducted, which revealed some gaps in the literature and threw into the research field some research questions. An attempt was therefore made to address these research questions. The results obtained when compared with the findings from the previous thermal comfort studies from different parts of the world are expected to contribute to the knowledge base by providing additional information to the research community, primarily, about the thermal comfort requirements of school children from the warm and humid climate in Nigeria. Furthermore, the information may guide the policymakers in Nigeria when considering energy efficiency guidelines or appropriate temperature benchmarks in school buildings. Using air-conditioning systems to achieve thermal comfort in private schools in Nigeria is becoming popular. This use of air-conditioning systems leads to high levels of energy consumption. There is a likelihood that this tendency to air-condition classrooms may in the nearest future extend to public schools in Nigeria. In its Fourth Assessment Report in 2007, the IPCC working group identified the building sector as possessing the greatest potential for deep cuts in CO_2 emissions. For significant CO_2 reduction to be realized, it is important that sustainable buildings (both newly built and renovated) are required to meet some energy-saving benchmark. This can be achieved but not at the detriment of the comfort of building occupants. In Nigeria, there has been an increase in the demand for more buildings and infrastructural development, including primary schools. The process of running these infrastructure requires energy, and the demand for this energy is usually met by electricity.

Of recent, designers began to consider other options of providing comfort for building occupants and would require information on the thermal conditions to provide sustainable designs. Achieving thermal comfort in educational buildings is associated with specific challenges that are related to the students or the buildings (Al-Khatri, Alwetaishi, & Gadi, 2020). This information can be obtained by conducting a survey that measures the environmental parameters of a building with the involvement of the building occupants or the measurements can be taken without involving the occupants in the survey (Nicol et al., 2012). Field surveys among the acclimatized population are the ideal methods in which comfort standards can relate realistically to peoples' needs (Nicol, 2004). Furthermore, comfort models specific to an area should be developed based on the indoor and outdoor temperatures, relative humidity and clothing pattern of the region. Thus, further studies in different climates are needed to understand how people respond to thermal comfort questions (Humphreys & Hancock, 2007), and the thermal performance of the indoor spaces.

1.3 Research Aim and Objectives

This thesis aims to determine the perception of the thermal environment by primary school children (aged 7-12 years), in particular, and that of their teachers and to assess the thermal performance of the naturally ventilated primary school buildings in the warm and humid climate of Imo State, South Eastern Nigeria. To achieve the purpose of the research, the following are the specific research objectives:

(i) To examine the relationship between the thermal performance of naturally ventilated 'open-space' (with dwarf external walls) and 'enclosed-plan' (with complete external walls) classrooms, and to compare the findings with the adaptive thermal comfort model

(ii) To examine and compare the relationship between measured thermal variables and subjective comfort responses of the children in the classrooms based on adaptation, corresponding to different time periods.

(iii) To determine the thermal perception of the children, corresponding to different time periods, and to compare the findings with the prescriptions of ASHRAE Standard 55 and with previous works.

(iv) To determine the thermal perceptions of the teachers and to compare the findings with that of the schoolchildren.

(v) To recommend thermal comfort guidelines that will apply to children in the study area, considering adaptive thermal comfort.

1.4 Scope of the Research

The anticipated prolonged period of the survey will impact on time, personal and cost. To reduce the impact of these constraints, this study is limited to public primary school buildings located in the warm and humid climate zone of Imo State. ASHRAE Adaptive comfort model will primarily be adopted in this research journey to address the objectives of this thesis. Fig 1.3 presents a diagrammatic representation of the thesis scope.

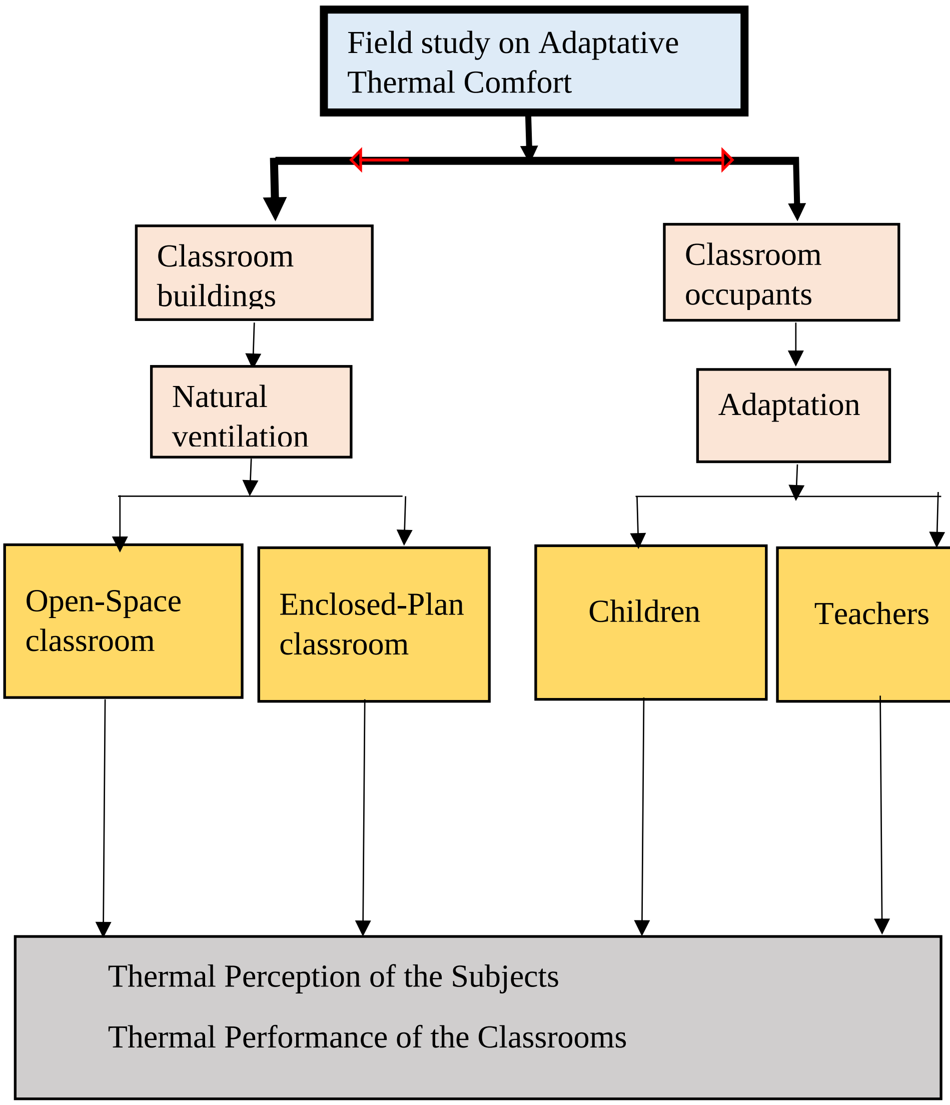

Figure 1.3: Thesis scope

1.5 Research Methodology

The main aim of this research is to determine the thermal perception of children who conduct their class lessons in naturally ventilated classrooms located in the warm and humid climate of Imo State, Nigeria. The thermal perception involves determining how they feel about the temperature changes in their classrooms. The need to carry out this work was based on information obtained from primary and secondary data. The primary data was obtained after a Post Occupancy Evaluation (POE) to rate the various components of IEQ was conducted in a school setting. The components of IEQ considered include lighting, noise, thermal comfort, and indoor air quality. To represent a typical classroom setting in the warm and humid environment, university classrooms (from Anambra state university) were used for the pilot study because ethical approval to study children was yet to be approved at the time of the study. Results from the survey showed that the classroom occupants rated thermal comfort above other IEQ components as the number one that gives them the most concern. A critical review of literature on thermal comfort with a focus on adaptive thermal comfort in naturally ventilated classrooms formed the base of the secondary data. Furthermore, feedbacks from papers presented at various conferences (based on early findings from this work) necessitated the need to also investigate the thermal perceptions of the teachers who stay in the same classrooms with the schoolchildren. The thermal comfort in the classrooms was evaluated by applying objective measurements and subjective assessment. The objective measurement involved the use of data loggers to collect the environmental parameters, while the subjective assessment involved using structured questionnaires to collect the responses of the subjects.

1.5.1 Subjective Evaluation

Field study was the research method adopted in this research. The subjective aspect of the fieldwork involved the use of questionnaires in judging the responses of the subjects to the thermal conditions they encountered during their day-to-day activity in their classrooms. The information obtained from the questionnaire is to be merged with measurements from the objective assessment in order to determine the perception of the indoor thermal environment by the participants. Thermal perception is primarily categorized as; thermal sensation, thermal preference, and comfort temperature. However, some of these variables can be categorized as objectives. The aspects of the questionnaire that will be characterized as objective are questions on gender, age group, the period of stay. Furthermore, information regarding occupants' satisfaction with their indoor thermal that will include their thermal sensation and preference will be categorized as subjective.

1.5.2 Objective Evaluation

The objective data collected were the indoor environmental parameters and the physical variables. These were achieved using data loggers with a built-in-temperature sensor with 32,000 reading capacity and with a high reading resolution program. Furthermore, conducting research that involves children requires obtaining permission to have access to them. Ethical approval was obtained from the University of Salford before the commencement of the survey (please see Appendix A). Furthermore, approvals were also obtained from the ministry of education in the state (Appendix E) this survey was conducted, and consent was also obtained from the parents of the children. Chapter four of this thesis discusses, in detail, the research methodology adopted in this study.

1.6 Research significance

Understanding thermal comfort in classrooms is important because students spend up to one-third of the day in school. The major contribution of this research work is to determine the acceptable range of indoor temperatures for the primary schoolchildren in the warm and humid climate of Nigeria, using Imo State as a case study area. This information will be an original contribution to the research community and to the policymakers in charge of providing primary school buildings in this geographical area.

Secondly, energy conservation in primary school buildings necessitates the need for this study, given the alarming rate of private schools in the study area that rely on air-conditioning systems to provide thermal comfort. Because thermal comfort is linked to energy conservation in buildings, taking advantage of adaptation in naturally ventilated buildings is a key consideration in this energy conservation. Knowledge of the thermal performance of the two types of classroom buildings (how the buildings respond to changes in temperature) found in the study area, may provide some vital information to be used in the design, construction, and operation of sustainable primary school buildings in the warm and humid environment in Nigeria.

Finally, the most recent approved draft (review still in progress) of the Nigerian National Building Code addresses the issue of thermal comfort on residential buildings and offices and did not consider school buildings and children. Moreover, the thermal comfort recommendations in this draft code are based on findings where only adults were used to determine acceptable ranges of temperature. The findings from this study may provide some useful information to the building code reviewers, regarding the thermal comfort requirements of school children.

1.7 Thesis Structure

This thesis is presented in seven chapters. These are described as follows:

Chapter one is the introduction.

Chapter two presents a literature review of thermal comfort including the historical progression of the general thermal environment. The literature review narrows down to adaptive thermal comfort and discusses extensively the previous thermal comfort studies conducted in other parts of the world that focused mainly on the tropical environments.

Chapter three presents an overview of the study area that involves the climate of Nigeria and that of Imo State. It also presents a brief history of educational growth in Nigeria, with a focus on primary schools.

Chapter four presents the research methodologies adopted in thermal comfort studies. The chapter discusses the need not to deviate much from the use of traditional approach to thermal comfort investigations.

Chapter five presents the results and the analysis of the field work.

Chapter six discusses the research findings of this study under sections 6.1 to 6.4. Sections 6.1 introduces Chapter 6, while section 6.2 addresses research objective i. Section 6.3 addresses the research objectives ii and iii. Section 6.4 addresses objective iv.

Chapter seven concludes the research work and highlights the research limitations and opportunities for future work.

2 Chapter 2: Literature review

2.1 Introduction

This chapter discusses the thermal environment and highlights the efforts of some pioneers of thermal comfort and the various suggestions proffered before researchers accepted and started adopting various thermal comfort concepts and indices that determine comfort. Furthermore, the various arguments that questioned the applicability of the current thermal comfort model (obtained from adults) on children were also discussed with various suggestions on the need for more information coming from different climatic and cultural regions. The base of the comfort discussion expands as the thermal comfort paradigm shifts from physiology setting to psychology level. The proponents of the psychological aspect of thermal comfort accommodate some other variables they think may influence peoples' perception of the thermal environment. This chapter also discusses the different methods used in determining thermal comfort, narrowing the discussion to the adaptive thermal comfort model and the justification for its adoption in this study to determine the thermal comfort perceptions of primary schoolchildren. The outdoor climate and its relationship with the indoor thermal performance of buildings are also discussed.

2.2 Definition of thermal comfort

Since ages, human beings have been adopting different strategies to achieve the desired level of thermal comfort. Different creative ways, such as behavioural adjustment, choice of clothing and the use of fireplaces, were adopted to achieve comfort. The assessment of thermal comfort is one of the oldest judgments made by man, where the prevailing weather is an acceptable opening for any polite conversation of the day (Macpherson, 1962). In later years, during the 19th century, comfort research concentrated in industrial buildings and coal mines because of health and safety issues, and on vulnerable populations such as school children and hospital patients (Nicol et al., 2012). By the end of the 19th century, significant progress was made in thermal comfort research when scientists discovered the four environmental parameters (temperature, humidity, air movement and solar radiation) and personal factors that can be assessed to determine thermal comfort. In the 1920s, the American Society of Heating and Ventilation Engineers (then called ASHVE) made efforts to define the comfort zone, and the foundation for the methodological approach to adaptive thermal comfort was laid by Dr. Thomas Bedford in 1930s and Nick Baker. Considerable progress in adaptive thermal comfort was made in the 1960s when the ‘focus of research shifted away from winter heating towards modelling the dynamic response of buildings in summertime, where highly glazed buildings were overheating on sunny days and during heating waves’ (Humphreys, Nicol, & Roaf, 2015). Some of the pioneer researchers who did extensive research work on adaptive thermal comfort in this regard are; Professor Fergus Nicol, Charles Webb, Edward Danter and Professor Michael Humphreys. Other notable researchers were Gagge, Givoni, Professor Ole Fanger, Don McIntyre and Griffits. Thermal comfort is defined by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) as the ‘condition of mind that expresses satisfaction with the thermal environment’ (ANSI/ASHRAE Standard 55-2013, 2013). ASHRAE’s definition of thermal comfort is about a person’s psychological condition of mind, whether the person feels neither ‘too hot nor too cold’ or thermally neutral provided that the person is healthy and wears a normal amount of clothing at the time of assessment. The latest version of the ASHRAE Standard updated the definition of thermal comfort by including the word ‘subjectivity’ in the definition. This psychological component in the definition is difficult to assess and to understand.

Prior to the acceptance of this definition by the research community made up of architects, engineers, quantity surveyors and others in the building industry, this definition by ASHRAE was placed under scrutiny by some members of the research community. For instance, it was the opinion of (Olesen & Brager, 2004) that thermal comfort was a subjective response, or state of mind, where a person expresses satisfaction with his environment. Heijs, (1994) argued from a psychological point of view that ‘condition of mind could be the result of either a perceptual process, or a state of knowledge or cognition, or a general feeling or attitude, and could take many different forms such as a feeling of well-being, or in a pattern of behaviour or clothing’. Furthermore, Heijs submitted that if comfort is a subjective mental state, it will be indefinable because it cannot be measured objectively and therefore suggests that thermal comfort should be considered ‘an environmental property, determining the satisfaction of thermal needs both physiologically and psychologically’. Meyer, (1993), on the other hand, questioned the meaning of ‘satisfaction within the thermal environment’ asking whether it is an objective criterion. Also, (Givoni, 1981) defined thermal comfort as the absence of irritations and discomfort due to heat or cold, or in a positive sense, as a state involving pleasantness. McIntyre (1980) defined thermal comfort as the absence of thermal discomfort, that is to say, an individual feels neither too warm nor too cold. From the foregoing discussions, a good thermal environment can be summarized as one where occupants carry out activities without feeling too cold or too hot.

The keywords in the various opinions of the researchers about thermal comfort are 'satisfaction', 'cold', 'warm' and 'discomfort'. These words form the basic terminologies associated with the PMV (Predicted Mean Votes), an index, discovered by Fanger used in determining thermal comfort. Fanger devised a Predicted Mean Votes (PMV) index, and the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE), earlier called 'ASHVE', provided various thermal comfort standards when four environmental parameters (temperature, humidity, air movement and solar radiation) were acknowledged as factors that determine thermal comfort (Humphreys, 2016). There have been updates in the comfort standards based on later findings from various researches. The current update in the ASHRAE standard is ASHRAE standard 55-2017.

Various research works conducted by people such as Huizenga, Abbaszadeh, Zagreus, & Arens (2006) Mohamed (2009); Arif, Katafygiotou, Mazroei, Kaushik, & Elsarrag (2016); Munonye & Ji, (2017) confirmed, from their separate studies, that thermal comfort consistently came as the number one complaint by building occupants over other indoor environmental attributes namely; air cleanliness, odour, and noise especially in the tropics. For one to be thermally comfortable, the excess heat in the human body produced by metabolism must be transferred into the surrounding for the body core temperature to be kept constant. Thermal comfort is related to the energy balance between metabolic rate and heat loss from the human body. A person must keep his core body temperature constant and therefore, to be able to transfer the excess heat produced by the metabolism into the surrounding. The heat loss is demonstrated by three types; radiation (45%), convention (35%) and evaporation (20%) (Baker & Steemers, 2003). Pandolf, Givoni, & Goldman, (1976) pointed out the heat transfer between a human body and the environment as shown in Equation 2.1.

$$M \pm R \pm C - E = Q \qquad (2.1)$$

Where,

M *is the metabolic rate*

R *is the radioactive heat loss from the clothed body*

C *is the convective heat loss from the clothed body*

E *is the evaporative heat*

Q *is the heat content of the body*

This heat transfer differs from one individual to another; thus the temperature acceptability varies among individuals, even when exposed to the same indoor environmental conditions. This is because of the differences in age, health status, type of clothing worn, rate of activity and how the person acclimatizes to the environment. Thus, it will be difficult to establish a condition or standard that will satisfy everyone because of these differences. In order words, it is not possible to specify the environments known to be acceptable by all the building occupants. Because of this unlikeliness to satisfy 100% of the people at the same time in the same indoor space, ASHRAE Standard 55 suggested that an indoor environment can be deemed acceptable when 80% or more of the occupants accept the indoor thermal conditions (ASHRAE, 2017). Furthermore, this international standard recommends that the most acceptable method to define thermal comfort conditions of a group of subjects is to carry out the subjective and objective evaluation, by recording the subjects' thermal feelings, preferences, physical and personal comfort variables and statistically relate them to arrive at some quantity which will be acceptable, at least 80% of the sample size. The International Standard Organization (ISO) 7730 recommends that the Percentage of People Dissatisfied (PPD) in a given indoor environment should be lower than 20%, i.e. Predicted Mean Votes (PMV) of the space users should be within the range -1 to +1 for the environment to be considered comfortable (Iso, 2005). Two popular models thermal comfort researchers adopt to evaluate the thermal comfort of building occupants (discussed in sections 2.7.1 and 2.7.2) are the heat balance model and the adaptive model (that considers adaptation).

Apart from using thermal comfort to evaluate the thermal conditions of building occupants, it can also be used to determine the performance of a building and its energy-saving potentials. Therefore, exploring buildings' thermal behaviour is necessary; to predict occupants' comfort, to identify energy consumption, and to examine alternate enhancements for achieving better indoor thermal environments and energy-efficient buildings (Elaiab, 2014). It is important to assess the thermal comfort of buildings because it guides the design of enclosed spaces and one becomes aware when our environment is too cold or hot for human habitation (Raw & Oseland, 1994).

In the south-eastern part of Nigeria (the study area of this work) all the public primary school buildings are naturally ventilated with few of them additionally ventilated with fans. There still exists in some of these public primary schools the old pattern classrooms (‘open space’) which is gradually being phased out in preference for the conventional classroom structure (referred to in this paper as ‘enclosed plan’ classrooms). It will be interesting to understand the thermal conditions and the perception of thermal comfort in these types of classrooms because of the differences in their architectural characteristics and construction methods. Typical examples of these two types of classroom buildings are shown in Appendix I. The thermal conditions in an indoor space is one of the study areas researchers worldwide are very interested in because most people spend more of their time indoors than outdoors. It is important to observe that at present the Nigerian building code does not have any reflection of thermal comfort. This allows for the design of primary school buildings that do not consider the thermal comfort requirements of the occupants. However, research works from different building types are going on to recommend acceptable temperatures of different age groups in different building types in Nigeria.

2.3 Thermal indices

A thermal index is a measure that aims to arrange thermal environments according to how warm they feel (Humphreys et al., 2007). Thermal comfort index describes the thermal environment and its effects on the subjects being evaluated, and it is represented as a single value. Notable researchers such as Bedford (1936), Fanger (1970), A Pharo Gagge, Fobelets, & Berglund (1986), Olgyay (2015), Yaglou & Minard (1957) developed various thermal comfort indices. Most of these indices have ceased to be used to assess ordinary indoor conditions, however still in use are the air temperature and the operative temperature, (Humphreys et al., 2007).

Standard Effective Temperature (SET) and the Predicted Mean Votes (PMV) are usually called the rational indices, obtained from the heat exchange between the human body and the environment in a controlled chamber experiment. The term ‘rationale’ is used to differentiate them from other indices derived empirically from statistical multivariate analysis of data obtained from fieldwork.

2.3.1 Effective temperature (ET)

The Effective Temperature (ET) is defined as the temperature of a still, saturated atmosphere, which would, in the absence of radiation, produce the same effect as the atmosphere in question. This thermal scale developed by Houghton & Yaglou was originally used to provide a method of determining the relative effects of air temperature and humidity on comfort (Blazejczyk, Epstein, Jendritzky, Staiger, & Tinz, 2012). In this index, the effect of temperature, humidity and air movement are combined into a single value on the sensation of warmth or cold felt by the human body. The temperature of the still, saturated air, that can induce the sensation of warmth or cold that experienced in the given condition is the numerical value of effective temperature. For example, if the environment has an ET of 29^{o}C, it implies that the subjective sensation will be the same as the saturated atmosphere of 29^{o}C with no air movement. However, this index does not consider the effect of radiation from the surrounding structures. One problem with ET was that it did not consider radiation when evaluating thermal comfort. ET* replaced Yaglou's original effective temperature (ET).

2.3.2 Standard effective temperature (SET*)

SET* is the temperature of an isothermal environment (air and mean radiant temperature equal to each other, relative humidity of 50%, and air velocity of 0.1 m/s) in which a sedentary person with standard clothing would have the same heat loss (at the same skin temperature and skin wittedness) that the same person would have in an actual environment.

2.3.3 PMV-PPD indices

The Predicted Mean Vote (PMV) and the Predicted People Dissatisfied (PPD) are index established by Fanger. Both are single evaluation tools that are expressed in two different ways. ASHRAE PMV thermal scale of ideal acceptability ranges between -0.5 to +0.5, while ISO Standard of acceptability ranges from cold (-1) to hot (+3) where only 10% are dissatisfied. When an acceptable thermal environment has a PMV value in the range of -0.85 and +0.85, less than 20% of the occupants are dissatisfied (Fanger, 1970). To date, PMV as a building environment evaluation index, has been adopted by international standards such as ISO 7730, ASHRAE Standard 55 and CEN 15251. This index is further discussed in section 2.5.

2.3.4 **The use of Operative temperature (Top)**

Thermal comfort is affected by human factors and indoor parameters. The indoor parameters are air temperature, mean radiant temperature, relative humidity and air velocity. The local climate and building envelope have influence on the effect of these variables on thermal comfort of building occupants. Globe temperature can be used to estimate the mean radiant temperature using equation provided in ASHRAE Handbook Fundamentals reproduced in equation 2.2. Nicol et al (2012) suggested that because of cost, the measurement of globe temperature can be simplified using a black globe thermometer.

$$\bar{T}_r = \left[(T_g + 273)^4 + \frac{1.1\times10^8\, v^{0.6}}{\varepsilon D^{0.4}}(T_g - T_a)\right]^{\frac{1}{4}} - 273$$

where:

$\bar{T}_r$ = mean radiant temperature, °C

$\mathcal{E}$ = emissivity (surface emissivity constant = 0.95 for black globe)

D = globe diameter, m

T_a = air temperature, °C

T_g = globe temperature, °C

v = air speed, m s^{-1} **(2.2)**

The operative temperature can be calculated as the average air temperature and mean radiant temperature for a given space in a room (ASHRAE, 2013), with air temperature usually measured with dataloggers. ASHRAE standard 55 permits the use of equation 2.3 to calculate operative temperature provided that the occupants are involved in sedentary activities with metabolic rates in the range between 1.0 and 1.3 met, are not exposed to direct sunlight and the airspeed is not more than 0.2m/s.

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

where:

T_{op} = operative temperature

T_r= mean radiant temperature

T_a = air temperature **(2.3)**

The standard also allows the use average of air temperature in place of operative temperature when the following conditions are met in a given room.

- there is no radiant panel cooling or radiant panel heating system in place
- the area-weighted average U-value of the outside wall or window satisfies the following inequalities in equation 2.4:

$$U_w < 50/\,(t_{d,i} - t_{d,e}) \qquad (2.4)$$

Where,

U_w is the average U-value of the wall or window, W/m2. K

$t_{d,i}$ is the internal design temperature, ^oC

$t_{d,e}$ is the external design temperature, ^oC

(the coefficients of the window solar heat gain are less than 0.48).

2.3.4.1 Previous Studies

In the opinion of Humphreys et al (2007), the air temperature and the operative temperature differ little, so either is usually an adequate measure of the temperature-component of the thermal environment. This is mostly applicable in well-insulated buildings where direct radiation from the sun or other high-temperature radiant sources are away from such buildings. Both ASHRAE 55 and the CEN 15251 Standards use operative temperature to express comfort temperature (Nicol et al., 2012). Nicol et al (p. 92) further posited that in indoor spaces away from direct radiation from the sun or high-temperature radiant sources the difference between the air and the mean radiant temperature, and hence between the air, the globe, and the operative temperature, is small.' Furthermore, some modern data loggers that record air temperature is comparable in size to a 40 mm globe thermometer and may record a temperature that is close to the globe temperature (Nicol et al, 2012). According to Kazkaz & Pavlek (2013), it is possible to say that the globe temperature is equal to the operative temperature depending on the prevailing air velocity. Shajahan & Ahmed (2016) in a study aimed at evaluating the thermal comfort perception of the occupants in naturally ventilated residential houses located in Bangladesh assumed the mean radiant temperature to equal the globe temperature having found airspeed during the field survey to be 0.008m/s. The author adopted operative temperature as an index to determine the thermal comfort perception of the building occupants. Haddad (2016) during a field study conducted in Iranian primary school classrooms to evaluate the comfort temperature of the students found the air temperature equalling the operative temperature (mean values of 23.6^{o}C each).

Some other research works also used different approaches to determine the comfort temperature of building occupants. Abreu-Hardbich et al (2012) carried out a field experiment aimed at improving thermal comfort in naturally ventilated classroom buildings in Brazil. The construction features of the buildings were of reinforced concrete structure. The author adopted the indoor air temperature for analysis having assumed air temperature to be equal to mean radiant temperature. Part of the reasons given for the assumption was that 'the southern façade is adjacent to many trees that reduced the wind speed (to 0.10m/s), and provided shade throughout the day'. Other reasons given by the author were that the occupants engaged in near-sedentary physical activity (sitting) and had a metabolic rate of 70w/m2 with clothing insulation of 0.44clo at the time of the survey. Yao et al (2010) conducted a field experiment aimed at determining occupants' adaptive responses and perception of thermal environment in naturally ventilated university classrooms in Chongqing China. The author measured the indoor air temperature instead of globe temperature. The author observed that the difference between air temperature and globe temperature varied significantly during the pre-test. Arsandrie et al (2012) conducted a study aimed at finding the level of thermal comfort accepted by people from the low-income group in Surakarta Indonesia, a region that experiences a hot-humid climate. The data collection approach adopted was a momentary measurement of globe temperature used to estimate mean radiant temperature and continuous measurement of air temperature and relative humidity. Wong & Khoo (2003) adopted spot measurements of the globe temperature, air temperature, relative humidity, and air velocity to collect objective data in a study conducted in classrooms in Singapore. The equipment used to collect globe temperature was left to run about 3 minutes after which the maximum, minimum, and mean values of globe temperature were collected. Berquist et al (2019) conducted a field study to evaluate the environmental quality and perceived occupant comfort. The indoor thermal variables measured were the air temperature, relative humidity, and carbon dioxide concentration. Furthermore, James & Christian (2012) conducted a field survey to determine the comfort temperature of students and teachers in a school building in Medina, Accra. Hobo sensors were used to measure two environmental parameters (air temperature and relative humidity). These two environmental parameters were adopted in data analysis. Also, Treblicock et al (2014) carried out a field experiment on thermal comfort in school buildings in Chile aimed at determining the comfort temperature of students in state-owned primary schools. Dry bulb temperature, globe temperature, relative humidity, and air velocity were measured during the fieldwork. The researcher adopted dry bulb temperatures obtained during the fieldwork in determining thermal sensation and neutral temperature of the subjects but did not provide a reason for adopting only dry-bulb temperature for the analysis. Aghniaey et al (2019) investigated occupants' thermal sensation, acceptability, and preference in a university campus in USA. Indoor environmental parameters were collected. The globe temperature was collected once in the beginning of the survey and once at the end of the survey. Efeoma (2016) adopted operative temperature as an index to evaluate the thermal comfort of office workers in southeast Nigeria having observed that the thermal transmittance (u-value) of the outside walls satisfied the inequality provided in equation 2.4, while Kaja & Srikonda (2019) also adopted operative temperature as an index having equally observed the u-value of the outside walls adopted in naturally ventilated classrooms in India satisfied the same inequality.

2.4 Perception of thermal comfort

Researchers adopt different methods to determine the thermal comfort of building occupants. Some use thermal sensation and neutrality. Some others use thermal acceptability and thermal preference, while in some cases, some adopt the whole metrics.

2.4.1 Thermal sensation and neutral temperature

Thermal sensation and thermal neutrality are some of the conventional methods researchers use to determine what occupants feel is a comfortable indoor environment (Zhang, Wang, Chen, Zhang, & Meng, 2010; Kwong et al., 2014). Thermal sensation is a psychological dimension of thermal comfort and expresses the feeling warmth or cold. The sensation of acclimatized populations in any geographical area is found to be within the neutral point in the ASHRAE 7-point thermal sensation scale. Linear regression analysis of the operative temperature against the mean thermal sensation votes is one recognized method of predicting the subjects comfort temperature (de Dear et al., 2015; de Dear & Brager, 1998). The regression produces a model equation. Where the intersection of the model line with the zero scale of the Y-axis reads a temperature value on the X-axis, the value represents the predicted neutral temperature of the model. Neutral temperature can also be predicted from the model equation by substituting the value of TSV (Y) = 0 as represented in Equation 2.5.

$$TSV = aT_{op} + b \qquad (2.5)$$

Where,

TSV *is the mean thermal sensation*

a *represents the gradient or coefficient*

$\boldsymbol{T_{OP}}$ *represents the operative temperature*

b *represents the value at the intersection*

The neutral temperature or optimum temperature which corresponds to thermal sensation (*TSV*) value 0 indicates total approval of indoor temperature. In order words, the occupants feel thermally satisfied having indicated feeling neither cold nor warm. According to Nicol & Humphreys (2002), the neutral or comfort temperature is the temperature defined as the 'operative temperature at which the average person will be thermally neutral'.

The Adaptive model in EN 15251 or ASHRAE Standard 2017 can be used to determine the neutrality of occupants of a building. The adaptive model in EN 15251 adopted the exponentially weighted running mean temperature, while the adaptive model in ASHRAE standard adopted mean monthly outdoor temperature while determining comfort temperature. These are further discussed in the subsequent section.

Relationship between neutral temperature (Tn) mean indoor temperature (To): According to the adaptive principle, people often resort to behavioural adaptations, such as clothing change, posture adjustment, etc, to fit into local conditions they find themselves and so become comfortable at the temperatures in that environment. According to Humphreys et al., (2015), this process of adaptation tends to make their neutral temperature close to the mean temperature they experience. The mean warmth sensation of a group of people was usually close to thermal neutrality and marginally warmer than neutral, and the populations worldwide were quite well adapted to be comfortable in their thermal environments whether the temperature as low as 17^{o}C or as high as 34^{o}C (Humphreys et al., 2007).

Relationships can be established between neutral temperature and the indoor temperature. Humphreys & MA, (1976) showed a strong relationship between the mean indoor operative temperature indoor operative temperature (T_{OP}) and neutral temperature (Tn). The simple regression is represented in Equation 2.6.

$$T_n = 0.831 T_{op} + 2.6 \qquad (2.6)$$

Auliciems & De Dear (1986) developed another equation that expressed comfort as a function of mean indoor air temperature. The equation is represented in Equation 2.7

$$T_n = 0.73T_{op} + 5.41 \qquad (2.7)$$

The more adaptation is complete, the higher the correlation coefficient. However, several factors can make adaptation weak. If the survey is short, and the room temperature varies from day to day, people are unlikely to adapt completely to day to day changes. Furthermore, where occupants are not free to change their clothing, due to social customs, adaptation becomes difficult Humphreys et al., (2015).

Relationship between neutral temperature (Tn) and mean outdoor temperature (To): Figure 2.1 compares the relationship between the outdoor temperature and the comfort temperature in free-running and air-conditioned buildings. A look at the fitted lines shows that the two ventilation types depict different relationships with the outdoor temperature. The fitted lines in naturally ventilated classrooms show linearity with the outdoor temperature, while that of the airconditioned buildings do not.

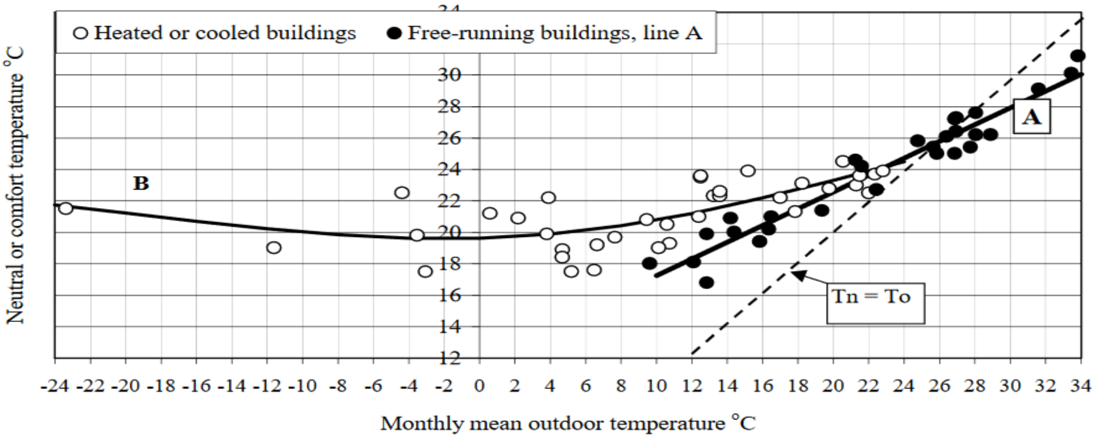

Figure 2.1: The change in comfort temperature with monthly mean outdoor temperature (Source: Humphreys, 1978)

This strong relationship between the temperature observed to be comfortable indoors and the prevailing outdoor temperature in free-running buildings is further illustrated in Figure 2.2. The temperatures used in the analysis are from the meta-analysis plotted against the prevailing outdoor temperature. Each of the points, in the Figure, represents a separate survey or block of data within a larger survey. The indoor comfort temperatures on the figure lie anywhere within the band. Furthermore, the comfort of the building occupant can further be enhanced by achieving good climate design that considers the option of opening and closing windows

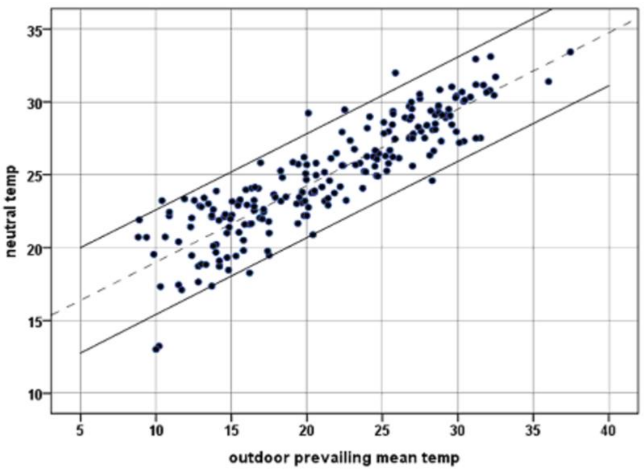

Figure 2.2: Relationship between the indoor comfort temperature and the prevailing mean outdoor temperature in naturally ventilated buildings from a database of summary statistics.
(Source: Humphreys, Rijal, & Nicol, 2013)

Furthermore, a relationship can be established between neutral temperature and mean outdoor temperature. The regression equation for free-running buildings according to Humphreys' research is:

$$T_n = 11.9 + 0.534\, T_{op} \qquad (2.8)$$

Where Tn is the neutral temperature and T_{OP} is the operative temperature

Auliciems & De Dear (1986) proposed another equation for this relationship:

$$T_n = 17.3 + 0.36\, T_{op} \qquad (2.9)$$

Many other thermal comfort researchers have established numerous relationships between neutral temperature and the indoor temperature or outdoor that apply to their various localities and often compare their findings with the above equations. Their models are often compared with the models expressed in Equations 2.8 and 2.9.

2.4.2 **Thermal acceptability**

Thermal acceptability can also be used with the assumption that acceptability is equal with 'comfort'. According to Bordass & Leaman (1997), there is a tendency for building occupants to 'forgive' and overlook the shortcomings in the thermal environment (especially) when the occupants have more access to building controls. It is possible when people are not in their ideal state of comfort, they may still find it is tolerable or not bad enough to complain. According to ASHRAE (2017), an acceptable thermal environment should have 80% of occupants vote for the central three categories (vote = -1, 0, +1). Using this assumption as a base, some researchers consider this by using various methods to determine the thermal conditions of building occupants. A typical example is Kwok et al., (1998) who adopted four methods to assess the thermal conditions of primary school children in Hawaii, a tropical country. In the first method, a direct acceptability question, 'are the conditions in this classroom acceptable to you right now', was adopted. Also used was the indirect acceptability that assumed the voting on the middle three categories by the respondents as indicating acceptance to thermal conditions. The third method compared the physical conditions of the classrooms and the environmental prescription of standard 55, while the fourth method used the votes of general comfort questions where the assumption of acceptability included a response of 'slightly comfortable' on the general scale.

2.4.3 Thermal Preference

Researchers also use thermal preference to determine thermal comfort (Huizenga et al., 2006); Arens, Turner, Zhang, & Paliaga, 2009; de Dear, 2011). Thermal preference is a closer measure of what ideal conditions would be. Most thermal comfort research works came out with findings that people living in tropical climates prefer temperature lower than their neutral temperature.

2.5 Thermal comfort standards

Some international organizations set the minimum standards used to determine thermal conditions in a built environment. Standardization is the process of taking approaches and creating a common set of rules about ways of perceiving, describing and behaving. Standards structures the world, provides social order, and focus actions and could be crucial in defining comfort temperatures and to tackle climate change. These main international bodies put in place regarding the determination of indoor environmental conditions are International Standard Organisation (ISO) 7730:2005; Comite´ Europe´en de Normalisation CEN) 1525:2007, and ASHRAE 55 (ASHRAE, 2017).

2.5.1 European Standard ISO 7730

International Standard Organisation regulates and standardizes thermal comfort guidelines, using PMV and PPD indices and local thermal comfort criteria relating to specific issues about discomfort such as 'draught risk'. The comfort zone of PMV is defined as $-0.5 \leq PMV \leq +0.5$. This comfort zone is valid in both summer and winter. ISO considers mechanically conditioned buildings in its application. Complaints about discomfort caused by draughts are common in mechanically conditioned buildings. However, in fieldwork most people prefer more air movement Zhang et al., (2010) in naturally ventilated buildings and there are fewer complaints of draught risk.

2.5.2 EN/CEN Standard EN15251

The European Committee for Standardisation (Comite´ Europe´en de Normalisation – CEN– CEN/EN 15251 addresses indoor air quality, thermal environment, lighting, and acoustics. This standard apart from adopting PMV and PPD in its thermal comfort assessment also contains the adaptive comfort component. The standard considers the free-running buildings in its application.

2.5.3 ASHRAE Standard 55

ASHRAE Standard 55-2017: Thermal Environmental Conditions for Human Occupancy. To assess the thermal comfort conditions of a group of people, researchers use models to determine a neutral or optimal thermal condition considering the six factors affecting thermal comfort as discussed in the subsequent section. This standard uses the PMV index to define acceptable internal environments. It also contains the adaptive component. These two measures of determining occupant's comfort are widely adopted in various academic researchers works. This model is suitable for use in naturally ventilated buildings. ASHRAE standard 55 is further discussed under section 2.7 of this work.

2.6 Thermal comfort parameters

To have an acceptable thermal environment, a majority of the occupants in a building (80% or more) need to feel thermally comfortable (ASHRAE, 2017). Two main factors that influence thermal comfort are environmental and personal. The main environmental factors are; air temperature, mean radiant temperature, air velocity, and relative humidity while the main personal factors consist of clothing insulation value and metabolic rate (Fanger, 1970 Szokolay, 2008; Parsons, 2014).

2.6.1 Environmental Factors

Air temperature: is 'the temperature of the air surrounding the person' (ASHRAE, 2017). Air temperature is the most commonly used indicator of thermal comfort and is considered the most important factor determining heat stress. Results from many researchers indicate the relationship between air temperature, indoor thermal comfort, and productivity. A thermometer that should not be affected by any radiant heat is usually the best instrument for measuring air temperature (CIBSE, 2006).

Mean Radiant Temperature: (MTR) is defined as 'the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation as in the actual non-uniform environment' (ASHRAE, 2017). MRT can be obtained by using the plane radiant temperature or by measurement using a globe thermometer. Thermal radiation is the heat that radiates from a warm object. The sun, furnaces, cookers, dryers, hot surfaces and machinery, molten metals are some of the radiant heat sources. The exchange of heat between the human body and the environment is done by radiation conduction and convention. Equation 2.10 can be used to calculate the mean radiant temperature.

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

where:

T_{op} = operative temperature

T_r= mean radiant temperature

T_a = air temperature

(Figure 2.10)

Air speed: is defined as 'the average of the instantaneous air velocity over an interval of time' (ASHRAE, 2017). Air movement plays an important role in the comfort of a building occupant by causing the feeling of freshness. This is achieved by increasing the rate of evaporation in a human body, especially at high humidity where evaporative cooling is the main source of heat loss from the body. Wind, therefore, reduces the adverse effects of thermal discomfort caused by high temperature and humidity. However, high air movement in a cool or cold environment may be perceived as draught, if the air temperature is less than skin temperature, it will significantly increase convective heat loss. While in winter high air movement may be viewed as unwelcome by building occupants, the opposite is the case in summer especially when the indoor temperature becomes unbearable.

Results from many researchers have indicated the importance of air movement in an indoor environment, especially in the tropics. According to Zhang et al., (2017), inadequate ventilation is probably the most important reason for occupant discomfort in naturally ventilated buildings. (Mishra & Ramgopal, 2013) reviewed field studies on thermal comfort and reported that in very few cases where a great number of occupants voted in the zone of discomfort in naturally ventilated buildings, this was attributed to low air pressure recorded. Both the field measurements and the subjective investigation showed that the indoor air velocity might be a big problem in naturally ventilated classrooms, especially where there are inadequate openings. Fieldwork by Zhang et al., (2007) indicated that while only 46.1% of the respondents in classrooms felt the air velocity was just right (okay), 53.5% perceived the air too steady. A very low percentage of 0.5% felt the velocity should be less indicating a large majority would prefer more air.

Various researchers argued from their field works the need to increase airspeed above the one recommended by ASHRAE 55 and ISO 7730. Humphreys & Nicol (2002) argued that subjects could be comfortable at temperatures up to or even exceeding 30^{o}C, in hot climates, especially if fans are used to increase indoor air. In separate studies carried out by Zhai, Arens, Elsworth, & Zhang (2017) and Cândido, de Dear, & Lamberts (2011) both observed that more people view air movement as positive in offices and in classrooms. Children requested slightly more air movement in the study conducted by Wigö (2013) in a school in Sweden during the spring and autumn when they were subjected to air velocity at irregular intervals. Schiavon, Yang, Donner, Chang, & Nazaroff (2017) assessed the thermal comfort conditions of Singaporean office workers in a tropical setting and observed that the occupants felt more thermally comfortable at the temperature of 26^{o}C with the aid of fan than at 23^{o}C when fan was not used. Some other researchers also supported the extension of the width of the comfort zone with increased air movement (Zhang et al., 2007). Arens et al. (2009) supports an increase in air velocity for thermal sensations from 0.7-1.5. Cândido et al., (2010) is of the opinion that the limit for a neutral-to-warm conditions be relaxed when the temperature is above 26^{o}C. Zhai et al. (2015) confirmed that the air movement highly improves thermal comfort at 30^{o}C.

Furthermore, fieldwork carried out on naturally ventilated residential buildings in Jos Nigeria by Ogbonna & Harris (2008) gave a low coefficient between air velocity and actual votes by occupants. The researcher attributed the likely cause to the low sensitivity of occupants to air velocity. McIntyre (1978) suggests that overall comfort deteriorates when the temperature reaches 30^{o}C even when airspeed is as high as 2m/s. However, Zhai et al., (2015) argue that at that temperature (30^{o}C) subjective thermal sensation remains in the neutral zone and with a fan it could be comparable to the thermal conditions of the subjects without fans at 26^{o}C. Building bioclimatic chart adopted by Givoni (1998) reports that the upper- temperature boundary could be up to 3K more in a little breeze condition with air speed of 2m/s compared with the still air condition with an airspeed less than 0.25m/s. This means that the rising of air velocity can extend people's comfort zone.

Having observed the importance of increased air velocities to thermal comfort especially at high temperatures, researchers, such as (Zhang et al., 2007), went further to suggest recognizing an increase in air velocity as one of the actions to enhance thermal comfort. The airspeed limit was extended to 0.8m/s (160fps) by ASHRAE for operative above 25.5^{o}C (77.9^{o}F) in all types of buildings (Cândido et al., 2011). Further research based on numerous reports from fieldwork, convinced ASHRAE to vary the airspeed from 0.2m/s to 1.2m/s, and for higher activity levels over 1.3met there is no limit (Nicol et al., 2012). Elevations allowed in comfort limits are 1.2^{o}C, 1.8^{o}C, and 2.2^{o}C for airspeeds of 0.6m /s, 0.9m /s, 1.2m /s respectively (Mishra & Ramgopal, 2015). This limit for airspeed level is based on the operative temperature and also on the difference between the mean radiant temperature and air temperature, and this limit of air speed level is based on the operative temperature (Toftum, Zhou, & Melikov, 2000). With the building occupant not having control over their environment, the limit goes back to Fanger's laboratory-based limits for draft in which the air velocity value must not exceed 0.2m/s.

Also, some thermal comfort researchers have advocated for the allowance of higher air movement in buildings that have no individual control. For example, Cândido et al., (2010) posited that it is important to investigate other sources of effects of air movement in actual buildings, with or without individual control. Candido argued that air movement limits imposed by current standards come out with inherent energy penalties and may not be providing occupants with the indoor environment they prefer. However, the low range of air movement specified was recently removed from ANSI/ASHRAE 55 (Schiavon et al., 2017). The new ASHRAE comfort standard 55-2017 specifies an extension of summer comfort zone with elevated air movement up to 0.8m/s (without personal control) and 1.2m/s (with personal control) (Zhai et al., 2015). However, when the air movement in a room is so slight, it will be unnecessary to include air speed in thermal comfort assessment since natural convention prevails at the clothed surface of the body. (Humphreys et al., 2007).

Clearly, a specific airspeed has many possible physiological and subjective effects that range from a pleasant sense of coolness to an unpleasant sense of draft, depending on the condition of the indoor climate variables and the occupants' individual factors (Candido & Dear, 2012). However, designers of buildings located in the tropics should take advantage of the recent suggestion in ASHRAE standard, for higher air velocity consideration in the warmer climates, to produce sustainable designs that rely on the infiltration of more air into naturally ventilated buildings. Apart from the ultimate benefit of providing buildings that contribute a reduction of greenhouse gas emission and cheaper to maintain, it could also provide what Jørn Toftum, (2004) refers to as indoor environments that are stimulating and pleasurable to the occupants.

Apart from the evidence of the benefit of increased air velocity to enhance thermal comfort, there are also reports that link it to better health and academic performance. The study conducted by Bakó-Biró, Kochhar, Clements-Croome, Awbi, & Williams (2007) found a positive relationship between increased ventilation rates and higher alertness, better work mood, the tendency for less tiredness and increased attention among pupils in schools.

Relative humidity: is defined by ASHRAE (2017), as 'the ratio of the partial pressure of the water vapor in the air to the saturation pressure of water vapor at the same temperature and the same total pressure'. It is the quantity of water vapour a unit volume of air holds at any given time. This could be classified in varying expressions like dew point temperature, humidity ratio and relative humidity (Djamila, Chu, & Kumaresan, 2014). When water is heated and it evaporates into the surrounding environment, the resultant water in the air is the humidity. A highly humidified environment has a lot of water vapour in the air, impairing the evaporation of sweat from the skin. High relative humidity can inhibit effective evaporative cooling by loss of moisture through the skin which leads to uncomfortable 'sticky' feeling characteristics to hot and humid climates.

Various researchers have indicated the relationship between relative humidity and thermal comfort of occupants of a space. Rajasekar & Ramachandraiah (2010) and Indraganti (2010) in their separate studies on apartment blocks posit that adding humidity in correlations between thermal sensation and indoor temperature changes their predictive power very little. Appah-Dankyi & Koranteng, (2012) argued further that a high relative humidity has no significant psychological or physiological influence in human response. According to Aljawabra (2014) under steady-state conditions and moderate air temperature (15-25°C) in temperate climates, the average relative humidity has little impact on thermal sensation. de Dear et al., (1991) evaluated the preferred temperature of two subjects with different clothing values and reported that there are no significant differences when the RH was set at 70 and 55%. Mallick (1996) earlier posited that there are instances where people have reported to be comfortable in a humidity above 95%. Givon, (2006) related acclimatization as one of the reasons why humidity does not affect the thermal sensation of some people. Junjie, Ling, Cunen, & Qinglin (2011) suggested that people in locations that experience high humid conditions regularly are better acclimatized to such humidity levels. The various research results may have been the reason why less emphasis is paid on Relative humidity when determining occupants' comfort, as reported by Liang, Lin, & Hwang (2012) that there is no limit in humidity required when the adaptive model developed in the ASHRAE Standard 55 is used.

However, Nicol (2004) reported that an elevated humidity of more than 75% has the tendency to reduce the comfort range and lowers temperature occupants feel comfortable. A higher relative humidity (RH) levels (more than 60%) can encourage the growth of mould and mildew. For some people, low relative humidity (RH) may aggravate allergies and can also lead to increased survival of some viruses and according to Indraganti (2010) low humidity can cause health-related issues. In EN ISO 7730, a humidity range of 30-70% is recommended for indoors (Olesen & Parsons, 2002).

2.6.2 Personal Factors

Clothing insulation: is defined as 'the resistance to sensible heat transfer provided by a clothing ensemble' (ASHRAE, 2017). In order words, clothing insulation is the thermal insulation provided by the clothing worn by a person. This clothing insulation reduces the transfer of heat energy between two objects of different temperatures. Usually, a hot object that comes into contact with a cold object will lose heat to the cold object, as there is always a natural tendency for thermal equilibrium. Insulation greatly reduces the effects of this heat transfer, and does not create heat; instead, it traps pre-existing levels of heat to prevent its loss. However, many layers of clothing when worn in a warm or hot environment may cause heat stress. Less clothing when worn during cold periods may cause frost bite or hypothermia, and this is common in cold countries especially during winter.

Clothing insulation can be described in terms of its Clo value, where 1Clo = 0.155 m^2 °C/W Clo=0 corresponds to a naked person whereas Clo=1. An overall insulation or Clo-value can be calculated by simply taking the Clo value for each garment worn by a person and adding them together. The mean surface area of the human body is approximately 1.8m^2. 0.02 Clo to m^2k/w = 0.155×0.02 (0.003 m^2k/w). Clothing is an important adaptive action to temperature variabilities. One may add extra layers of clothing when feeling cold or remove the extra layers when feeling warm or hot. However, this adaptive tendency is reported to be restricted in some offices or schools where the dress code is enforced.

When clothing is restricted by dress code (in some offices), by uniforms (in some schools), or by religious norms, adaptation is hindered and may provide thermal discomfort to such occupants. When people dress according to the weather, it is likely to extend their comfort range. However, Mishra & Ramgopal (2013) clothing adaptation is often seen reaching the point we would like to term as 'adaptive saturation' and this situation is mostly observed in hot seasons and less commonly during cold weather. Furthermore, as the environment gets warmer the clothing pattern gets lighter. This trend will continue until the clothing pattern reaches a minimum socially acceptable limit.

Metabolic rate: is defined as 'the rate of transformation of chemical energy into heat and mechanical work by metabolic activities within an organism, usually expressed in terms of unit area of the total body surface'(ASHRAE, 2017). According to Fanger (1970), the comfortable skin temperature decreases with increasing activity while the internal temperatures of the body rise with activity. The metabolic rate is largely dependent on the level of activity and the more the activity the more heat is produced inside one's body (CIBSE, 2013). When too much heat is stored in the body, some of it needs to be removed to prevent thermal discomfort. One of the several components of energy requirement is Basal Metabolic Rate (BMR), which represents the energy essential for life, for example, to maintain the body temperature and cardiac and respiratory functions. MBR constitutes 45-70% of daily energy expenditure and is primarily a function of age, body size and body composition (Luo et al., 2018). The other important component of daily energy expenditure is associated with physical activity. The rate of energy use of an individual or a group of individuals engaged in a specific activity can be estimated by multiplying the BMR value by a factor that characterizes the specific activity (FAO, 2001).

The human body needs to maintain an internal body temperature of around 37^{o}C and may suffer some health-related issues when this limit is exceeded or is dropped. According to Den Hartog & Havenith (2010), if too little heat is produced blood, will be withdrawn from the hands and feet, skin temperature will fall, and the person feels cold and uncomfortable. However, comfortable skin temperature decreases with increasing activity, while the internal temperatures of body rise with activity (Fanger, 1970). The influence of metabolic rate on thermal comfort prediction is significant. For example, Humphreys et al., (2015) established that the PMV was only applicable to the real situation with less than 1.4 met heat production, and an error of up to 1-unit scale is caused when the activity was 1.8 met. Furthermore, Luo et al., (2018) reported that the metabolic rate will change when people stay in the same environment when performing different activities. Tomonobu Goto, Toftum, de Dear, & Fanger (2006) found out in their study that subjects' thermal sensation rises or declines immediately (1min) after a change of activity but it takes 15-20 minutes to reach another state after the activity change.

Researchers confirm that adults have different metabolic rates than children, which may result in differences in their thermal perception. Humphreys (1977), indicated that there is a wide variation among the responses of children to thermal sensation. He went further to explain that it could be because of the higher normal activity level of children compared with adults. Shamila Haddad et al., (2017), attributed the lower thermal neutrality in children (when compared with that of adults) to their higher metabolic rates because of their smaller surface (body) area. Juna et al (2011) investigated subjective responses of thermal comfort of students in a University in Korea. It was found that children are more sensitive to changes in their metabolism than adults are, and their preferred temperature is lower than predicted by the standard model. Havenith (2007) investigated the metabolic rate for children and concluded that their metabolism varies from 52 to 64 Watts per m^2 body surface for various sedentary classroom activities and for adults this would be higher, around 70-100 W/m^2. Rashidi (2011) adopted this approach while investigating the thermal comfort of younger and older children in Kuwait schools arguing that Havenith's research was the only one that practically measured the children's metabolic rates during their lesson hours. ISO 7730:2005 estimates sedentary office activity metabolism at 1.2 met (1 met = 58.2 W/m^2), which is equal to the ISO 8890 estimation lower limit of 70 W/m. The ASHRAE adaptive comfort applies to spaces where the occupants are engaged in near sedentary physical activities with metabolic rates ranging from 1.0 to 1.3 (ASHRAE, 2017). Furthermore, ASHRAE Standard 55 requires the nature of the activity (examples; standing, walking, reading or writing) to be specified during fieldwork through the questionnaire by referring to the list in the table to match the correct metabolic rate. This is illustrated in Figure 2.3 and summarized in Table 2.1. This has been widely adopted in adaptive thermal comfort studies globally.

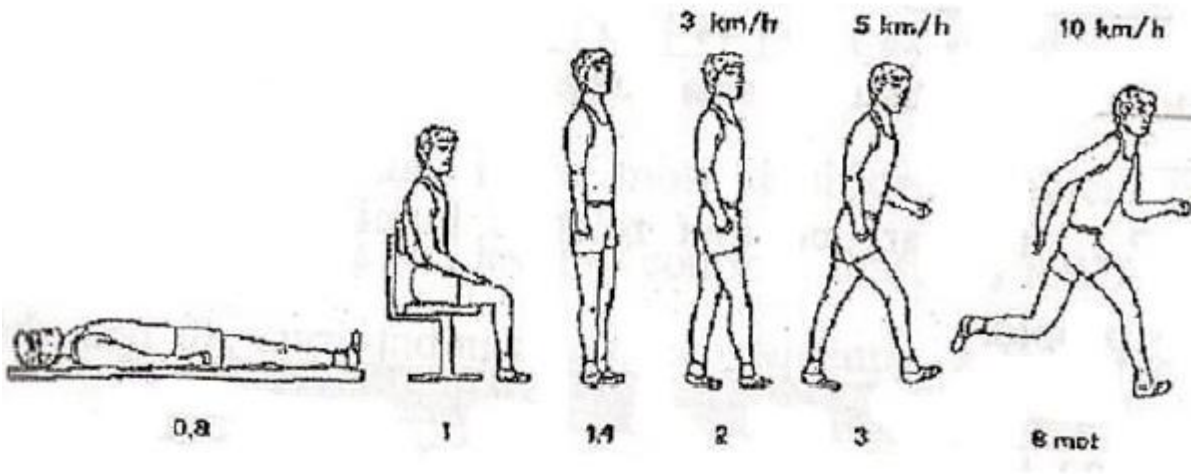

Figure 2.3:Metabolic rates according to the activities by P.O. Fanger (Steemers, Lewis, & Goulding, 1992)

Table 2. 1. Summary of estimated metabolic rates.
(Source: ASHRAE, 2017)

Activity	W/m²	MET
Resting		
Seated quiet	60	1.0
Standing relaxed	70	1.4
Walking		
0.9m/s, 3.2km/h	115	2.0
1.2m/s, 4.3km/h	150	3.6
1.8m/s, 6.8km/h	220	3.8
Office Activities		
Seated, reading and writing	60	1.0
Walking about	100	1.7
Driving		
Automobile	60-115	1.0-2.0
Aircraft, routine	70	1.2
Miscellaneous Occupational Activities		
Cooking	95-115	1.6-2.0
House cleaning	115-200	2.0-3.4
Pick and shovel work	235-280	4.0-4.8
Miscellaneous Leisure Activities		
Dancing, social	140-255	2.4-3.4
Tennis, single	210-270	3.6-4.0
Wrestling, competitive	410-505	7.0-8.7

2.6.3 Other factors affecting comfort

In addition to the two major factors discussed in the previous section (environmental and personal), that cause building occupants to perceive an environment as acceptable or not, there are other known factors pointed out by some researchers, that may influence the perception of thermal comfort. For instance, in an office setting, it has been observed that good viewing positions, privacy, cleanliness, aesthetics, and furniture layout directly related to workplace satisfaction (Bluyssen, Aries, & van Dommelen 2011). These may play part in influencing the perception of thermal comfort. Frontczak & Wargocki,(2011) & Alozie et al, (2015) argued that the type of building one occupies can also influence thermal perception. The country of origin, possibility to control an indoor environment, age, menstruation cycle, the pattern of smoking and coffee drinking and job stress were also listed as affecting thermal comfort (Frontczak & Wargocki, 2011). However, there may be some other hidden variables that can affect occupant's perception of thermal comfort, which field studies may reveal. Some other known factors that can affect the comfort of building occupants are:

Local Thermal Discomfort: Respondents can feel the impact of local discomfort if their level of activity is low (less than 1.2 Met). However, if the level of activity is not below 1.2 met, they will be less sensitive to thermal discomfort (Efeoma, 2017). Specifically referred by ASHRAE Standard 55 and ISO 7730 as causing local discomfort include; 'draft'/draught (current of air), vertical air temperature difference, warm and cold floors, and radiant temperature asymmetry.

'Draft' or Draught: is the unwanted local cooling of the body caused by air movement (ASHRAE, 2017). The predicted percentage dissatisfied for drought risk was developed for climate chamber experiments (ASHRAE, 2017; Iso, 2005). In cold and temperate climates, where the mean daily operative temperature is most of the period lower than 20^{o}C, air movement may be unpleasant to building occupants if the air velocity exceeds 0.2m/s. One of the challenges when optimizing natural ventilation is to know the limit when air movement is desirable and when it is not. Based on the argument that elevated airspeeds in indoor environments could be unwanted (draft), air velocity limits have been traditionally skewed downwards in the standards and the prediction of draft discomfort overestimates the dissatisfaction percentage observed in naturally ventilated buildings (Cândido et al., 2010). Results from various field studies, from the hot and warm humid climates, where the mean operative temperature is above 20^{o}C indicated that building occupants can welcome air

movement even when it exceeds 0.2m/s. Generally, local thermal discomfort (caused by drought) is usually felt by building occupants with low activity levels usually below 1.2 met and occupants who are engaged in activities that are higher than 1.2 met are less sensitive to thermal discomfort (Efeoma, 2017).

Vertical Air Temperature Difference: Air temperature at the head level when higher than that at the ankle level may cause thermal discomfort. ASHRAE 55 recommends that the difference be not more than 3^{o}C for a seated person or 3^{o}C for someone standing (ASHRAE, 2017). However, this vertical air temperature difference is not usually observed in most cases.

Floor Surface Temperature: Thermal discomfort may also be caused by floors that are too cold or too warm. What one wears as footwear determines that. For people wearing shoes, it is the temperature of the floor and not that of the material of the floor covering which is the most important factor for comfort (ASHRAE, 2017, Iso, 2005).

Radiant Temperature Asymmetry: Radiant heat sources such as the sun, fire, electric fires, ovens, kiln walls, cookers, dryers, hot surfaces and machinery, molten metals may produce thermal radiations that warm inside of a building. Radiant temperature has a greater influence than the air temperature on how we lose or gain heat to the environment. Generally, people are more sensitive to radiant asymmetry caused by warm ceiling than those caused by warm or cold vertical surfaces (Olesen & Brager, 2004). According to ASHRAE (2017), the ceiling is not allowed to be more than +5.0^{o}C warmer, whereas a wall may be up to +23.0^{o}C warmer than the other surfaces.

2.7 Thermal Comfort Assessment

Two traditional approaches have been commonly used by researchers to determine optimum conditions occupants of indoor spaces are deemed to be thermally comfortable. These two models illustrated in Figure 2.4 are the heat balance model and the adaptive comfort model.

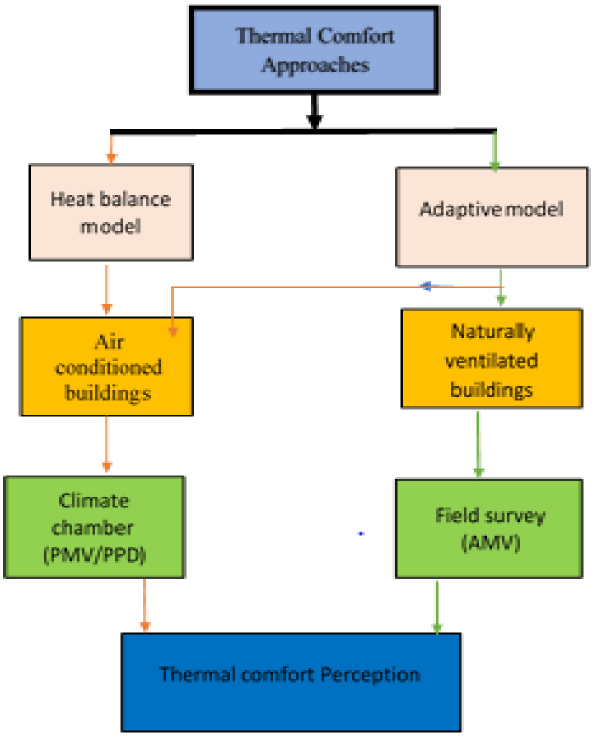

Figure 2.4: Thermal Comfort Approaches

2.7.1 **Heat balance model (HBM)**

This is a laboratory study based on the theory of heat balance between the human body and it involves experiments on human subjects in controlled laboratory environments. It is also called a rationale model. 'Heat balance' models view the person as a passive recipient of thermal stimuli, based on the assumption that the effects of a given thermal environment are mediated exclusively by the physics of heat and mass exchanges between the body and the environment' (Cândido et al., 2010). The heat balance model, developed by Fanger gave birth to the Predicted Mean Vote and Predicted and the Predicted Percentage of Dissatisfied indices (Fanger, 1973). This model is also called a steady-state model or rational model. It was developed specifically for air-conditioned spaces and was based on the data collected mainly from North America and Danish subjects. The studies were carried out at Kansas university by Professor Ole Fanger and others, in 1970, who identified comfort perception as a complex relationship between various environmental and personal factors.

Furthermore, the rational model is a product of a laboratory or chamber experiment in which all the six factors were controlled in a steady state (Humphreys et al., 2015). The conventional heat balanced based thermal comfort models, example the ISO7730 model, are all based on these six environmental parameters:

(Environmental factors)

- Air temperature (TA)
- Mean radiant temperature (MRT)
- Air Velocity (VEL)
- Relative humidity (RH)

(Personal factors)

- Activity rate (MET)
- Clothing insulation (CLO)

The model describes the heat balance between the human body and its ambient environment. To ensure that the internal body temperature is kept near to 37^{o}C, there is a continuous heat exchange between the human body and its environmental components such as air temperature, wind speed, humidity, solar radiation, building characteristics and personal factors such as activity and clothing, which are individual controls. This is illustrated in Figure 2.5. When the heat that is lost in a human body is too small, it leads to overheating and too much heat loss leads to too much cooling. For an average male, a 335Kj of heat storage is equivalent to about 1.4^{o}C rise in core temperature (Gagge, 1971). Furthermore, Fanger posited that when an activity of a typical person rises, the comfortable skin temperature of that person decreases. In order words, the metabolic rate, representing the heat generated within the body, determines the human body's steady heat balance.

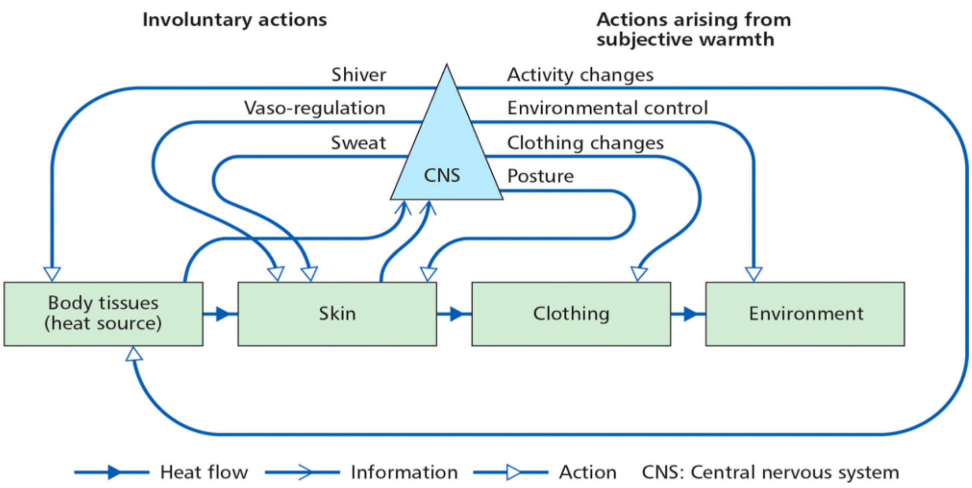

Figure 2.5: Thermal regulatory system
(Source: Nicol & Humphreys, 1973) and subsequently used in T. CIBSE, 2013).

To validate the importance of this very variable, Luo et al., (2018) argued that changing the metabolic rate from 0.9met to 1.5 met, for example, could result in an over 3.2k variance in thermal neutral(comfort) temperature.

The rational model uses the Predicted Mean Votes (PMV) and the Percentage of Dissatisfied Persons (PPD) as index to predict thermal comfort. Adopting ASHRAE 7-point thermal sensation scale, the PMV index predicts the mean value of the thermal sensation votes of a large group of persons on a sensation scale expressed from -3 to +3 corresponding to the categories ‘cold’, ‘cool’, ‘neutral’, ‘slightly warm’, ‘warm’ and ‘hot’ (ASHRAE, 2017). The PMV does not mean every individual in a given environment has thermal neutrality (ter Mors et al., 2011). Some of the people who were not satisfied could be because of their different physiological states and environmental preferences. The ‘sister’ model, the PPD, is an index that establishes a quantitative prediction of the percentage of dissatisfied persons in a given environment. The dissatisfaction is defined as those who vote -2(cool), -3(cold), +2 (warm) or +3 (hot) on the 7-point ASHRAE thermal sensation scale (Fanger, 1970). These two indices are currently being used for thermal comfort evaluation in ASHRAE standard 55 ASHRAE (2017), and the Chattered Institute of Building Services (CIBSE, 2006 and Iso, 2005). The basic equation for thermal heat balance as represented in equation 2.11 shows the skin temperature and sweet rate limits, within which a person feels thermally comfortable, if the thermal load of the body is equal to 0 (Nicol et al., 2012; Xiong, 2011). Furthermore, from a thermo-regulatory perspective, Equation 2.11, also represents the requirement for thermal comfort, implying, heat production must equal heat losses (Donald Alistair McIntyre, 1980). If the body is not in thermal balance, its temperature will change and eventually become uncomfortable.

$$M - W = C + R + E\ (C_{res} + E_{res}) + S\ [W/m^2] \qquad (2.11)$$

Where

M *is the metabolic rate,*

W *is mechanical work,*

C *is convective heat loss from the clothed body,*

R *is radiative heat loss from the clothed person,*

E *is evaporative heat loss from the clothed body,*

C_{res} *is convective heat loss from respiration,*

E_{res} *is evaporative heat loss from respiration, and*

$\boldsymbol{S}$ is the rate at which heat is stored in the body tissues.

Furthermore, the environmental parameters and the clothing values collected during field survey are the inputs in the calculation of the PMV and PPD, using (Iso, 2005) standard calculation method shown in the equation below.

$$PMV = [0.303 \times e^{-0.036 \times M} + 0.028] \times L$$

Where;

$\boldsymbol{L}$ is the therma load difference between the internal heat production and the heat loss to the actual environment,

$\boldsymbol{M}$ is the metabolic rate.

The PPD is calculated by using the Equation below.

$$PPD = 100 - 95 \times e^{-(0.03353 \times PMV^4 + 0.2179 \times PMV^2)}$$

The PMV and PPD results can be cross-checked using the CBE/Berkley-2017 (PMV-PPD) calculation tool (ASHRAE, 2017).

The steady-state model was incorporated into the International Standard Iso 7730 in 1984 (P Ole Fanger & Toftum (2002), and in ANSI/ASHRAE standard 55 in 1992 (Standard, 1992). Olesen & Brager (2004) and later into the Chinese GB/T standard 18849 in 2000 (Li, Yao, Wang, & Pan, 2014).

Limitations of PMV model; According to PMV, people could not be comfortable at high temperatures, such as 30^{o}C, (Humphreys et al., 2015). However, reports from the various field surveys indicate that people can be comfortable at such temperatures. There are people who live in countries where the temperature peaks to 52^{o}C, such as in Islamabad, and in Karachi where temperature can also reach 54 ^{o}C Hyde (2008), and still live and survive at such temperatures.

The PMV results do not usually correlate with findings from field work. In most cases, the comparison of PMV results with a database of thermal comfort assessments and physiological measurements from numerous field studies, showed that at higher temperatures PMV overestimated how warm the people felt (Doherty and Arens, 1998). It also overestimated how cold they felt. The findings were similar to what Humphreys (1975) earlier observed in field studies. Furthermore, Moujalled, Cantin, & Guarracino (2008) carried out field studies in two naturally ventilated office buildings, all located in France, on both the hot and rainy seasons. Results indicate that occupants actually accepted a higher temperature than predicted by PMV model in summer and lower temperature in winter. Yao et al., (2009) added that the PMV actually predicts thermal sensations wamer than those the occupants in naturally buildings feel. Humphreys (1978) analysed thermal comfort survey results from 36 places world wide and found that the comfort temperature range is much wider than the narrow comfort zone which is given by the heat balance model. Reports from various field studies indicate that PMV values estimated by these methods overestimate the thermal conditions in summer season and underestimate the thermal conditions in winter.

Using a clothing value and a metabolic value as input in calculating a PMV of a group of people wearing varieties of clothings and who are, probably, engaging in different activities may not give a true value of how each person feels to the thermal conditions in the space they occupy. Moreso, it is difficult and, indeed rare for everyone to wear the same clothing or to engage in the same activity in a given space. Furthermore, the clothing insulation and metabolic rates used in calculating PMV are difficult to assess accurately, and that includes airspeed where value is hard to measure (Nicol et al., 2012). Furthermore, reports indicate that the more the metabolic rate the PMV gains more values near zero in winter case as the human body produces metabolic energy to keep te body in a heat balance, hence the human body will be more thermall comfortable.

In winter conditions, the higher insulation makes great impact on preventing the heat loss from occupants' body, then they lose less (energy) heat from their body so as to feel more thermally comfortable (Baker & Steemers, 2003). In the warmer climates, higher clothing insulation makes the subjects to retain heat and making them thermally uncomfortable, thus the limitation in the application of PMV is more pronounced in the tropical areas.

The thermal comfort vote results from the actual environmental conditions is more dynamic than the steady state environment in the weather chamber, and this may be the reason for the gap between the two approaches to thermal comfort. The PMV model does not consider the importance of outdoor temperature. The other traditiinal approach used to determine the optimum temperature of building occupants is the adaptive model.

2.7.2 Adaptive comfort model (ACM)

The adaptive approach to thermal comfort was considered as a result of the oil shock in the 1970s. This oil shock caused energy crisis, resulting to the high cost of heating indoor spaces in order to provide the desired thermal comfort to building occupants. According to (Humphreys et al., 2015), energy is saved because the adaptive approach allows the indoor temperature to drift closely with the prevailing outdoor temperature, and the reduced difference between the two variables reduces energy needed to heat or cool indoor environments. The adaptive approach to thermal comfort was also introduced to encourage reduction of greenhouse gas emissions in the building sector. The adoption of the adaptive model in buildings can help to meet the goals set by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Conventions on Climate Change (UNFCC) regarding the reduction of greenhouse gas emissions in the building industry.

The journey towards the achievement of this objective (reduction in greenhouse gas emission) started on a serious note in the 1970s. At that period, Nicol and Humphreys hypothesized the existence of a feedback between the occupants' thermal comfort and their buildings, with occupants adapting to a much larger range of temperatures than that predicted by PMV/PPD model (Carlucci et al., 2018). Adaptation refers to the initiatives and measures used as strategies to reduce the vulnerability of natural and human systems against happening or and the potential climate change effects (IPCC, 2014). In order words, it can be defined as the gradual decrease of the organ's response to a stimulus, involving all the actions that make them better suited to survive in such an environment (de Dear & Brager, 1998, & Kenawy & Elkadi, 2011). According to Kenawy & Elkadi (2011), in the context of thermal comfort, adaptation may involve all the processes that people go through to improve the fit between the environment and their requirement. The relationship between the thermal environment and the occupants' is quite complex. Occupants' adaptation and sensation of the thermal environment is the comprehensive effect of the three adaptive behaviours; behavioural (clothing and window), physiological (acclimatization) as well as psychological (expectation). These three adaptive behaviours are further discussed below.

Behavioural Adaptation: includes all actions taken by a person consciously or unconsciously to maintain comfortable thermal condition. According to Thapa, Bansal, & Panda (2016) the behavioural adaptation strategy is in form of personal, technological and cultural adjustments. Personal level are actions taken by people on personal variables, like changing clothing level, changing activity, changing posture, eating, drinking or moving to different locations. In technological level, the surrounding environments are modified by opening/closing of windows, doors, switching on/off fans. While the cultural adjustments include activity according to socio-cultural and traditional setup including adaptation to various clothing based on social norms.

Physiological Adaptation: is a change that would result from long-term exposure to thermal factor which makes the occupant habituated (Singh, Mahapatra, & Atreya, 2011).

Psychological Adaptation: are the effects of cognitive and cultural variable on the thermal sensation of the individual and the extent to which one's perception and expectations are altered towards a thermal environment (Singh et al., 2011).

Further detail of the complex mechanisms humans can adopt in order to achieve the desired thermal comfort are illustrated in Figure 2.6.

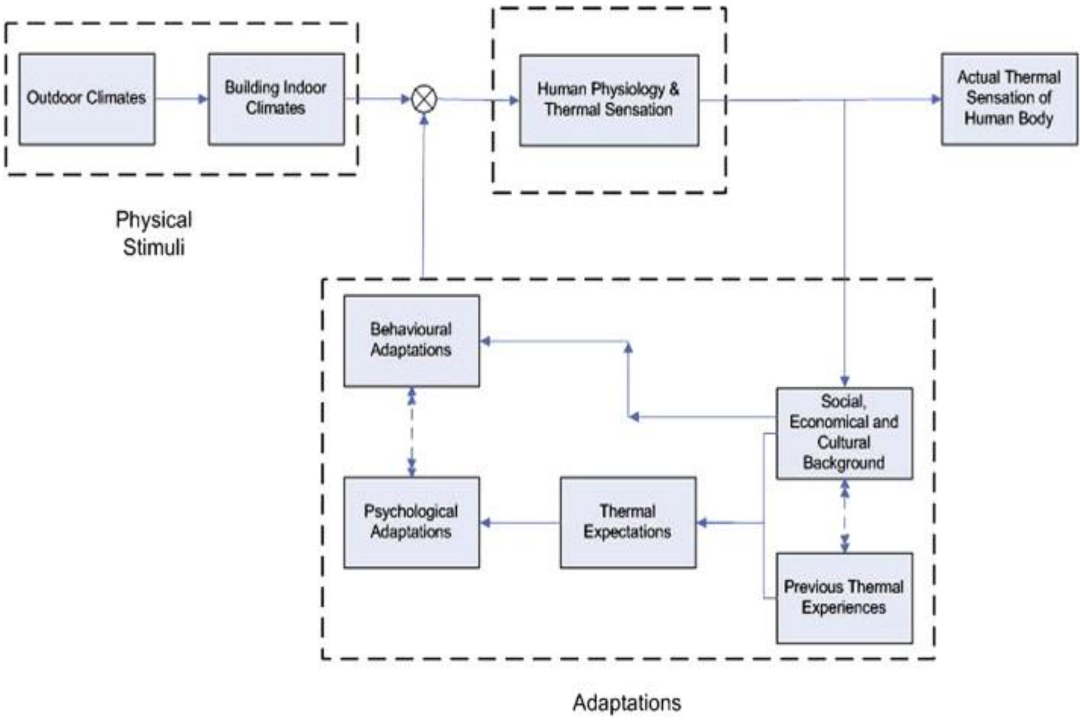

Figure 2.6: The thermal comfort adaptive model mechanism
(Adapted from Yao et al., 2009)

The adaptive comfort approach investigates the dynamic relationship between occupants and the real-world environments Humphreys et al., (2007), and accounts for changes in the comfort temperature made by occupants' adaptation to their thermal environment. Humphreys and

Nicol continued in this journey by analysed the thermal comfort data gathered from different field surveys across all the climatic zones and observed that there exists insignificant difference on how warm people felt in winter and summer, despite the seasonal variation in the room temperature (Humphreys et al., 2015). It was also observed that people seem to adapt to the seasonal drifts in the indoor temperature during the month, however adapting less to short-term fluctuations of the room temperature. Furthermore, the supporters of adaptive approach to thermal comfort are of the opinion that factors beyond fundamental physics and physiology play an important role in building occupants' expectations and thermal preferences. That people tend to adapt naturally to the changing surrounding environment. The adaptive approach to thermal comfort hinges on the argument that building occupants will take some voluntary actions such as removing or putting on extra clothing, posture and activity changes, for example, together with involuntary physiological responses to achieve and maintain the desired thermal comfort. Since ages, human beings have been adapting to the various temperatures found in their places of abode by taking some adaptive actions that makes them thermally comfortable in their environment. This was succinctly put by (Humphreys et al., 2015 pp. 3-4;)

'People like other animals, have been adapted too, and where fuel was scarce and warmth needed, they largely controlled their comfort behaviourally – adaptively. ... (For example) British Iron Age dwellings had a wood-fuelled fire burning at the centre of the dwelling and radiating heat to the occupants, who have moved closer to the fire to get warmer and further go away to get colder'.... So that they were not wholly dependent on the body's built-in systems of thermal regulation'.

With the existence of large variations in indoor thermal comfort according to different climate, time of year and culture (as indicated in various field works), the responses to these thermal conditions and the actions the respondents take (to restore comfort) ensure that the human race could survive in almost all the wide variety of conditions to be found across the planet (Nicol & Roaf, 2017). For instance, in earlier survey conducted by (Nicol, Raja; Allaudin, & Jamy, 1999), it was observed that Pakistani office workers reported being comfortable at temperatures of up to 31^{o}C and that preferred indoor temperature varied with climate and season. Results from field study in a hot and humid climate China confirmed that human thermal comfort could be maintained at air temperatures of 27-30°C and humidity of 40-80% (Chen, Zhang, & Tang, 2017).

The results from the various research works summarized that it is not possible to have a standard temperature in which everyone will be comfortable at the same time. This was echoed by Nicol et al., (2012), who posited that it is 'impossible to use a simple theoretical model of adaptive approach to understand the complex workings of a local comfort system that involves ever changing people, buildings and climates' (in line with adaptive thermal comfort). Because the adaptive model relates the indoor comfort temperature to the outdoor temperature, outdoor temperature is an important parameter in Adaptive model because weather and seasons influence on our behaviour adaptation to the thermal environments (Humphreys, 1975). For example, before we go out we often check what the weather would be like. The outcome influences the decision of the choice of clothing to wear. The adaptive model is mainly intended for people with sedentary activity such as office workers and, to some extent, school children. Their metabolic rates are usually less than or equal to 1.3 met, the clothing is approximately 0.5clo and 1.0clo for summer and winter, respectively.

Various results from field works reinforce the belief that thermal environmental conditions perceived as unacceptable by the occupants of centrally-conditioned buildings can be regarded as perfectly acceptable, if not preferable, in naturally ventilated buildings. The result of these actions is an increased range of conditions that designers can consider as comfortable, especially in naturally ventilated buildings where the occupants have a greater degree of control over their thermal environment by utilizing the adaptive actions to control them by way of interacting with the environment. The interactions between occupant and the immediate environment in a naturally ventilated building are much more dynamic and the occupant's behavioural, physiological and psychological adaptations are wider compared to conditioned buildings (Singh, Mahapatra, & Teller, 2015). Humphreys et al., (2015) further suggests that it is possible to design and operate buildings that provide comfort in the free-running mode, at least within a range of prevailing mean outdoor temperature from 10-30^{o}C. Other results also indicate that different cultures and climates are factors that influence what people consider as comfortable under different temperatures.

Study conducted by Vecchi et al., (2014) came out with findings that it is not impossible to find significant percentages of thermal acceptability data outside of the comfort zone proposed by ASHRAE Standard 55 adaptive model. In some previous studies on thermal comfort, it was noted that temperatures above 30^{o}C are not considered as uncomfortable in many places. (M A Humphreys et al., 2013; India Indraganti, 2010; Singapore Yang et al., 2014). Furthermore, a field experiment performed by Saleem, Abel-Rahman, Ali, & Ookawara, (2012) in naturally ventilated public schools in the hot and humid climate of upper Egypt found the occupants accepting indoor operative temperature within the range of 25.5°C-29.5°. Wong & Khoo, (2003) conducted study in naturally ventilated classrooms in tropical Singapore and found range of indoor temperature between 27.1°C-29.3°C, which is outside the comfort zone of ASHRAE Standard 55. The high tolerance to the indoor thermal conditions in the tropics may be related to adaptation. According to Yao et al., (2009), PMV predicts thermal sensations warmer than those that the occupants in naturally ventilated buildings feel. Another set of field study examined differences in thermal perceptions and practices between the occupants of artificially and naturally ventilated buildings, again recorded variations related to cultural expectations and climatic conditions. These reports from many studies indicate that building occupants can accept thermal range beyond ASHRAE comfort zone (Hussein & Rahman, 2009).

After an extensive review of ASHRAE RP- 884, that contained 21,000 samples collected from buildings world wide (Jindal 2018), and from different countries and buildings by de Dear and Brager, a gap between the results of field measurements and the PMV was found (Goto, Mitamura, Yoshino, Tamura, & Inomata, 2007). The results of the field studies imply that universal methods for measuring and calculating comfort and the design standards are inadequate because they fail to account for culture and climate variations in peoples' interpretation of comfort. The result of the findings from ASHRAE RP-884 review of projects, that collected field data from various climatic zones (de Dear & Brager, 2001) led to the incorporation of the adaptive model in ASHRAE 55:2004. ANSI/ASHRAE is actually a standard for the American National Standards Institute. However, it is acknowledged as an International standard organization since the field data adopted in their research (ASHRAE RP-884) covered 160 different buildings located in dozens of countries spread across four different continents (Carlucci et al.,2018). Furthermore, in the year 2004, a new Dutch guideline called the Adaptive Temperature limits Guideline (ATG) was introduced in the Netherlands (Van der Linden, Boerstra, Raue, Kurvers, & de Dear, 2006). In addition, the European union included the adaptive component in EN 15251 in 2007 after a three-year SCAT'S project was undertaken in Europe. Field studies were conducted in 26 European offices resulting to the proposal. The project was undertaken to reduce energy consumption in Europe's air conditioning buildings. To achieve that, naturally conditioned buildings were considered as an option. The findings from the various fieldworks reinforced the argument about the influence of outdoor temperature on the indoor temperature.

The difference between outdoor and indoor air temperature and air flow can also affect perception of comfort (Du, Bokel, & van den Dobbelsteen, 2019). The comfort temperature in the buildings can change with the outdoor conditions Nicol et al., (2012), and this is explained by the graph that related the prevailing outdoor temperature to the temperature required for comfort indoors (Figure 2.7) and presented statistically in Equation 2.12. The graph is used to provide zones within which 80% and 90% of building occupants may be thermally comfortable (ASHRAE, 2017). This graph indicates what temperatures are acceptable in a building at an outdoor temperature. The adaptive approach does not express indoor comfort temperature in form of a standard. It also does not predict what temperatures are comfortable, rather it expresses its standard in terms of the provisions of a building, based on adaptive opportunities adopted to obtain thermal comfort Humphreys et al., (2015) that gives range of comfortable temperatures. Figure 2.8 presents a diagram where other factors play part in adaptive thermal comfort.

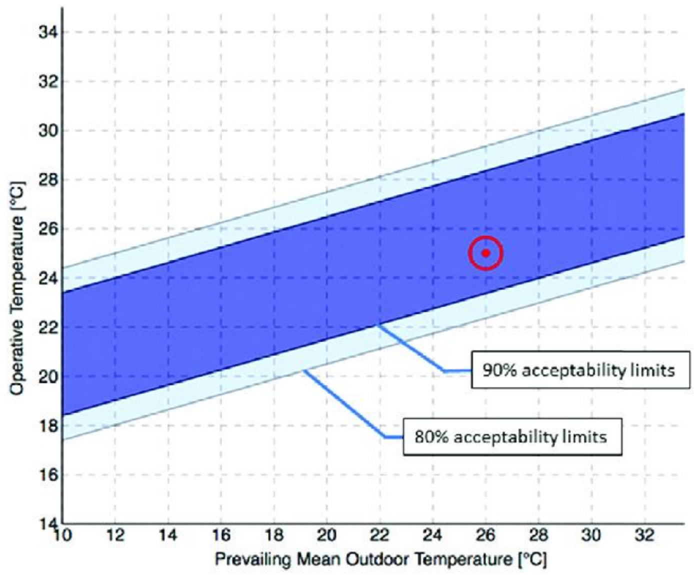

Figure 2.7: Adaptive thermal comfort chart according to ASHRAE Standard 55-2017 (Adapted from ASHRAE, 2017).

$$\boldsymbol{T_{comf} = 0.31T_{pma(out)} + 17.8} \qquad \textbf{(2.12)}$$

Where,

T_{comf} *is the indoor comfort operative temperature (°C)*

$T_{pma(out)}$ *is the prevailing mean outdoor air temperature(°C)*

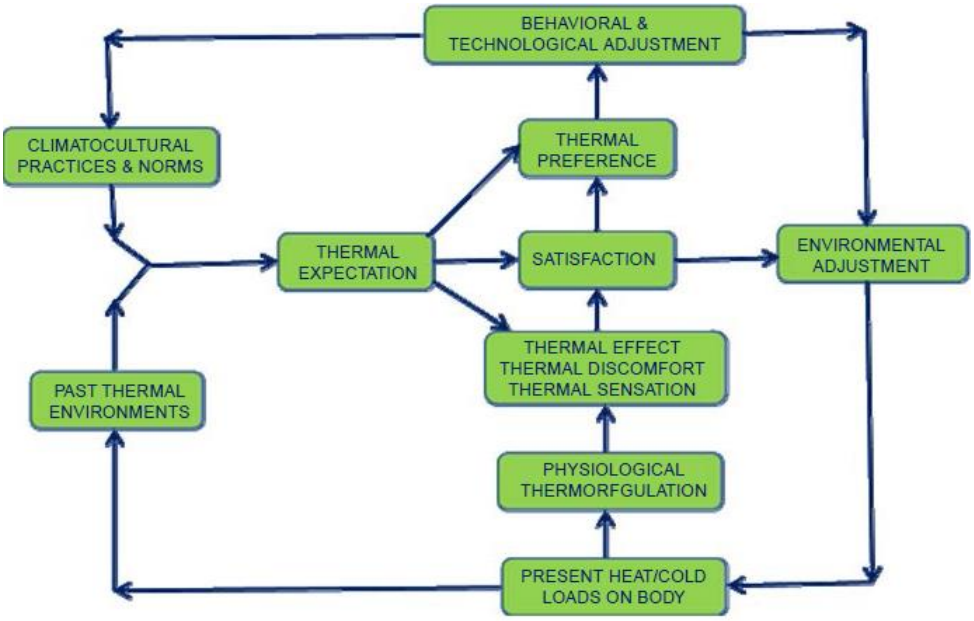

Figure 2.8:The 'Adaptive model' of thermal perception
(Adapted from Andris Auliciems, 1981)

The peculiarity of the adaptive approach is that the coefficients linked to outdoor and indoor temperatures are very hard to be experimentally evaluated. It is obvious that the overall indoor thermal condition strongly depends on the external climate and the acceptance of higher indoor temperatures in summertime conditions are linked to the occupant's expectation. As a result, many authors have studied and proposed methods to develop an adaptive thermal comfort equation for naturally ventilated buildings in hot climates and the issue has been addressed by different points of view.

The simplicity in the use of the adaptive model in evaluating thermal comfort is the input of only one variable (the mean monthly outdoor temperature). Furthermore, of all the adaptive measures, window opening was the most favoured adaptive option (Indraganti, 2010; Wang, Zhang, Zhao, & He, 2010). In addition, opening of windows decreases the feeling of 'stuffiness' and increases the wind speed (Mishra & Ramgopal, 2013). Building designers in collaboration with engineers can prepare ideal designs likely to provide thermal comfort at different outdoor temperatures. Furthermore, climates in each locality may influence different perceptions of thermal comfort, thus there is no doubt that the comfort expectations of a tropical population and people from temperate or cold climate are different.

The only variable input required for this model in finding thermal comfort is the mean monthly outdoor temperature. This model is easier to apply than that of PMV. While one will require estimation of the personal factors; clothing and activity before using the PMV model; the relationship between these factors and climate has already been accounted for in the adaptive model (Efeoma, 2017).

ASHRAE standard 55 suggests an optimal method for determining acceptable thermal conditions in Naturally ventilated buildings. According to the graph and based on indoor comfort temperatures, limits of 80% and 90% of thermal acceptability are possible. The criterion is applicable to spaces equipped with operable windows, without mechanical cooling system with occupants engaged in almost sedentary activities and being able to freely adapt their clothing insulation. The criterion is only applicable to where the monthly mean outdoor temperatures are not lower than 10°C or higher than 33.5°C (ASHRAE, 2017).

Limitation of the adaptive model:

1. Adaptive model is criticized for overlooking the four conventional indoor thermal factors, clothing and activity level and focusing on the operative temperature and the outdoor temperature in calculating comfort temperature (Fanger & Toftum, 2002).

2. The adaptive model show poor predictive accuracy when applied to a small group of people or individuals because they are designed to predict the average comfort of a large population.

2.7.3 Justification for adopting ACM instead of HBM by comfort researchers in tropics

Literature review in the previous sections, sections 2.7.1 and 2.7.2, reported that the Heat Balance Model (HBM) uses the PMV/PPD to determine thermal comfort of building occupants, while the Adaptive Comfort Model (ACM) uses both the PMV/PPD and adaptive component to evaluate thermal comfort. Initially, ASHRAE Standard 55 was completely based on studies done in climate chambers. Later, the adaptive model reflected the adaptive thermal comfort component in its guidelines. The review observed that there is a relationship between the indoor and outdoor temperatures in determining thermal comfort of occupants in naturally ventilated spaces. From the various reports, the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) adopted the adaptive component in its regulations. According to Humphreys & Nicol (2018) the adaptive approach to thermal comfort ‘has been present in ASHRAE standard 55 since 2004 edition. It has been present in standard CEN 15251 for Europe since 2007 (BSI 2007). It has a place in the all-China standard for thermal comfort

(MOHURD, 2012). It appeared in the CIBSE Guide in the 1981 edition and reappeared in 2006 and is in the current (CIBSE, 2013). In addition, the first guidelines for thermal comfort in buildings in The Netherlands were based on PMV-PPD, but now the new guidelines contains are based on adaptive thermal comfort (Van der Linden et al., 2006). Figure 2.9 illustrates the graphical representation of the stages of the adoptions of various thermal comfort models. Figures 2.10 illustrates the various thermal comfort standards while Figure 2.11 depicts the model for predicting predictions of comfort temperature.

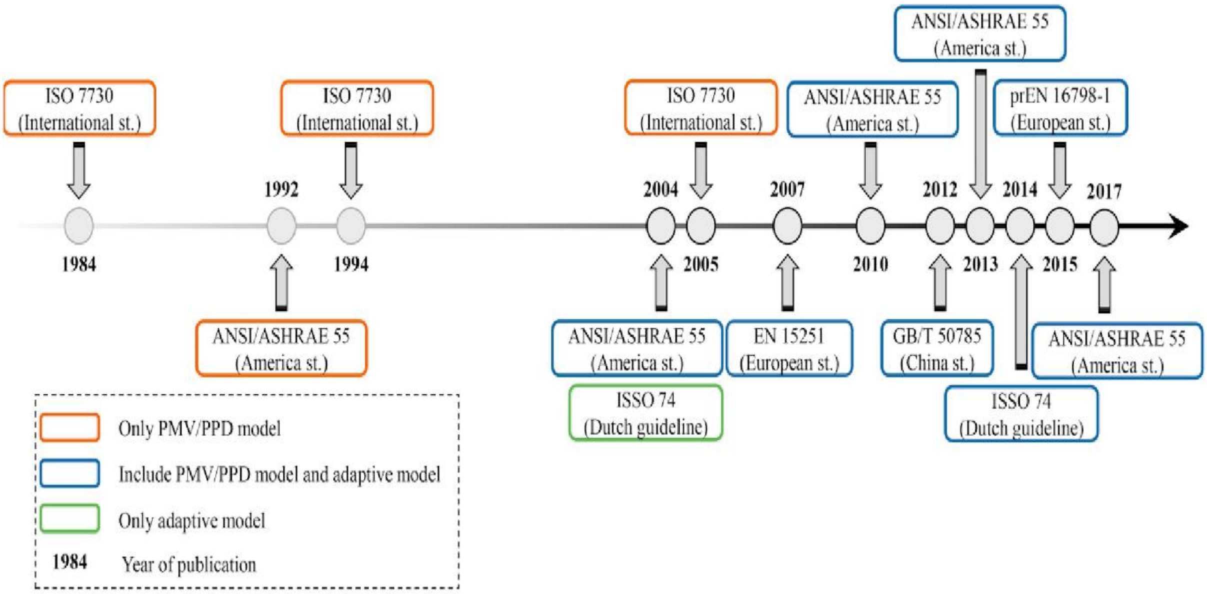

Figure 2.9: Graphical representation of the stages in the adaption of various comfort models (Source: Carlucci, 2018).

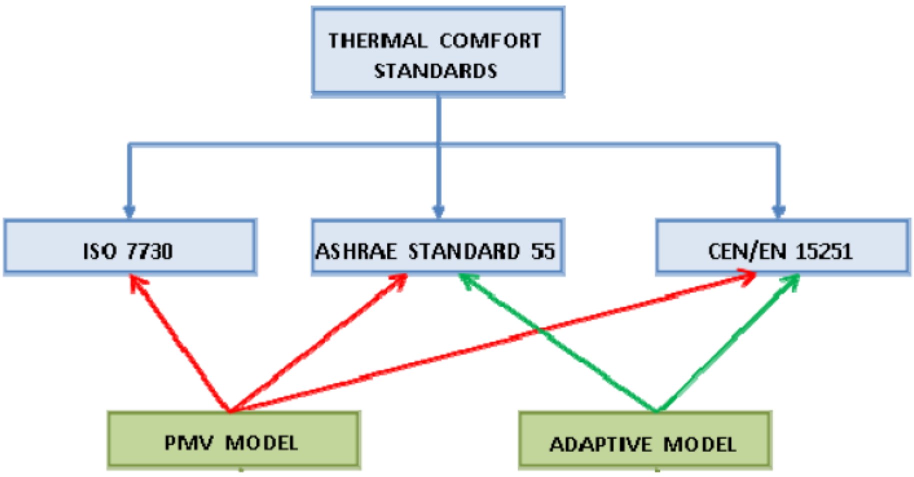

Figure 2.10: Thermal comfort standard and their respective model (source: adapted from Ahadzie et al., 2014)

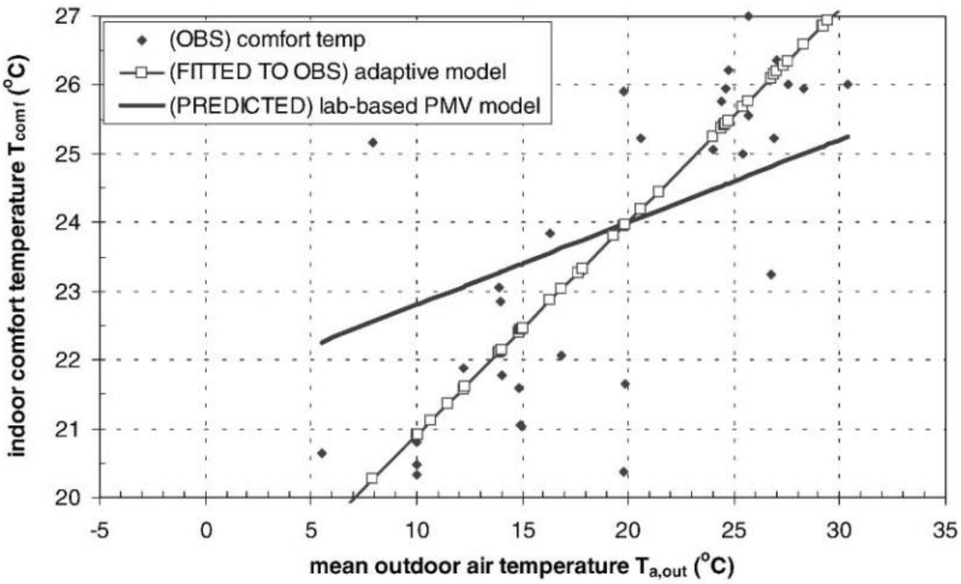

Figure 2.11: Predictions of comfort temperature using adaptive model and PMV model (Adapted from de Dear & Brager, 2002)

Further reasons that justifies the adoption of the adaptive comfort model instead of heat balance by thermal comfort researchers from the tropics are:

- From the literature review, occupants of naturally ventilated buildings evaluated with the adaptive model are reported to accept wider ranges of internal operative temperature when compared with those evaluated with PMV/PPD.

- Researchers prefer using the adaptive thermal comfort model, rather than that of the PMV/PPD, while conducting thermal comfort studies in the tropical areas having observed that PMV/PPD does not effectively describe comfortable temperature.

- Adopting PMV model, produced from study on adults only (and conducted in climate chamber), may not accurately reflect the thermal sensations and preferences of school children (de Dear et al., 2015; Teli et al., 2012; ter Mors et al., 2011).

- The PMV can accurately predict comfortable temperatures for airconditioned buildings but not for free-running buildings.

- Using the adaptive approach in NV buildings helps to determine the actual temperature limit acceptable to the occupants based on adaptation, which can help reduce energy use by discouraging the use of mechanical heaters, or coolers within the range occupants accept the temperature.

The above reasons justify why researchers from the tropical climates prefer using the adaptive model instead of HBM to determine thermal comfort in NV buildings. However, having recognized that the adaptive model is best suited for use in evaluating occupants in naturally ventilated buildings, some thermal comfort researchers are often at crossroads on whether to adopt the adaptive component of ASHRAE standard 55 or the adaptive component of CEN-15251.

2.7.4 ASHRAE Standard 55

ASHRAE (2017) defines an acceptable zone for naturally conditioned buildings within which 80% and 90% of building occupants find the thermal conditions acceptable. The comfort zone (also referred as the acceptable zone) is expressed as a temperature range around the neutral temperature. This acceptable zone can be determined using the relationship between the indoor comfort temperature and the outdoor climate, as reflected in a linear regression as Equation 2.13.

$$T_{comf} = 0.31T_{pma(out)} + 17.8 \qquad (2.13)$$

Where,

T_{comf} *is the optimal operative temperature* (^oC)

$T_{pma(out)}$ *is the prevailing mean outdoor air temperature*(^oC)

The reflection of adaptive component on ASHRAE standard 55 was done after a comprehensive analysis that involved database of 21,000 samples collected from buildings worldwide which confirmed that comfort temperature has a relationship with the outdoor temperature. The results were subsequently incorporated in the ASHRAE (2004) standard as the adaptive comfort model, and it is regularly updated. The first publication of ASHRAE standard 55 was in 1966, and subsequently revised in 1994, 1981, 1992, 2004, 2010, 2013, and most recently in 2017 (Carlucci et al., 2018).

The upper and lower limits of thermal acceptability are determined by ASHRAE Standard 55 based on the T_{comf} criterion. The acceptability limits are derived considering operative temperatures within which 80% and 90% of the occupants are satisfied; T_{lim} (80) =3.5K for normal application and T_{lim} (90) =2.5K when a T_{lim} (80) standard of thermal comfort is desired. The equation used for 80% acceptability limits in (ANSI/ASHRAE Standard 55-2013) are as follows:

The lower 80% acceptability limits (°C) = 0.31$T_{pma(out)}$ + 14.3 **(2.14)**

The upper 80% acceptability limits (°C) = 0.31$T_{pma(out)}$ + 21.3 **(2.15)**

Where,

$\boldsymbol{T_{pma(out)}}$ is prevailing mean outdoor air temperature.

There are further individual findings from the field work that indicated that fixing a range of thermal comfort to serve the different climates and people may not be realistic. For example, two separate studies aimed at establishing the comfort zone for Pakistan investigated by Nicol in 1995 and 1999, at the same climatic zone, yielded regression equations $T_{comf} = 0.38T_{out} + 17.0$ and $T_{comf} = 0.36\ T_{out} + 18.0$, respectively. These two comfort models provided different comfort temperatures, indicating that there is no universal comfort temperature. The operative temperatures, in these studies, were observed to be influenced by the corresponding outdoor temperatures in the determination of these comfort models. This indicates that, specifying a particular range of thermal comfort, in form of a standard derived from an experiment from a particular zone, may not realistically reflect the actual temperature of people in other zones. In addition, a comfort standard derived from a group of people in a particular month may not be the same comfort standard if the same people are evaluated in a different time period (month or year). An example is shown in Figure 2.12. However, to use the adaptive component in ASHRAE, Standard 55 specifies that the outdoor temperature should be in the range 10 to 33.5°C (ASHRAE, 2017; Calama-González, Suárez, León-Rodríguez, & Ferrari, 2019).

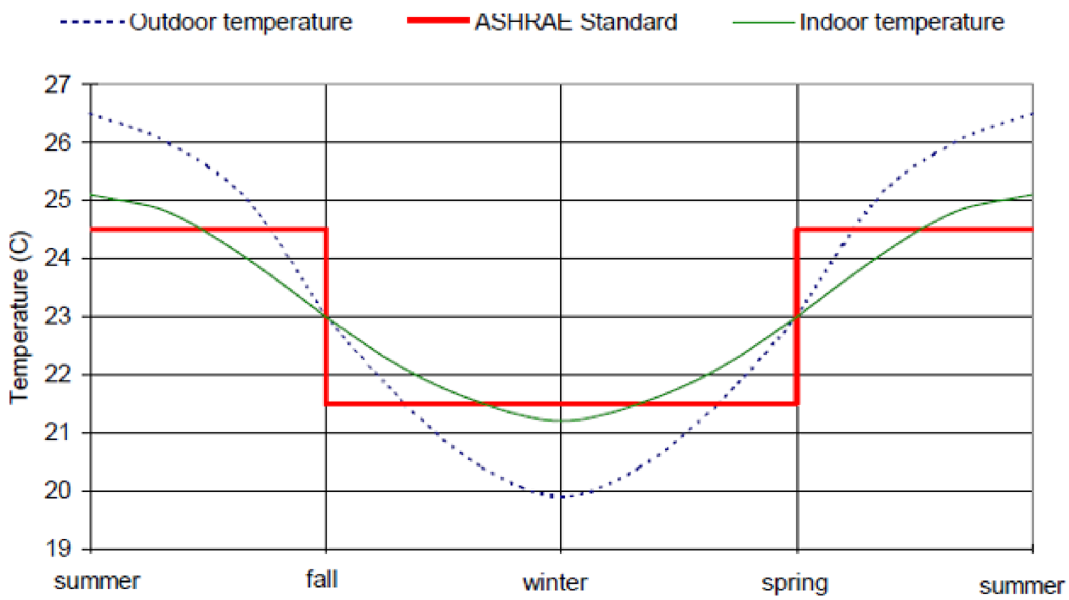

Figure 2.12: The adaptive model concept @Macquarie University 1996
(de Dear http;//atmos.es.mq.edu.au/rdedear)

Furthermore, the adaptive model predicts a comfort or neutral temperature (T_{comf}), defined as 'the operative temperature' at which either the average person will be thermally neutral or at which the largest proportion of a group of people will be comfortable (Nicol & Humphreys, (2010), p. 12). As earlier stated, the only variable input required for this model in finding thermal comfort is the mean monthly outdoor temperature, an index calculated as an average of the monthly mean maxima and the monthly mean minima (ASHRAE, 2004; Humphreys, 1978). Earlier, T_{out} was defined by Standard 55 as the *monthly mean of the outdoor temperature* (i.e., the average of the mean daily minimum and maximum outdoor temperature for the month in question) but is now defined as the *prevailing mean outdoor temperature*. ASHRAE Standard 55 is not restrictive on using only monthly mean outdoor temperature. The prevailing mean outdoor temperature is defined as the arithmetic average of the mean daily outdoor temperatures calculated over some period of days that have to be 'no fewer than seven days and no more than thirty sequential days prior to the day in question' (Nicol et al., 2012). For example, Efeoma (2017) used weekly mean outdoor temperature, while de Dear & Brager choice of monthly was made on the grounds that 'months represent the temporal scale most commonly adopted by national weather bureaux'.

2.7.5 Adaptive Comfort Model using CEN 15251 (CEN, 2007)

CEN/EN 15251 also adopted the adaptive thermal comfort component (CEN, 2007); (Humphreys et al., 2015) from the results of the Smart Control And Thermal Comfort (SCATs) comfort database provided from a yearlong study of the indoor environmental conditions selected from offices in Western Europe. CEN 15251 was developed by Comité Européen de Normalisation (CEN), as a result of the need to have standards that consider the Energy Performance of Buildings Directive (EPBD). The current revision renamed prEN 16798-1, came out in 2015. In this version, the lower limit of optimal operative temperature is lower by 1^oC lower than that of the previous version, while the available range of outdoor running mean temperature that corresponds with the lower limit of thermal comfort zone extended from 15 to 30^oC to 10 to 30^oC (Carlucci et al., 2018). Furthermore, the adaptive component in CEN 15251 specifies that temperature must be above 10 and below 30^oC, for the upper limit, and for the lower limit it must be between 15 to 30.0^oC (Calama-González et al., 2019).

An adaptive thermal comfort equation (Equation 2.16) from CEN 15251 was adopted in order to evaluate the users' thermal comfort perception;

$$T_{comf} = 0.33T_{rm} + 18.8 \qquad (2.16)$$

Where.

T_{comf} is the comfort temperature (^oC)

T_{rm} is the outdoor running mean temperature (^oC)

A weighted running mean of outdoor temperature T_{rm} (Nicol & Humphreys, 2010) is calculated as follows:

$$T_{rm}=(1-\alpha_{rm})\ [T_{e(d-1)} + \alpha_{rm}\ T_{e\ (d-2)} + \alpha_{rm}^2\ T_{e\ (d-3)} \ldots\ldots] \qquad (2.17)$$

Where,

α_{rm} *is a constant between 0 to 1,*

$T_{e(d-1)}$ *is the daily mean outdoor temperature (^oC) for the previous day,*

$T_{e\ (d-2)}$ *is the daily mean outdoor temperature (^oC) for the day before*

The value α_{rm} defines the speed at which the running responds to outdoor temperature, with value of 0.8 recommended in EN15251 (CEN, 2007). However, α_{rm} with value 0.9 is given to be more suitable for climates with minimal day to day temperature variation eg, humid tropical climates, while lower values eg α_{rm}=0.6 seems more appropriate for climates where people are more familiar with day to day temperature dynamics (Vecchi et al., 2014; Shamila Haddad, 2016). The outdoor daily mean temperatures of the days preceding the examined ones can be obtained from hourly data, measured by the metrological station.

The European Standard 15251 (CEN, 2007) specified the building categories of indoor environment as shown in Table 2.2. The table shows that building categories 1,11 and III are considered for different levels of acceptable environments whilst the building category IV is out of expectation and should only be accepted for a limited time of the year (CEN, 2007)). The recommended values and the adaptive thermal comfort equation for each building category are summarized in the Table 2.2. Figure 2.13 also shows the EN 15251 adaptive model represented graphically.

Table 2. 2. Recommended criteria for thermal comfort in classrooms
(Source. CEN, 2007)

Building Category	Temperature range	Adaptive equation
Category 1	23.5 – 25.5°C	$0.33T_{rm}$ + 18.8 ±2
Category II	23.0 – 26.0°C	$0.33T_{rm}$ + 18.8 ±3
Category 1II	22.0 – 27.0°C	$0.33T_{rm}$ + 18.8 ±4
Category 1V	<22.0 or >27.0°C	-

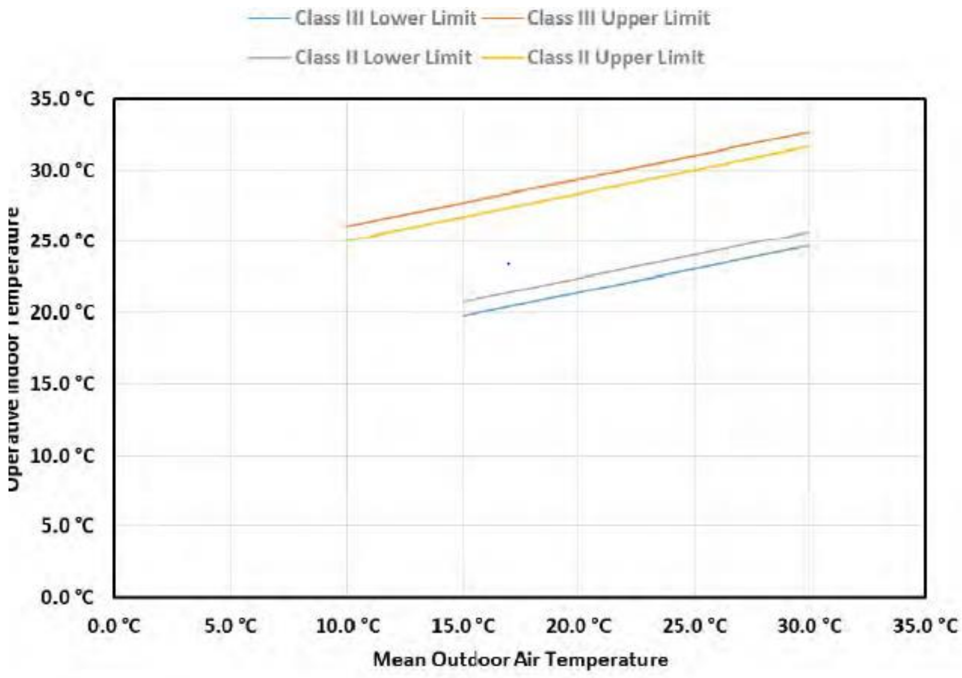

Figure 2.13: The EN 15251 adaptive comfort model for buildings operating in the free running model (adapted from Humphreys et al., 2015).

2.7.6 Justification for adopting ASHRAE Standard 55 ACM instead of CEN 15251 by thermal comfort researchers in the tropics

Based on information from literature review in this work, partly summarized in Table 2.3, the following reasons justify the adoption of ASHRAE 55 adaptive comfort model instead of EN 15251 adaptive comfort model for fieldwork and data analysis by most thermal comfort researchers in the tropics.

- The data of ASHRAE RP-884 were obtained from climate zones that covered four continents (de Dear & Brager, 1998). That formed the bedrock of the adaptive comfort model. The study area of this research work falls into one of the continents. The CEN/EN 15251 was based on the European SCATs database. The data of SCATs database were collected from five western European countries only (Nicol et al., 2012), excluding the African continent.

- Some researchers consider the ASHRAE scale easier for children to understand and also simplified in some researches (Zomorodian et al., 2016).

- ASHRAE 55 undergoes constant revisions and updates of its guidelines by considering the current results from field experiments on thermal comfort studies in different climates and cultural areas. The last revision in ASHRAE Standard 55 adaptive model was in 2017 while that of CEN was reviewed in 2015.

- In general, ASHRAE adaptive comfort model has wider coverage when compared to CEN adaptive comfort model
- The upper limit of applicable outdoor temperature is higher in the ASHRAE adaptive comfort model (33.5 ^{o}C,), while that of CEN is 30.0 ^{o}C,. Higher temperatures are found in the tropical climates as observed in the literature review.
- As discussed in section 2.76.4, ASHRAE Standard 55 adaptive comfort model has undergone more reviews and updates compared to CEN 15251.

The adaptive comfort model is often employed by thermal comfort researchers to assess the comfort requirements of a group of people in naturally ventilated spaces. This model is also adopted in this study. However, there are instances the PMV model is also used in this study to assess the comfort requirements of the subjects to compare the results from the fieldwork and that of the laboratory experiment (PMV).

Table 2. 3. Summary Comparison of the adaptive comfort standards in free-running / NV buildings.

	ASHRAE 55-2017	**EN 15251-2007**
Current update	2017	2007
Database	ASHRAE RP-884: Data mainly from office buildings	SCATs project: Data mainly from office buildings
Neutral temperatures	Using regression analysis	Assumed- Griffiths method
Applicability	Primarily for office buildings with sedentary activity level 1-1.3 MET	Offices and comparable building with sedentary activities 1-1.3 MET
Building classification	NV buildings There is no mechanical cooling System	Free running buildings There is no mechanical cooling operation
Occupancy	Occupants must be free to adapt their clothing	Occupants must be free to adapt their clothing
Acceptable operative Temp. range (ºC)	90% accept: ±2.5 80% accept: ±3.5	Category I: ± 2 Category II: ± 3 Category III: ± 4
Outdoor Climate Index	Prevailing mean outdoor air temperature	Exponentially weighted running mean temperature (α=0.8)
Range of Outdoor temperature	Prevailing mean outdoor temperature of 10-33.5°C	Running mean outdoor temperature of 10-30°C
Equation	$T_{comf} = 0.31 \times T_{pma(out)} + 17.8$	$T_{comf} = 0.33 \times T_{rm} + 18.8$
Comfort band	Defines limits for 80% and 90% satisfaction	Defines limits for classs, I, II, III comfort
Access to Window	Operable windows are required	Easy access to operable windows
Increasing air speed	The upper acceptable operative temperature limit	The upper temperature limits can be increased by a few

2.8 Thermal Comfort and Built Environment

This section reviews the literature of thermal comfort studies in the built environment, focusing on primary schools located in naturally ventilated (NV) classrooms mostly located in the tropical climates. The section is broken into two. Section 2.8.1 discusses thermal comfort studies conducted in classrooms with children and young adults in different age groups at different locations covering the hot dry, warm humid, Mediterranean and temperate climates. Section 2.8.2 discusses thermal comfort studies conducted in Nigeria that used adults as subjects covering different building types and climatic zones. Literature on adults were used to thermal comfort studies in Nigeria because of limited studies that used children in the evaluation.

2.8.1 Thermal Comfort Studies in NV classrooms

The influence of indoor classrooms thermal environment on the academic and general wellbeing of school children in their classrooms may have motivated the increase in tempo on thermal comfort research in the recent times. Table 2.4 summarizes thermal comfort studies conducted in schools. The fieldwork duration varies from one study to another, with the sample size varying from 45 to 4000. From the Table, comfort range can be as low as 24 to 26°C (Humphreys & MA, 1976) and 23.4 to 25.8°C (Nematchoua, Tchinda, & Orosa, 2014) or as wide as 18°C to 27.5°C (de Dear et al., 2015). Furthermore, the neutral temperature can be as low as 16.5°C (A Auliciems, 1969) or as high as 29.2°C (Liang et al., 2012) in naturally ventilated classrooms.

In the tropical climates, various thermal comfort studies have been conducted in schools with varieties of results. Wong & Khoo, (2003) conducted study in naturally ventilated classrooms in Singapore, a tropical country, to determine the thermal conditions in some selected classrooms. Findings show that with the acceptability temperature range between 27.1 to 29.3°C, with 28.8°C as the neutral temperature, none of the classrooms had thermal conditions falling within the comfort zone of ASHRAE standard 55. However, the occupants still accepted the thermal conditions in these classrooms. Hussein & Rahman (2009) conducted field study in naturally ventilated classrooms located in Malaysia to determine the perception of the thermal environment by the occupants. The study was carried out in two schools where objective physical measurements and subjective assessments through questionnaires were carried out. The results indicated that the occupants in the classrooms accepted thermal range beyond the ASHRAE comfort zone. Kwok (2019) assessed the thermal comfort and air quality in naturally ventilated Chilean schools and the perceptions of students and teachers. Students within the age range from 10-14 years were evaluated where physical measurements and subjective responses were collected through electronic surveys. The thermal sensation trends, perceptions of comfort and air quality were analysed. Results show that about 80% of teachers and students voted their thermal sensation primarily within the central categories of ASHRAE scale (-1,0,+1). Noda et al, (2020) investigated the thermal and virtual comfort in children aged between 9 and 11 years in air-conditioned public elementary schools located in hot and humid climate of Brazil. Quantitative and qualitative study approaches were adopted during the survey. The students were answering the questionnaires while the data loggers placed at the heights of 0.6m and 1.1m at the centre of the classrooms were measuring indoor temperatures. The author observed that even when using the air-conditioning systems there was a high incidence of discomfort among the children.

Mishra & Ramgopal (2015) conducted thermal comfort field study in naturally ventilated classrooms in the hot humid climate of India during the autumn of 2013 (5 days' survey) and during the spring semester of 2014 (7 days' survey). A neutral temperature of 29.0°C and preferred temperature of 26.8°C were obtained, with 80% occupant satisfaction found between 22.1 to 31.0°C. Wargocki & Wyon (2007) conducted two independent field intervention experiments in elementary public-school classrooms of 10-12 years old children. The purpose of the experiment was to determine the effects of moderately raised classrooms temperature and the ventilation rate on the performance of the classrooms. Results showed that reducing moderately high classroom air temperature from the region of 25-20°C by providing enough cooling improved the academic performance of the children. Some thermal comfort studies compared the thermal perception of school children with that of their teachers. One of such findings from field work research conducted by Yun et al., (2014) who found that children perceived thermal comfort temperature lower than adults by 3°C. In the study, kindergarten age group from 4 to 6 years were randomly selected from 10 naturally ventilated classrooms. The field work lasted from April to June where dry-bulb temperature, relative humidity and air velocity were measured three times a day. Le, Gillott, & Rodrigues (2017) investigated the thermal conditions in a primary school in a city in Vietnam where the students and their teachers gave the long-term evaluation of indoor thermal comfort in the mid-season and the hottest season. The teachers' thermal sensation mean vote was 0.77, which was higher than that of children who were in the same class with them. This implied that the teachers could perceive higher thermal environment than the children in the same indoor space. This also suggested that children have higher temperatures than the recommended values in the standard. Also, Haddad et al (2017) conducted fieldworks in naturally ventilated classrooms in Iran to examine the thermal perceptions of children aged 10-12 years and to compare the findings with that of ASHRAE 55 adaptive comfort model. The studies were conducted during the warmest period of the year where the fieldwork lasted between 7-10 days. The schoolchildren filled the comfort questionnaires at the same time as the environmental parameters were being taken. The instruments for the environmental parameters were placed at the heights of 1.1, 0.6 and 0.1 m above the floor. The author reported that the result of the analysis may indicate that the sampled school children may be slightly less sensitive to indoor temperature changes than adults. The upper acceptable temperature derived from children's responses corresponding to mean thermal sensation +0.85 was 26.5°C. The author concluded that children feel comfortable at lower temperatures than predicted by the ASHRAE Adaptive model during the warm season. Furthermore, studies on classroom conditions also showed that they are likely a reflection of teachers' influence rather than children De Giuli et al., (2012), thereby raising the doubt that children may not feel thermally comfortable which may affect their academic performance and well-being negatively. This suggested that the teachers may be deciding how they want the indoor thermal condition in the classrooms to be, by taking some adaptive actions such as deciding when to open or close the windows

In Egypt, Mohamed (2009) assessed the thermal comfort of occupants in naturally ventilated primary school classrooms that experiences a hot and a humid climate, and observed that most of them were thermally uncomfortable, attributing the reasons to the high occupancy density of children in classrooms and to inadequate natural ventilation. In the same Egypt that has a hot and humid climate, Also in Egypt Saleem et al., (2012) examined the thermal performance of public primary school in upper Egypt that experienced hot arid climate. The aim of the study was to identify how much the pupils achieve thermal comfort conditions in their classrooms. Field measurements were carried out over three days where data loggers measured the operative temperature, relative humidity and air velocity during the students' lesson hours. An acceptable temperature in the range between 25.5 to 29.5°C was observed. In Medina Ghana Appah-Dankyi & Koranteng, (2012) investigated peoples' perception of comfort as well as the prevailing thermal conditions in naturally ventilated classrooms located in the warm and humid climate. The study employed the use of subjective assessments through questionnaires and physical measurements. The measured environmental parameters required the use of Hobo data sensors which measured temperature and relative humidity values. Results showed that the indoor air temperature in the occupied zones were between 29.4-32.3°C with indoor relative humidity in a range of between 60.8-74.2%. In Khartoum Sudan (a sub-Sahara country) Elsherif et al (2014) conducted study in six houses by adopting cross-sectional questionnaire written in Sudanese Arabic language to gather data from 99 participants with a view to understand the underlying thermal comfort issues in relation to those of airconditioned (AC) residential buildings. Three house were fitted with AC while the remaining were naturally ventilated. The analysis of the thermal performance in the six houses show that NV spaces in Khartoum during the summer are very uncomfortable. In Nigeria, Sen (2011) examined the issue of classroom design in primary schools in Nigeria by considering the micro-climatic conditions. The paper recommended that local climate should not be overlooked when designing elementary schools in Nigeria. Ogini (2011) assessed the building envelopes and thermal performance of public primary schools classrooms in Lagos Metropolis, Nigeria. Questionnaires were adopted to gather subjective data from the school children while objective measurement was carried out to record air temperature and relative humidity according to class 11 field experiment method in consonance with ASHRAE'S stipulated standards. Findings showed that comfort temperature between the range from 25.0 to 31.0^{o}C and neutral temperature of 27.0^{o}C were observed. The author recommended shading classroom layouts with verandas, galleries and with deep eaves on both wings of the classrooms to reduce direct penetration of solar radiation. Toyinbo et al (2019) assessed the indoor environmental quality of primary schools located in South Western Nigeria, where a total of 15 classrooms were randomly selected for the study. Data loggers were used to measure the indoor and outdoor temperatures, the relative humidity, the carbon monoxide (CO) and the carbon dioxide (CO_2). Results showed that the comfort temperature range was between 26.0 to 29.0^{o}C. The study however did not take advantage of the data obtained from the schoolchildren and their teachers to compare their comfort temperature.

Reports from literature showed that the acceptable range of temperature in classrooms vary from one study area to another, suggesting that no specific thermal comfort standard exists. Acceptable temperature varies from place to place because the context, culture, buildings, and climate that are unique to a place could imply that the comfort needs and expectations of its inhabitants may not be the same (Nicol et al., 2012). Yao et al., (2009) equally expressed the common concern that thermal comfort conditions be verified in the local context where local climate, culture and social backgrounds may have an influence on the thermal comfort perception of the inhabitants. Trebilcock et al., (2017) confirmed this argument, in a field study, where a correlation between thermal comfort and socioeconomic backgrounds of the participants was found. It is therefore evident that the comfort ranges and/or neutral temperatures can be significantly different from one location to another.

Table 2. 4. Summary of children's comfort/neutral temperature from previous studies

Some Previous Studies	Location	Climate	Season	Vent*	Age	Respondents	Comfort range (ºC)	Neutral temp (ºC)
(Karyono & Delyuzir, 2016)	Indonesia	Tropical Warm and Humid	Dry and Rainy	NV	8-13	501	26.9-29.5	28.2
(R. de Dear et al., 2015)	Australia	Subtropical	Summer	NV, AC	10-18	2850	18-27.5	22.4
(Pereira, Raimondo, Corgnati, & da Silva, 2014)	Portugal	Mediterranean	Mid-season	NV	16-19	45	22.1-25.2	-
(Shamila Haddad, Osmond, King, & Heidari, 2014)	Iran		Spring	NV	10-12	1605		22.8
(Trebilock & Figueroa, 2014)	Chile	Mediterranean	Winter/Spring	NV	9-10	2100		21.1summer
(Nematchoua et al., 2014)	Cameroon		Tropical	NV			23.4-25.8	
(Alfano, Ianniello, & Palella, 2013)	Italy	Mediterranean	Winter and summer	NV	11-18	App. 4000	-	20
(Teli et al., 2012)	UK		Spring	NV	7-11	230		20.8
(Liang et al., 2012)	Taiwan	Subtropical	Whole year	NV	12-17	1614		Autumn 22.4 Spring 29.2
(K. E. Al-Rashidi, Loveday, & Al-Mutawa, 2009)	Kuwait	Hot dry	Mid season	AC	12-17	336	19-23.5	21.5
(Hwang, Lin, Chen, & Kuo, 2009)	Taiwan	Sub tropical	Mid season and Winter	NV	11-17	1614	22.7-29.1	17.6-30.0
(Wong & Khoo, 2003)	Singapore		Summer	NV	13-17	493		28.8
(Kwok et al., 1998)	USA		Winter and Summer	NV, AC	13-19	NV 2181 AC 1363	22-29.5	NV 26.88 AC 27.48
(A Auliciems, 1975)	Australia	Subtropical	Winter	NV	8-17 12-17	--		Primary 24.2 Secondary 24.5
(Michael A Humphreys & MA, 1976)	UK	Temperate	Summer	NV	7-11	262	24-26	-
(A Auliciems, 1973)	UK	Temperate	Summer	NV	11-16	624		19.1
(Pepler, 1972)	USA	Temperate	Mid-season Winter	NV, AC	7-17	NV 100 AC 66		NV 21.5-25 AC 22-23
(A Auliciems, 1969)	UK	Temperate	Winter	NV	11-16	624		16.5
(Toyinbo et al, 2019)	South west, Nigeria	Warm-Humid	Rainy and Dry seasons	NV	Not mentioned	Pupils 106-371 Teachers 13-30	26-29	No result
(Ogini, O (2017)	Lagos, Nigeria	Warm-Humid	Rainy and dry seasons	NV	<11	-	25-31	27.0
Sen, G (2011)	Nigeria	-	-	NV	-	-	-	-

2.8.2 **Thermal Comfort Studies in Nigeria**

While browsing the literature, few thermal comfort field studies were found in Nigeria and most of them were conducted in residential buildings and few in offices and in university hostel (Table 2.5). The subjects used for the experiments were all adults and no young child was included in the experiments. From available records, the pioneers of thermal comfort studies in Nigeria are Ambler, H.R and Peel, M.C. Ambler, (1955) recorded information on the climate of Nigeria and observed the thermal comfort of male Europeans based in the country. Effective temperature was used as index to assess their thermal conditions. Result from the study showed that appreciable discomfort to the Europeans occurred when effective temperature was above 80^{o}F (22.6^{o}C). Peel investigated the physiological reactions of nursing students to their thermal environment in Kano, a hot climate. Result from the investigation conducted by Ambler indicated that a maximum comfort was achieved at the air temperature of 23.9^{o}C with 37% as the relative humidity.

Following the footsteps of these earlier researchers is Ojosu et al who conducted various thermal comfort research in the 80's (Ojosu et al., 1988). Later researchers such as Odim (2008) conducted experimental studies of comfort levels of East-West and North-South solar orientation buildings in a warm and humid climate of Nigeria. The primary data obtained were the indoor air temperature and indoor relative humidity while the secondary data were the outdoor air temperature, outdoor relative humidity and, air velocity. Results showed that the comfort levels of the buildings did not confirm to comfort standards, despite their orientation. Ogbonna & Harris (2008) conducted a thermal comfort survey in a total of 29 naturally ventilated residential buildings as well as in three university classrooms, in the city of Jos, during the rainy season in July and August. The approach of the study was based on the theory of adaptive comfort which posits that physiological factors play equally-central roles in the perception and interpretation of thermal comfort. Results reported 26.27^{o}C as the neutral temperature of the subjects which closely tracked the average outdoor temperature of 26.3^{o}C. Jimoh & Demshakwa (2020) aimed to understand the concept of thermal sensation in order to establish neutral temperature for office users in Jos, Nigeria. The study was carried out in the month of May where the CO_2 levels, wind velocity, operative temperature and humidity were recorded while the subjective data was collected from questionnaire administered to the participants. The study established a neutral temperature of 29.4^{o}C which is by 4.34^{o}C higher than that established by Ogbonna & Harris (2007) in similar locality (Jos). The author posited that the difference in the neutrality between these two surveys is likely as a result of the different buildings adopted in the surveys. Ojo & Lawal (2011) assessed the thermal performance of residential buildings that have different design characteristics in Ibadan, Nigeria a warm humid climate. The paper recommended that achieving the desired internal comfort for the occupants, requires adequate consideration to effective building architecture, with emphasis on window openings. Abiodun (2014) investigated thermal comfort and occupant behaviour in a naturally ventilated hostel block in Ile-Ife, Nigeria, a warm humid climate zone. Results indicate that all the measured environmental parameters fell below the comfort range recommended by ASHRAE 55 and ISO 7730 standards. However, respondents were comfortable and preferred cooler environment and more air movement. Uzuegbunam (2011) concerned with the need to reduce the high consumption of fossil fuel energy did evaluate the effectiveness of passive ventilation of students hostels in the hot-humid tropical environment of Eastern Nigeria. The study found significant correlation between design strategies and passive ventilation in the students hostels of the study area

Table 2. 5. Some thermal comfort research studies conducted in Nigeria

Location	Previous Studies	Climate	Building Type	Respondents	Season	Comfort Temperature
Okigwe	Okafor & Onyegiri (2019)	Warm Humid	Res	Adults	Dry Season	1. Traditional building recorded mean Indoor temp 28.2°C both seasons. 2. Contemporary building recorded mean indoor temp of 28.7°C for both seasons 3.Occupants of traditional building accepted indoor conditions more than occupants of contemporary buildings
Enugu	(Efeoma, 2017)	Hot Humid	Office	Adults	Rainy and Dry	1.Regression equation: TSV =0.250 T_{op} -7.197 2.Neutral temperature T_n = 28.80°C 3. Acceptable comfort range: 25.4-32.2°C
Abuja	(Adaji et al., 2017)	Hot Humid	Res	Adults	Dry Season	1. Regression equation house 1: TSV =0.46 T_{op} -9.62 2. Regression equation house 2: TSV =0.31 T_{op} -4.74 3. Neutral temperature house 1 T_n = 29.6°C 4. Neutral temperature house 2 T_n = 28.2°C
Ibadan	(Adunola, 2012)	Hot Dry	Res	Adults	April	1. Regression equation: TSV =0.483 T_{op} -15.59 2. Neutral temperature T_n = 32.3ºC
Ogun	Adebamowo & Akande	Warm Humid	Hostel	Adults	-	1. Regression equation: TSV = 0.24 T_{op} -6.982 2. Neutral temperature T_n = 29.09ºC
Bauchi	(Akande & Adebamowo, 2010)	Hot Dry	Res	Adults		1. Regression equation: TSV =0.357 T_{op} -10.2 (Dry season) 2. Regression equation: TSV =0.618 T_{op} -15.4 (Rainy season) 3. Neutral temperature rainy season T_n =28.44°C 4. Neutral temperature dry season T_n = 25.04°C
Jos	(Ogbonna & Harris, 2008)	Temperate Dry	Res & Classroom	Adults	July & August (Rainy season)	1. Regression equation; TSV =0.3589 T_{op} -9.4285 2. Neutral temperature T_n = 26.27°C 3.Acceptable comfort range=25.5-29.5°C Top 4. PMV neutral temperature T_n = 25.06°C
Jos	Jimoh & Demshakwa (2020)	Temperate Dry	Office	Adults	Rainy	1. Neutral Temperature = 29.4°C
Lagos	Adebamowo	Warm Humid	Res	Adults		1. Neutral temperature T_n = 29.09°C
Ibadan	(Akingbade, 2004)	Warm Humid	Res	Adults	Dry Season	1. Comfort range 28°C-32°C
	(Ojosu et al., 1988)	1.Temp Dry 2.Hot Humid 3.Warm 4.Humid	Office	Adults		1. Acceptable comfort zone=21-26°C 2. Acceptable comfort zone=18-24°C 3. Acceptable comfort zone=21-26°C 4. Acceptable comfort zone=21-26°C
P/Rivers	Amber (Pandolf et al., 1976)	Warm Humid		Adults		1. Neutral temperature T_n = 23.13°C

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Furthermore, Sangowawa et al., (2016) did a case study in office buildings in Lagos, a warm humid climate, to evaluate the indoor environmental quality. Results showed that more than 60% of the surveyed offices did not meet the International Standards for the indoor environmental parameters; however, the subjects still indicated satisfaction at their workplace indoor environment. A Post Occupancy Evaluation (POE) was conducted to determine the very component of Indoor Environmental Quality (IEQ) that usually gives the students in the studio classrooms the most concern to classroom work in university studios in a warm and humid climate during January. Questionnaires and observations were data collection methodologies. The result of the study showed that thermal comfort was considered the number one component of the IEQ components that gave the students the highest concern to comfort indoor comfort. Alozie & Alozie, n.d. investigated the impact of air temperature in the thermal comfort of indoors of residential buildings in Umuahia, Nigeria through questionnaire survey and field measurements of environmental parameters and building characteristics during the rainy season and dry season. Result revealed that only 29.7% of the residents accepted the indoor thermal comfort, attributed to poor design of the buildings. Adaji et al., (2017) carried out thermal comfort case study with a view to understand the ideal and preferred conditions of thermal comfort in low-income buildings in Abuja, Nigeria. Methodology used in the study included environmental monitoring, post-occupancy and comfort surveys. The environmental monitoring was carried out during the dry season from March to April. Results produced 29.6^{o}C and 28.3^{o}C as neutral temperature and preferred temperature, respectively, from a section of the residents, while the other section of the residents in Abuja reported a neutral temperature of 28.2^{o}C with 25.4^{o}C as the preferred temperature. Adebamowo & Olusanya, (2012) conducted a thermal comfort field study of a hostel block in Abeokuta, Nigeria, a warm and humid environment. The aim was to investigate the comfort temperature and the occupant's behaviour in the hostels. Results produced a neutral temperature of 29.09^{o}C, with highest percentage of adaptive action votes on window opening in both seasons (rainy season and dry season). Tammy Amasuomo & Oweikeye Amasuomo (2016) investigated the relationship between students' perceived behaviours and learning in a sampled lecture theatre in Niger Delta University Nigeria, that experiences a warm and humid climate where the surveyed students were randomly selected. Objective and subjective approaches were adopted in the survey. The objective instrument measured the indoor temperature and relative humidity while the self-report instrument was a questionnaire that asked questions about the indoor thermal conditions. Results showed that thermal discomfort in the indoor space had an influence on stress behaviours which can affect learning. Efeoma (2017) investigated to what extent regulated office clothing affects the perception and adaptation of office workers in Enugu, Nigeria to the thermal conditions using a field study approach. The environmental parameters; air temperature, relative humidity and air velocity were collected as quantitative data while observations was part of the qualitative data. Results showed that 80% of thermal satisfaction was in a comfort range of between 25.4 to 32.2^{o}C with 28.8^{o}C as the neutral temperature. Furthermore, the thermal comfort vote indicated that approximately 85% of office workers with flexible clothing policies were comfortable, at that uniform, whilst only 55% of workers who had to adhere to strict uniform policy voted that they were comfortable. The above studies were mostly carried out in residential and office buildings and theatre/studio classrooms and the participants used in the evaluation were adults only, leaving a gap of the non-understanding of comfort temperature for children. Furthermore, most of the surveys were carried out in limited time (mostly one month) and did not cover the two seasons experienced in Nigeria. Commonalities observed in these studies were the use of the random method in the selection of the surveyed subjects and the use of questionnaire in the collection of data from the participants

2.8.3 Thermal comfort and Buildings

One of the functions of a building is to provide the microclimate required for human habitation and the architectural design is one of the factors that determine the thermal conditions of the occupants. The construction and operation of buildings account for over 70% of global greenhouse gas emissions (Brandon et al, 2010). A significant portion of the end-use energy in buildings is dedicated to maintaining thermal comfort (Pérez-Lombard, Ortiz, & Pout, 2008). To maintain this thermal comfort nearly 30% of global carbon emission, primarily due to the need to heat or cool indoor spaces, is generated by buildings alone (Vellei et al., 2017).

However, there are some discordant tones among researchers regarding the relationship between building related features and thermal comfort. While a good number of researchers posits that relationships exist between these two variables, a few others argue that no relationship exists between the two. For example, Elwefati (2007); Frontczak & Wargocki (2011) and, Ojo & Lawal (2011) all argued, from their various findings, that the architectural elements, including location, the topography of a building along with outdoor climate and season all play a great role in influencing the thermal comfort of the building. Zomorodian et al., (2016) further added that the layout, spaces, dimensions, window-wall ratios of a building have relationships with the thermal comfort of building occupants. Literature reviews on various thermal comfort studies in different types of buildings indicate that occupants have different levels of perception of the indoor environment because of the differences in the site-specific context, culture, buildings and, climate particularities of the people (Akingbade 2004). Apart from human capital (teachers), physical capital (school building condition) also has the most influence on student achievement (Crampton 2009). Behaviours such as in-school use of alcohol also influence student achievement (Kumar et al, 2008). Also, absenteeism and dropout rate are also contributors to the poor achievement of students (Evans Yao & Sipple 2010).

Furthermore, Okafor & Onyegiri (2019) compared the thermal conditions of traditional and contemporary building types in the same location and observed some significant differences in their thermal performance. The differences were attributed to the different type of materials used in the construction of the two buildings. The consensus from these various arguments is that the internal environment of a building can create conditions that enhances thermal satisfaction of building occupants. In order words, buildings can adjust an internal environment to produce a satisfactory internal space for human occupation. Furthermore, studies on environmental comfort and educational buildings have suggested that new buildings provide better natural lighting, thermal comfort and indoor air quality than old buildings (Schneider, 2002). Teli et al., (2012) investigated the thermal comfort of children in naturally ventilated classrooms in Hampshire, England and observed some differences in thermal perception of the occupants. The author suggested that apart from environmental and personal parameters, building related factors, such as classroom orientation, rooms' design, solar shading orientation etc, may have influenced the perception of thermal comfort by the occupants. Ojo & Lawal (2011) assessed the thermal performance of residential buildings in the warm humid climate of Ibadan, Nigeria by comparing the efficiency of different building types. Result showed a very strong relationship between building type and ambient temperature. Alozie & Alozie, n.d. in a field survey conducted in some selected naturally ventilated buildings and observed that the building occupants felt thermally uncomfortable because of the poor architecture of the buildings. Zomorodian et al., (2016) and a host of other researchers argued that on the issue of thermal perception, no relationship exists between the students' thermal perception and the classroom architectural and constructional characteristics. However, the majority of research works indicated that building components (such as roof, walls, windows, doors, etc), indeed, influence the indoor thermal environment.

The roof, walls, windows, doors, floors constitute the building fabrics. The building fabric controls the flow of energy between the interior and exterior of a building. It can play an important role in sustainable buildings, by reducing the energy consumption and maintaining the indoor thermal comfort of the occupants. The heat absorption of a surface depends on the capacity of the building materials to reflect, absorb, and store radiation. The heat storage capacity of building materials is expressed by the thermal mass which is a function of material density and specific heat (Gregory, Moghtaderi, Sugo, & Page, 2008). A low thermal conductivity and appropriate heat capacity design of the building envelope or fabric can potentially reduce the heat gain or loss through the building components (Ramesh et al, 2012). Emmanuella & Alibaba, n.d. further posited that construction materials such as concrete, brick, cement block and other solid masonry materials used in the tropics are considered as having high thermal mass and are considered very effective against rapid heat transfer, which is due to their abilities to absorb heat from solar radiation at much slower rate than lightweight materials. The ambient temperature, solar access, humidity, wind patterns, and diurnal temperature variation of a location all influence the behaviour of thermal mass. An effective way to minimize energy consumption in warmer climates is to select building materials that contribute to cooling the indoor temperature. The characteristics of any building in terms of the materials used in the construction of the walls and the floors, including the type of doors, windows, ceiling, and the type of roof and the design determine the thermal condition of that building and to a large extent, the thermal perception of building occupants.

Thermal mass is the ability of a material to store energy at one point in time and release this energy later. Thermal mass depends on the relationship between the specific heat capacity, density, thickness and conductivity of the material. The measures of the heat flow through a material, which is also the ratio of heat transmittance to heat storage (conductivity divided by density and specific heat) is referred to as diffusivity, and diffusivity is dependent on the relationship between the specific heat capacity, density, thickness and conductivity of a material (Davies, 2004). For any given conductivity, the higher the density and specific heat, the lower the diffusivity. Concrete and bricks exhibit low diffusivity because it has very low conductivity, despite its thermal mass. Steel also has high thermal mass, high density and specific heat; however, the high thermal conductivity makes for high diffusivity and hence high heat flow through the materials. From the discussion in the literature, it is understood that the thermal perception of building occupants can be influenced by the building fabrics. Furthermore, the building fabric must be protected from direct impact of solar radiations, using different shading strategies.

Shading devices seem to be overlooked when considering reduction of heat gains in indoor spaces. Properly shaded indoor spaces enhance the effectiveness of indoor ventilation. Appropriate shading of windows, the doors including the external walls can significantly reduce solar gain inside the building by preventing the solar heat from reaching and entering interior spaces. Windows shaded from outside can reduce the solar heat gain considerably. Shadings act as important solar gain controls provided that their design and installation do not compromise the comfort of the building occupants. A well-designed overhang, on windows, can considerably shade the window from solar impact. Other shading strategies are roof overhangs (eaves), balconies, and trees. Roof is the most important elements of the exterior building envelope because it is exposed to the solar radiation for most part of the day. Figures 2.14 and 2.15 show the various shading devices.

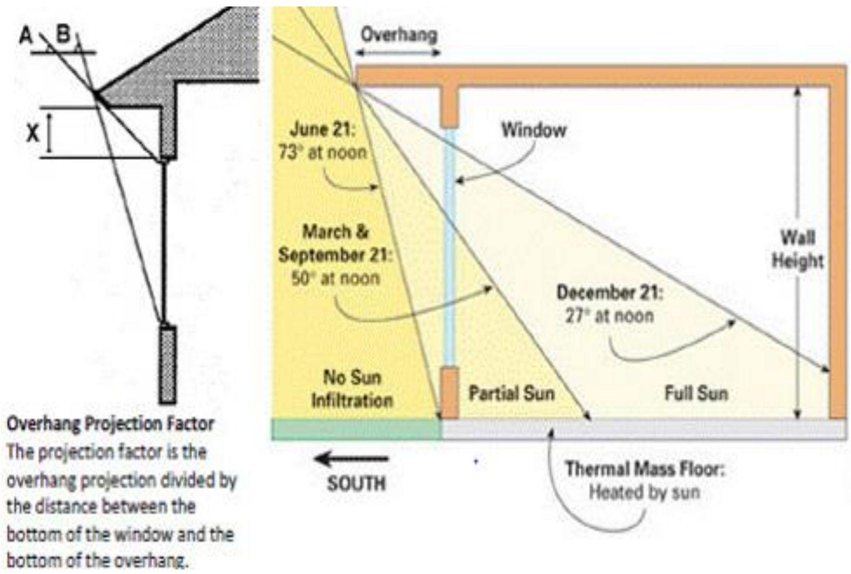

Figure 2.14: Shading device using appropriate design

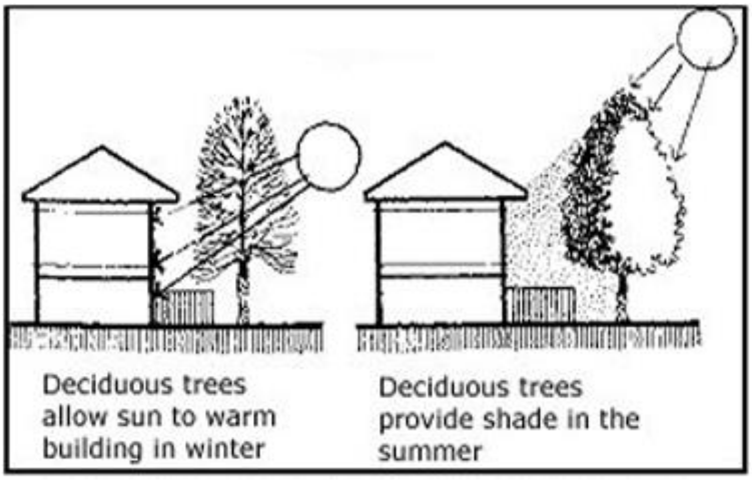

Figure 2.15: Shading device using trees

Furthermore, the continuous exchange of heat between the building envelope and its outdoor and/or indoor environment depends on the thermal characteristics of the building envelope. According to (Ghaffarianhoseini, Berardi, & Ghaffarianhoseini, 2015), the design of the building envelope is based on several best practices for sustainable architecture, basically aimed at reducing cooling and heating loads (especially in the cold climates), and enhancing natural ventilation to accommodate air changes and heat dissipation (especially in the hot climates). Where climate requires heating loads dissipation, minimizing energy consumption by using passive technologies such as natural ventilation is considered as an appropriate action in buildings located in the tropics. However, heat gains through exterior window accounts for 25-28% of the total heat gain (Al-Tamimi, Fadzil, & Harun, 2011). In addition, the thermal capacities of various materials respond differently on incident solar radiation (Stein and Reynolds, 2000). It is the opinion of many researchers such as, Nicol et al., (2012), Teli et al., (2013), Mishra & Ramgopal (2015), Lança, Coelho, & Viegas (2019) from their various field works that natural ventilation is an important consideration in energy savings and the comfort of building occupants.

Table 2. 6. Thermal properties of typical building materials

Material	Density Kg/m^3	Thermal conductivity W/mk	Specific heat J/kgk	Diffusivity M^2/s	Thermal mass
Timber	500	.13	1600	1.6	Low
Steel	7800	50	450	1.4	Low
Pre-cast and In-situ blocks	2300	1.75	1000	7.6	High
Brick and dense block	1750	.77	1000	4.4	High

(**Source:** Ghattas, Ulm, & Ledwith, 2013)

Ventilation types: Ventilation is the process of exchanging or removing air from a space for the purpose of providing high indoor air quality, controlling humidity or temperature within the space. The purpose of ventilation is to provide fresh air to cool the body or to remove accumulated noxious gases and contaminants and to remove heat generated in a working area by convection. Classroom spaces have different types of ventilations and the essence is to provide comfortable indoor comfort, and they are either mechanical ventilated, natural ventilated or have mixed mode ventilation. Mechanically ventilated spaces are ones that are ventilated by equipment such as motor-driven fans and blowers Schiavon, Hoyt, & Piccioli, (2014), while mixed mode ventilation, also known as hybrid ventilation, refers to a combination of natural ventilation (from operable window) and mechanical system. Naturally ventilated buildings do not ventilate the indoors with any form of mechanical means, and this type of ventilation is mostly available in Nigeria.

Naturally ventilated spaces refer to the flow of external air to an indoor space without the use of mechanical systems, but rather depending solely on the pressure differences arising from natural forces. When wind flows around a building, the windward and leeward areas witness a drop in pressure. The openings in the building will take advantage of the dynamic pressure drop to drive air through these openings helping to remove the heat and pollutants from the indoor space. This is diagrammatically shown in Figure 2.16. The difference in wind pressure between the openings on the high- and low-pressure sides is important to adequately remove the heat and pollutants from the space.

Authors analysed the factors affecting indoor air temperature in the tropical climate paying particular attention to indoor comfort level. Results demonstrated that the indoor thermal comfort is increased by natural ventilation system, while energy consumption decreased by 31.6% with respect to a typical mechanically ventilated one (Beccali, Strazzeri, Germanà, Melluso, & Galatioto, 2018). Designing naturally ventilation can be extremely complex because of the interaction between cross ventilation and the stack effect, especially in a building that has a complex design. Natural ventilation can also be influenced by occupant behaviour, for example, a person near to a window may choose to close it. However, if this is done against the wish of the other occupants it may cause thermal discomfort to them.

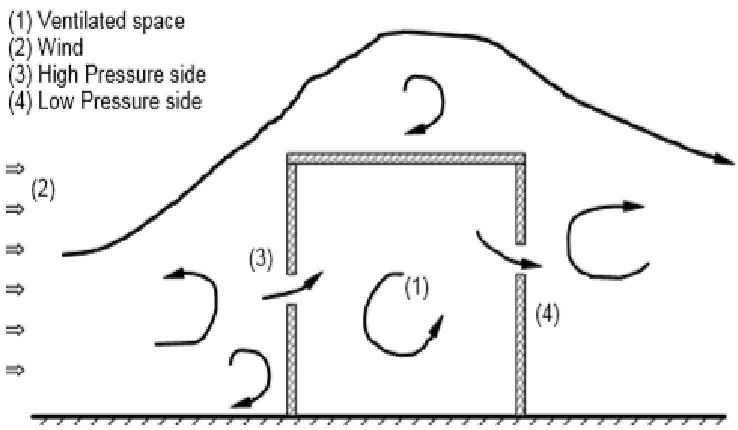

Figure 2.16: Schematic of wind driven cross ventilation through a single space

Furthermore, natural ventilation provides indoor environments that are more stimulating and pleasurable compared to the static indoor climate achieved by centralized air-conditioning (Gail Brager, Paliaga, & De Dear, 2004; Jørn Toftum, 2004). In the humid tropics characterized by high temperature and relative humidity with low wind velocity, one strategy for buildings in providing relatively satisfactory indoor space is the use of natural ventilation to enhance evaporative and convective cooling of occupants (Tammy Amasuomo & Oweikeye Amasuomo, 2016). The role of natural ventilation as an energy conservation strategy is a path towards more sustainable buildings. Natural ventilation is an energy conservation method which may help reduce buildings' energy consumption, improves thermal conditions and maintain healthy indoor environment (Gratia & De Herde, 2003). Reduction in energy consumptions in buildings can also be achieved through night ventilation. According to Lança et al., (2019) night cooling is a relatively simple strategy that can effectively reduce indoor temperatures during the summer time and account for overall energy reduction in buildings. This effect of cooling the buildings during the night time has been extensively reported in various research works of (Ji, Lomas, & Cook, 2009; Ramponi, Angelotti, & Blocken, 2014; Schulze, Gürlich, & Eicker, 2018).

In its Fourth Assessment Report in 2007, the IPCC Working Group iii Levin, McDermott, & Cashore (2008) identified the building sector as possessing the greatest potential for deep cuts in CO_2 emissions. Levin et al further pointed out that emissions from the building sector attributable to electricity use were about 8.6GtCO equivalent to a quarter of the global total. With buildings accounting for up to 40% of energy use in developed economies, regulatory and economic pressure are mounting to reduce the sectors' greenhouse gas emission. For significant CO_2 reduction to be realised, it is important that sustainable buildings (both newly built and renovated) meet some energy saving requirement benchmark. It has been established that behavioural change in buildings can deliver fast and zero-cost improvements in energy efficiency and greenhouse gas emission reductions and naturally ventilated buildings seem to encourage this behavioural adjustment. In order to provide such behavioural opportunities, or adaptive opportunities, buildings must be designed to re-engage 'active' occupants in the achievement of comfort. Furthermore, naturally ventilated buildings are 40% less in operation energy cost when compared to mechanically ventilated building (CIBSE, 2007).

Natural ventilation can be classified into three different types and these are; single sided ventilation, cross ventilation and stack ventilation. These ventilation strategies influence the indoor ventilation efficiency and airflow pattern resulting to different indoor thermal conditions. In single ventilation, the air enters and leaves at the same side of the room, while in stack ventilation the thermal buoyance and wind pressure would cause the pressure difference between two openings, on the same side of the wall, and then encourage the stack affect. In cross ventilation, both sides of the walls have openings so that air flows from one side of the opening to the other side, bringing airflow across the entire room, and at the same time carries off the heat and pollutants from indoors. Therefore, the windward and leeward pressures are important elements for cross ventilation. Natural ventilation utilization in buildings, compared to mechanical ventilation, has some advantages such as:

- It is fossil fuel free and has no negative impact like air pollution and global warming.
- It requires less construction and operation cost and low maintenance cost.
- It is reliable and easy-to-use in many types of buildings. The potential for personal control of the environment increases user's satisfaction and productivity.

However, natural ventilation has some disadvantages. Some of the advantages are summarized below:

- There is no guarantee in securing a stable indoor environment, compared to the steady conditions of mechanical ventilation
- It is very difficult to naturally ventilate buildings that have deep plans, or those requiring high control levels of indoor environment like in hospitals.
- It guarantees less security and safety, when compared to mechanically ventilated buildings.

2.9 Chapter Summary

Chapter 2 revealed that humans since ancient times have been adopting different creative ways to remain thermally comfortable. As time passed, these methods of providing thermal comfort were improved because of advancements in technology. It is observed from the previous thermal comfort research that thermal comfort perceptions of subjects in naturally ventilated buildings are better determined using ASHRAE standard 55, instead of International Standard Organization prescription such as ISO 7730. Naturally ventilated buildings are predominantly found in the tropical climates. The research area of this study is in Nigeria and is located in the tropics.

Also, the literature review justifies the reason for choosing the ASHRAE adaptive comfort model instead of CEN 15352 to determine the acceptable range of temperatures of the subjects.

Also observed in the literature review of previous research works is that the acceptable range of temperatures predicted by the ASHRAE standard 55 adaptive model is wider than that predicted with the Predicted Mean Votes (PMV). Though the adaptive model is the focus of this study, however, the PMV will be applied in the calculation of the comfort temperature of the children for comparison purposes.

Both the Heat balance model and the Adaptive model have their limitations. Because the adaptive model is the main focus of the study, this research works intends to limit the impact of its limitation by adopting a longitudinal research approach where substantial data will be gathered from a reasonably large group of people.

Chapter 2 further revealed that an overwhelming majority of thermal comfort studies in schools is from the colder climates compared to the warmer zones (tropical climates). The need for more information about the thermal comfort perceptions from other areas where limited studies have been conducted was championed by various thermal comfort researchers.

The current thermal comfort surveys in Nigeria have been mostly conducted in residential buildings, office spaces and hostel blocks. Moreover, the subjects used in the investigation were all adults. According to the literature review, adults are believed to have different activity rates and metabolic rates when compared to that of children. Because of these differences, the comfort temperature of both groups may differ.

Thermal comfort surveys in Nigeria have been mostly performed with few respondents and the evaluation periods were carried out in limited time, covering only one season. Rainy season and dry season are experienced in Nigeria and there is a need to carry out surveys that will cover the two seasons.

From the literature review, various methods (such as acceptability, thermal preference, comfort temperature) have often been used by researchers to assess the thermal requirements of building occupants.

Literature review from previous research works seems to suggest that the comfort temperature of children may differ from that of the adults. Suggestions were made in the various journal articles on the need to do more study on this assumption in buildings located in different climatic zones. This research work intends to determine the comfort temperature of schoolchildren and that of their teachers to do a comparison.

Finally, it was observed from the literature review that thermal comfort researchers carry out investigations focusing mostly on seasonal variation of thermal conditions. There is a need for data collection and analysis to consider the thermal perception of building occupants on the micro-level according to time of day categorized as morning and afternoon hours. This research work intends to fill some of these gaps identified in the literature.

3 Chapter 3: Study Location, Climate and Education in Nigeria

3.1 Introduction

This chapter describes the geographical location and the climate of Nigeria, with a focus on the climate of the study area, Imo State. It further discusses the school system and building pathology in Nigeria.

3.2 Location and climate of Nigeria

Figure 3.1 shows the location of Nigeria in Africa. Nigeria lies between latitude 4°N and 14°N and longitude 3°E and 15°E (Federal Ministry of Environment, 2014). It is boarded on the North, East, and West by Niger, the Cameroon, and the Benin Republic, respectively (Nwilo & Badejo, 2006). Nigeria is located just north of the equator, this makes it experience tropical climate which is characterized by hot and wet conditions associated with the movement of inter-tropical convergence zone both North and South of the equator. The country is typical of the tropical region where the sun is known to be directly overhead at noon and according to Adunola & Ajibola (2012); Eludoyin (2014), 1200 - 1600 Local Standard Time (LST) is the hot discomfort period of the day in the country. The country has a landmass area of 923,768km^2 and lays about 3.0 meters above sea level. With a population of over 180 million people, it is the most populous country in Africa with about 45% of this population within the age range of 0-14 years, majority of whom are of primary school age. By 2050, the population of the country is projected to be more than the United States of America (Nations, 2015). The country comprises 36 states and one Federal Capital Territory with Abuja as the capital. These 36 states are grouped into six geopolitical zones, made up of north-west, north-central, northeast, south-west, south-south and south-east zones.

Figure 3.1: Map of Africa showing the location of Nigeria

Nigeria is in the tropical zone and is defined as the area of land and water between the tropic of cancer (latitude 23.5°N) and the Tropic of Capricorn (latitude 23.5°S). The tropical zone occupies approximately 40% of the land surface on the earth, and it is the home to almost half of the world's population (Dilshan, 2008). Though some variations on climate exist within the tropics, however, 90% of the tropical zones are hot and humid, and the remaining ten percent is desert-like and characterized as hot and dry climate (Baish, 1987). The climate classification globally recognized was developed by (Köppen, 1936), who sectioned the world in five climatic groups; Tropical, Dry, Warm, Boreal and Polar (Lopez et al, 2017). Evans contributed by presenting three types of tropical climates: Warm-humid, Hot-dry, and Monsoon or transitional and added three sub climates upland, maritime desert, and Tropical Island and defined each climate zones using different geographical variables.

Nigeria experiences two major seasons throughout the year, the dry season and the rainy season. For most parts of the country (South East inclusive), the wet season runs from April to the first week of December, while the dry season runs from December to late March. There is usually a short break from the rain during the rainy season in August, a period known as the 'August break'. During the months of November to mid-March, the city is also affected by a weather condition called 'Harmattan', (Iloeje, 2001). 'Harmattan' is often accompanied by a dusty trade wind with excessive dryness having an RH of about 80% (Okonkwo, 2004). The dry season comes with high seasonal temperatures, which is accompanied by West African trade wind blowing from the Sahara Desert in the North. According to the Köppen-Geiger climate classification the three predominant climates experienced in Nigeria are the tropical savannah

(Aw), tropical rainforest climate (Am) and the semi-arid or tropical dry (BSh) climate. (Peel, Finlayson, & McMahon, 2007). Figure 3.2 shows the location of south eastern states in Nigeria

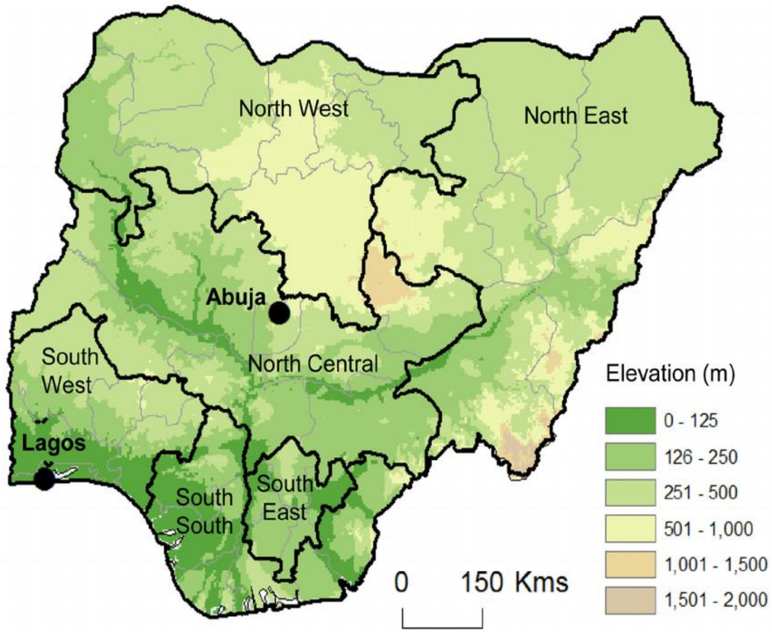

Figure 3.2: Map of Nigeria showing the location of South Eastern States

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3.2.1 Location and climate of Imo State

Imo State is located between latitude 4° 45′N, 7° 15′N, longitude 6° 50′E, and 7° 25′E, and has a population of 3,927,563 people and an area of 5,530km^2. The state is one of the 36 states in Nigeria and one of the 5 states in Southeast Nigeria.. Imo state is bounded by Abia State on the East, Anambra State on the North and, Rivers State to the South. Figure 3.3 shows some of the states that share boundaries with Imo State. Furthermore, Figure 3.4 shows that there are twenty-seven (27) Local Government Areas, (L.G.A.), that make up the state in the three (3) geo-political zones otherwise known as senatorial zones. The three senatorial zones are Imo West (Orlu), Central (Owerri), and East (Okigwe).

This study area is in the South East of Nigeria categorized according to the climatic classification of Köppen–Geiger in the group of tropical climates (Am) (Zomorodian et al., 2016). It lies within the humid tropics and is generally characterized by a high surface air temperature year-round. The mean minimum temperature is 23.5°C and the mean maximum temperature is 32.1°C. Two seasons, wet and dry, are observed in the year. The rainy season begins in mid-April (Okorie, 2015). The rainy season usually lasts till late November. The temperatures are constant throughout the year, with the warmest indoor temperatures mostly reported in February as summarized in Table 3.1. The temperatures also fall within the limit of the mean monthly outdoor temperature (10ºC ≥ 35.5ºC≤) for the adaptive thermal comfort study in naturally conditioned buildings as specified in ASHRAE standard 55. The wind speed in the warm and humid zone area is generally of low strength (Tammy Amasuomo & Oweikeye Amasuomo, 2016). The highest temperature is experienced in January, February and March, while the lowest temperature is observed in October and November. Mean annual rainfall ranges from 2500 to over 4000 mm, with a mean maximum temperature of about 30ºC.

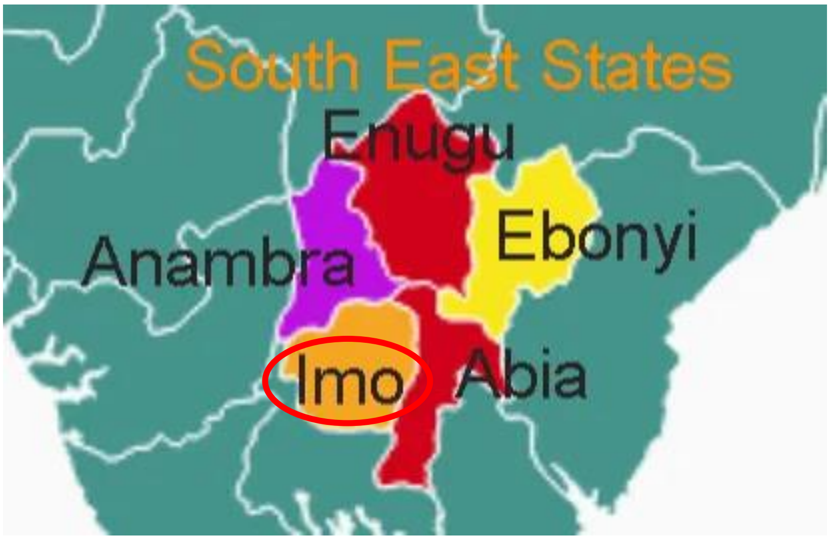

Figure 3.3: Map of South East showing the location of Imo State

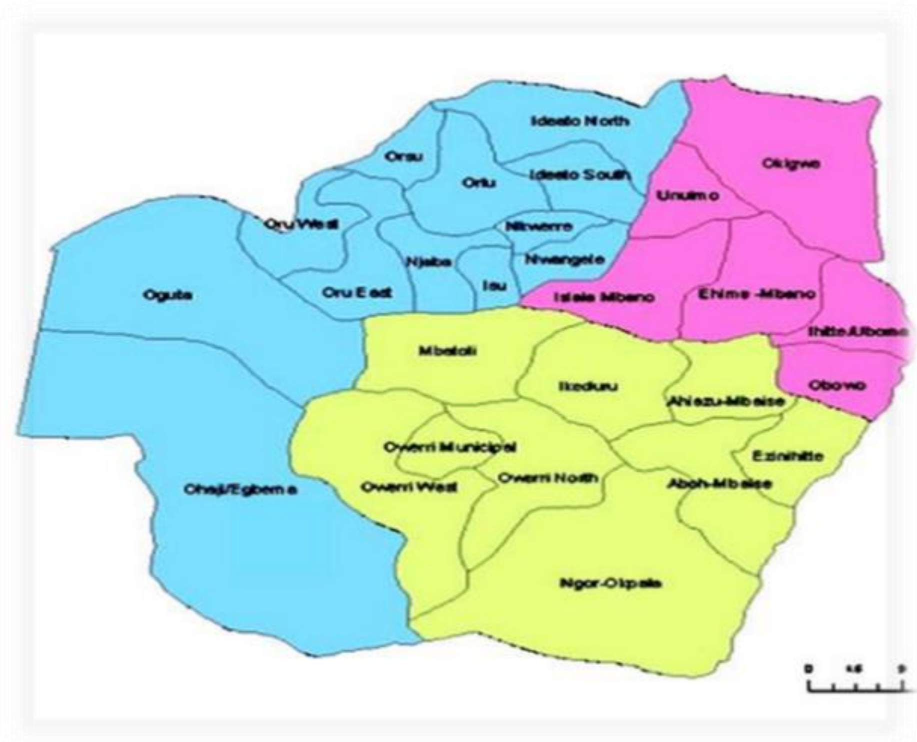

Figure 3.4: Map of Imo State showing the case study areas in the 3 Senatorial Zones.

Table 3.1 summarizes the weather statistics per month for Imo State, while Figure 3.5 presents the graphical mean daily max, min and the hot days and cold nights for a period of 30 years in the study area. The table shows that with an average max temperature of 32.4 ^{o}C, 33.4^{o}C and 32.7^{o}C January, February and March, respectively are the warmest months of the year. The month of July and August presented the lowest max temperature with value 28.7^{o}C for each of the two months. However, the difference between the max temperature in these months did not vary by more than 4.5^{o}C.

Table 3. 1 Tabular view weather statistics per month for Imo State, Nigeria

Months	Temperature (°C)	
	Warmest	Coldest
January	32.4	21.2
February	33.4	22.6
March	32.7	23.2
April	32.1	23.3
May	31.3	23.0
June	30.0	22.6
July	28.7	22.3
August	28.7	22.4
September	29.3	22.3
October	30.2	22.3
November	31.2	22.3
December	31.8	21.3

The climate statistics of an air temperature of Imo State spanning a period of 30 years is summarized in Figure 3.5. The Figure further confirms that January, February and March present the highest maximum temperature in the state. The lowest maximum temperature in the state is experienced during the months of July, August, and September. The dashed lines on the upper part of the graph show the average hottest day, while the dashed lines on the lower part of the graph show the average of the coldest days. Furthermore, Figure 3.6 shows the graphical representation of the mean monthly sunshine hours while Figure 3.7 presents the histogram of average annual and average daily precipitation for Imo State.

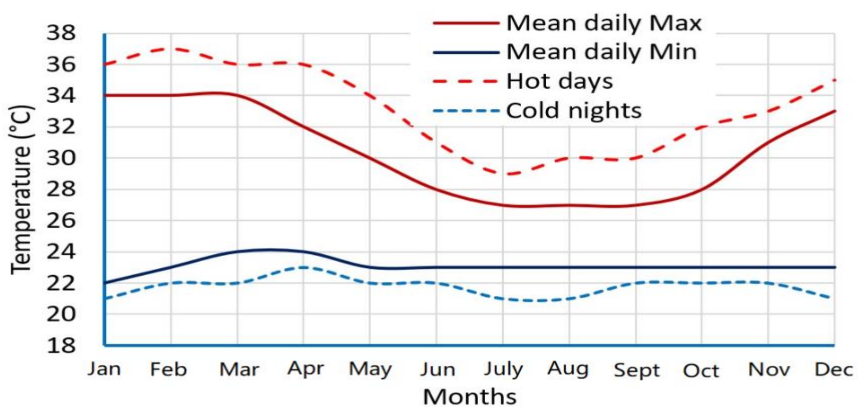

Figure 3.5: Graphical representation of the mean daily max, min, the hot days and cold nights (data taken from local Met Office Nigeria).

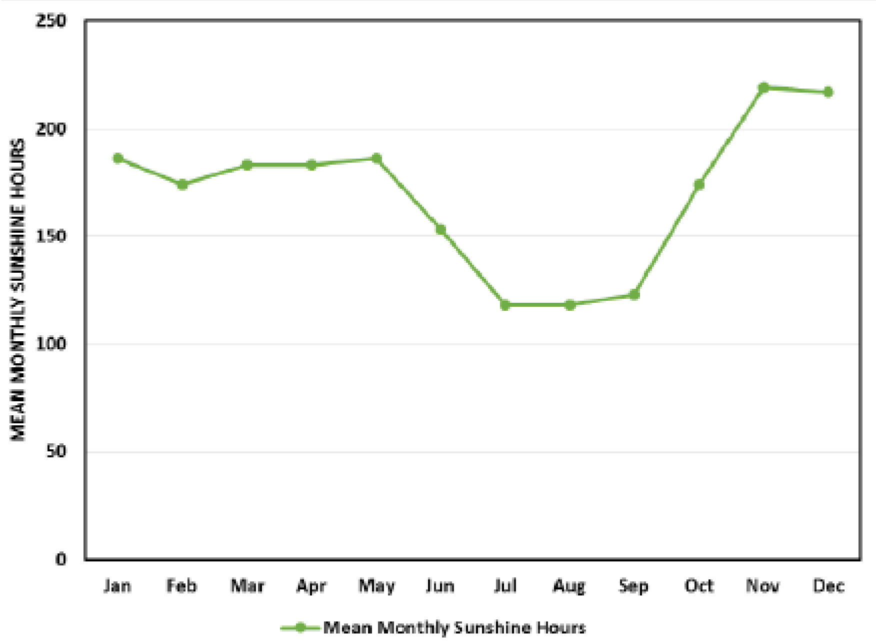

Figure 3.6: Mean monthly sunshine hours in Imo State

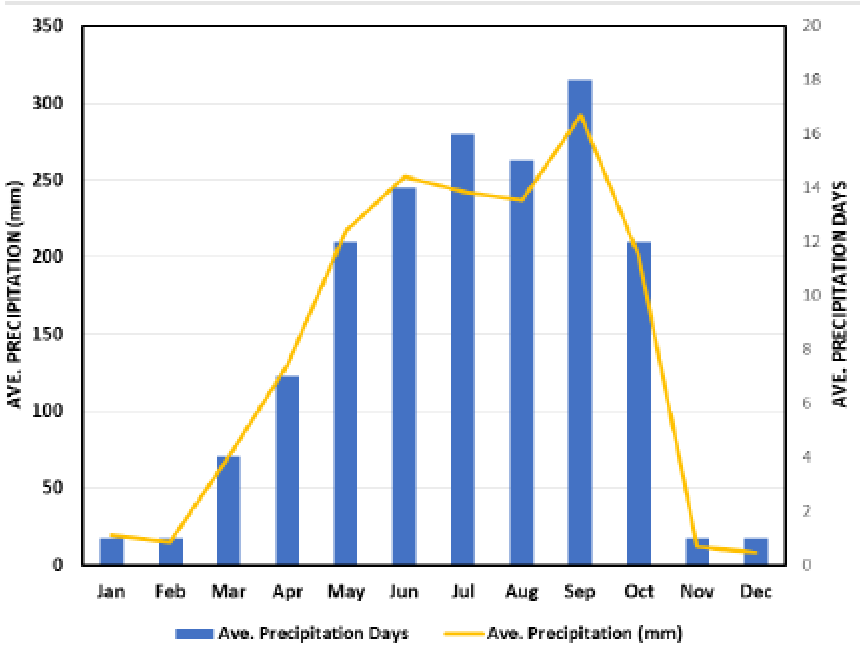

Figure 3.7: Average annual precipitation (mm) and average precipitation days for Imo State

3.3 Climate Classification for Design Considerations

Eludoyin (2014) examined the daytime variations in the physiological comfort of Nigeria and classified the country into two major climatic zones: the warm humid zones of southern Nigeria. The current approved Nigerian National Building Code classified Nigeria into two main climates: hot and dry (Northern Nigeria) and hot and humid (Southern Nigeria) (Federal

Ministry of Housing and Environment). For the purpose of design of thermal comfort in buildings, Ojosu et al., (1988), divided Nigeria into four climatic zones: Hot Dry zone, Temperate Dry zone, Hot Humid zone and Warm Humid Zone. These are briefly discussed below.

Hot-Dry (H.D.) Zone: The diurnal temperature variation for this climatic zone ranges from about 15-20^{o}C. This zone is marked by a long dry season and a short rainy season. The mean annual rainfall ranges from 530-1000mm. Some of the major cities in Nigeria that fall into this zone are Maiduguri, Sokoto, Katsina, Bauchi, Kano, and Yola.

Temperate Dry (T.D.) Zone: For this climate zone, the diurnal temperature range is about 10^{o}C, with a mean yearly rainfall that ranges from 1070 to 1400mm. Some of the major cities, which experience this climate, include Zaria, Kaduna, Jos and part of Abuja.

Hot-Humid (H.H.) Zone: The daily temperature variation between the highest and lowest temperature is less than 10^{o}C. This zone also experiences mean annual rainfall that varies from 1180 to 1800mm. Some of the major cities within the climatic zones are part of Abuja, Enugu, Bida, Lokoja, Ilorin, Oshogbo, Ibadan and Onitsha.

Warm-Humid (W.H.) Zone: The study area is located in this climatic zone. The temperature variation throughout the year in the zone is low compared to other climate zones in Nigeria. The difference between the maximum mean daily temperature and the minimum mean daily temperature is approximately 4^{o}C, with a mean yearly rainfall of 1190 to 2800mm. Some major cities in this zone include Owerri (Imo State), Port Harcourt, Calabar, Benin City, Lagos, Warri, and Asaba.

3.4 Primary Education in Nigeria and Facility

3.4.1 Brief History of Education in Nigeria

The modern state of Nigeria originated from British colonial rule at the beginning of the 19th century, and in 1914 Britain united the Southern Nigeria Protectorate and the Northern Nigeria Protectorate into one nation called Nigeria. An administrative and legal structure was set up by Britain. An indirect rule was practiced through traditional chiefdom. Nigeria got independence in 1960 and has been alternated between democratically-elected civilians' government and military dictatorships until it achieved a stable democracy in 1999.

Education is 'the knowledge and development resulting from the process of being educated'. (Merriam-Webster Dictionary). The period of education, when considered from the Hellenistic period(500BC-200BC), was the time education was generally conducted in the open air, sometimes in the shadow of a temple, or in an enclosure that would barely protect the students from the harsh weather (Castaldi, 1977). A similar form of educational set up took place in Nigeria as soon as the British officially berthed at the shores of the country in about 1851 and formally got the country annexed in 1861, and in 1901, Nigeria became a British protectorate. The British immediately encouraged their representatives to play key administrative, business and religious roles in the country. These representatives were; colonial masters who came as administrators, the British industrialists who came in because of commerce and the Christian mission who came in as the religious. These representatives ensured that the indigenes learned about foreign ways of life and language. For instance, the Christian missionaries, in 1842, introduced western education and started educating young children. The first school named St Thomas Anglican Nursery and primary school, was established by Methodist Church in 1843 at Badagry, Nigeria. Later, a host of other schools were established in other parts of the country. Initially, the colonial government was reluctant to finance these established primary schools. The missionary took up the responsibility through Sunday collections (after church service) and from philanthropic donations (Adesina, 1982; Fafunwa, 2018). Youths in Nigeria school system consist of six years of primary education and near to half of the population falls within the age of 0-14years. Children are expected to start schooling at the age of 6 and finish at the age of 12.

In Nigeria, there are three regions; the Western region, the Eastern Region, and the Northern region. The governments of the Western region and the Eastern region established the Universal Primary Education (UPE) in 1955 and 1957, respectively. This resulted in the high increase in primary school enrolment from 240,000 children, in 1947, to 982,755, in 1957 in the Western region, and in the Eastern region, the enrolment increased from 320,000 pupils, in 1947, to 1,209,167 pupils in 1957 (Fafunwa, 2018). Though the Northern region lagged in pupil's enrolment, however, the enrolment had a high increased from 66,000 pupils in 1947 to 205,769 pupils in 1957. The financing of primary education later came under the regional governments between 1960 to 1967. With the creation of states in 1967, the responsibility was carried by the state governments. In the recent years, the high enrolment of pupils has been achieved. For instance, there were 24,071,559 primary school children enrolled in 2013 as against 21,857,011 pupils enrolled in 2009 which represents an increase of 10%. In 1998 there were 41,814 primary schools in Nigeria (Asodike & Ikpitibo, 2013). By 2011 the number increased to 58,595 (World Data on Education, 2011).

There are two types of school systems in Nigeria; Government (public) and private (Härmä, 2013). The differences among the two are related to ownership, administration, economic levels of the families. The government schools receive all their funding from the state, which owes them, while individuals or religious organizations owe primary schools. The existence of an educational system, at whatever level, cannot be in isolation of the school facilities as this constitutes one of the essential variables instrumental to effective teaching and learning process (IBIJOKE, 2012). The Federal Ministry of Education while on nation-wide tour of the schools stated that the physical conditions of most schools were pathetic, requiring urgent attention (FRN, 2004). Most of the classrooms were reported to be overcrowded. The survey conducted by the officials of the National Policy on Education (NPEC) estimated that it will take billions of naira to build new classrooms and to renovate dilapidated ones. The subsequent creation of Education Trust Fund (ETF) was a welcome development with the expectation that 40% of the money collected from the education tax (from 2% tax on profits of companies operating in Nigeria) would be used to fund the building of new schools and the renovation of dilapidated ones.

Most activities of learning in a school environment take place in a school environment within building enclosures. Since the learning environment is a place where learners and educators gather for a long period in learning activities, it is important to create an enabling environment that will enhance learning (Hussein & Rahman, 2009). Studies on classroom indoor environments confirm that the classroom environment determines the students' outcomes and it affects productivity and learning. Students, overall achievements (academic) are also higher in these environments the students find comfortable (Kamaruzzaman & Tazilan, 2013). However, it is not in all cases that individuals perform better in a thermally comfortable indoor environment, even when the students perceive that the indoor thermal comfort level has increased their task performance. This was earlier discussed in the literature review.

3.5 School Building Type in Imo State

As part of the primary data collection, visits were paid to some primary school buildings located in south-eastern Nigeria. Observed during these visits were two types of buildings use0d for class lessons. These two building types are shown in Appendix 1. Through the secondary data collection route, an attempt was further made to classify these building types. However, the literature search did not come out with any specific internationally recognized standard that classified primary school buildings according to building type. However, the few information available seems to classify them into two categories; the ‘open-space’ (including dwarf walled) classrooms and ‘enclosed-plan’ classrooms. Hamilton (1976) defined the ‘open-space’ classroom buildings as ones that do not include self-contained classrooms and have fewer internal doors and walls than a school with traditional classrooms that have doors and windows.

While some people argue that ‘open-space’ classrooms are not appropriate learning spaces, some others, for example, Martino and Silvia (2008), argue that the ‘open-space’ schools have the advantage of lower construction cost. Furthermore, buildings with large openings with no doors, and windows located in the warmer climates have the advantage of encouraging cross ventilation and daylight, provided that they are effectively protected from the penetration of solar radiation, and driving rain. The ‘open-space’ concept was considered paramount in the welfare of school children in school design since the 1870s championed by the Edwardian school designs which reflected concern that children should have access to daylight and fresh air in their classrooms (Lowe, 2007). This ‘open-space’ classroom-building concept was introduced in many elementary school buildings built in North America and Scandinavian countries in the 1960s and 1970s and the concept later spread to other countries in the world. Brubaker, (1998) added that some of these schools have survived, and few more have been built in years and others are being planned.

In Nigeria, the same concept of ‘open-space’ classrooms predominantly dominated the number of classrooms in the 1950s before a good number of enclosed classrooms started springing up. At present, both categories of classrooms are still in use for classroom activities, especially in the South East, and all of them (publicly owned) are naturally ventilated. Furthermore, all the ‘open-space’ classrooms in Nigeria have the same basic architectural characteristics which comprise of dwarf walls with no installed windows and doors as observed during the site visits. The enclosed classrooms, however, all have installed windows and doors. What is paramount is that classroom buildings should be comfortable in order to inspire learning. The literature review in this chapter pointed out that there may be a relationship between building characteristics and the comfort of building occupants. Understanding this relationship in these classroom building types is part of the objectives of this research.

The basic building components commonly used in the construction of buildings in Nigeria are classified into; walls, windows, floors, and roofs as described below.

External walls: Sandcrete block is a composite material made up of cement, sand and, water molded into different sizes such as 450mm x 225mm x 225mm and 450mm x 150mm x 225mm (Rasheed & Akinleye, 2016). Over 90% of buildings in Nigeria are constructed with this material (Baiden & Tuuli, 2004; Oyekan & Kamiyo, 2011; Sholanke, Fagbenle, Aderonmu, & Ajagbe, 2015). The high thermal mass of the external walls delays the ingress of solar heat gain until after classroom occupied hours. The design of the roof overhang, which is usually up to 1.2 meters, in most cases, prevent solar radiation from striking a large proportion of the outside walls, and this is applies to buildings that are not high rise (Efeoma, 2017).

Windows: When the design of a roof overhang is up to 1.2 meters, it can prevent solar radiation from striking the window directly (Offiong & Ukpoho, 2004).

Floors: The thermal impact on the floor can be significant in places where people are bare feet (Effting, Güths, & Alarcon, 2007). Where the floor is finished with a cast in situ concrete, it will have no impact on the thermal sensation of the people.

Roof and Ceiling: In the tropics, the roof is the most exposed to solar radiation part of the building structure. Where Polyvinyl Chloride Ceiling (PVC) sheets are used, they can help to reduce thermal gain inside buildings because they have low density, low thermal conductivity and high thermal sensitivity, (Onyaju et al, 2012). Timber is also known to be a poor conductor of heat.

Furthermore, for thermal comfort evaluation, the operative temperature can be considered by taking the average of air temperature and mean radiant temperature if the occupants' metabolic rates are between 1.0 and 1.3 met, no direct sunlight into the space, average air velocity less than 0.2 m/s and the difference of average air temperature and MRT is not more than 4°C. As per ASHRAE, 2013, average of air temperature may be considered as operative temperature when there are no radiant heating systems in the space and the weighted average U value of the external wall or window (Uw), satisfies the equation 3.1.

$$U_w < 50(t_{d,i} - t_{d,e}) \qquad (3.1)$$

Where,

U_w *is the average U -value of the wall or window, W/m2.K*

$t_{d,i}$ *is internal design temperature,* ^0C

$t_{d,e}$ *is external design temperature,* ^0C *and SHGC of window glass is not more than 0.48*

The SHGC (Solar Heat Gain Coefficient) rating reflects how much solar heat gets inside the home once it has reached the glass. The SHGC rating is measured between 0 and 1, with lower SHGC ratings meaning the glass allows less solar heat from entering the home. The SHGC and U-ratings share an interesting relationship in that they share a relative correlation.

3.6 Chapter Summary

This chapter shows that the research area of this thesis falls within the tropical zone, classified by Koppen Geiger as tropical Savannah (Aw). The literature review further showed that January, February, and March are associated with the highest maximum temperature in the study area. Furthermore, the difference between the highest max temperature and lowest max temperature is not more than 4.5^{o}C. This suggests that the seasonal variation in temperature does not usually exceed 4.5^{o}C based on the max temperature observed in each month of the year, considering the months of the year. However, there is a lack of information about the day-to-day and time of the day variations in temperature. This research works intends to fill this gap.

Nigerian has three regions and the research area of this study is in one of the three regions; the Eastern region. The Eastern region has the greatest number of registered school children when compared to the other two regions.

School system in Nigeria is comprised of two types; Government (public) and the private. Children who attend public schools are usually from more diverse socioeconomic groups compared to those who attend private schools.

Finally, based on the literature review, this chapter attempted to categorize the two types of classroom buildings identified in the study area. They are categorized as ‘open-space’ and ‘enclosed-plan’ classrooms. These two types of classrooms were identified as having different architectural features. However both show commonality as being naturally ventilated. A comparison between the two was made in regards to their thermal performance and to understand the thermal comfort requirements of the occupants in these two types of classrooms.

4 Chapter 4: Methodology

4.1 Introduction

This chapter presents the various steps employed to achieve the aims and objectives of this research. The recap of the aims and the objectives of this thesis was done under the introduction of this Chapter. Section 4.2 explains the research methods of this thesis, while section 4.3 explains the fieldwork design. Section 4.4 describes how the schools used as case study were identified.

4.2 Research Methods

The two major approaches usually employed in thermal comfort research are the laboratory experiment and the fieldwork. Assessing thermal comfort through field studies, where occupants are questioned about their thermal state, is a common practice across the world, for example; in Japan (Indraganti, 2010), in Malaysia (Zaki det, al 2017), in Nepal (Rijali et al, 2010), in the UK (Brown et al, 1993), in Australia (de Dear et al, 1994), in the USA (Schiller, 1990), in Libya (Ealiwa et al, 2001), and in Iran (Heidari and Sharples, 2002). All these research works were carried out in naturally ventilated or free-running buildings. This research approach has been employed by international researchers in the field of adaptive thermal comfort studies. Field study results are used to create models that are subsequently used to predict thermal comfort. Designers in the tropical setting ought to take advantage of natural ventilation to design buildings that use less energy to provide thermal comfort to building occupants

Thus, the adaptive thermal comfort approach will be adopted to evaluate the primary school buildings since the public primary school building in the warm and humid climate in Nigeria are all naturally ventilated. The methodology, reflected in the conventional technique and protocols, adopted in this study will try not to deviate much from the traditional research approaches adopted by other thermal comfort researchers. Less deviation from known methodology will ensure adherence to a fair and objective comparison of the results or findings with that of previous studies worldwide. It may be inevitable to make some minor adjustments to this traditional method of getting information from the subjects being evaluated. The minor adjustment(s) may be made (if found necessary) during the questionnaire design to adequately capture the responses of the schoolchildren.

Furthermore, researchers on social science often conduct field study adopting either the quantitative or the qualitative method to assess the thermal comfort levels in accordance with ISO 7730 or the ASHRAE 55 standard regulations (Zomorodian et al., 2016). Over time, as research questions broaden and deepen, researchers started adopting multiple data gathering techniques to ensure that credible results are arrived at. Thus emerged the third research approach, called mixed methods, which tries to sieve and fuse information provided by qualitative and quantitative methods of research, with the overall aim of arriving at credible results. These research methods are discussed in subsequent sections and the reasons for the adoption of a particular method are proffered.

Qualitative Method: This is a process of naturalistic inquiry that seeks to have a deep understanding of the social phenomena within their natural setting, and relies on the direct experiences of human beings as meaning-making agents in their daily life. Qualitative purist, also called interpretivism or constructivist, contend that reality is subjective (Krauss, 2005; Asgedom, 2004). Qualitative research methods are more inclusive with psychological reactions than with physiological comfort models (Healey, 2012).

Qualitative researchers adopt different systems of inquiry for the study of human phenomena including case study, historical analysis, ethnography, grounded theory and phenomenology instead of taking the route of logical and statistical procedures. Qualitative researchers do less with numbers. The need for a qualitative study of human factors in the field of thermal comfort, according to Healey & Webster-Mannison (2012) is well established particularly within the context of naturally ventilated buildings where adaptation plays a significant role in occupant comfort. He further argued that qualitative methods, which adopt a view of comfort as a socio-cultural achievement, rather than an engineering problem, are better suited to identifying hidden issues, which affect occupant comfort and satisfaction and added depth to known issues. These advantages of qualitative methods can complement the weakness of quantitative methods; *vice versa*, in the field of thermal comfort studies, which involves people and their environment.

Quantitative Method: Quantitative purists articulate the assumption that is consistent with what is commonly called the positivist paradigm and believe that social observations should be treated as entities in much the same way that physical scientists treat physical phenomena. They maintain that social science inquiry should be objective. Quantitative methods are useful in dealing with precise and systematic measurements of veritable quantities, such as climate data

(Groat & Wang, 2013). Qualitative approach is also good for generalizing results from field works (Ivankova, Creswell, & Plano Clark, 2007; J W Creswell, Klassen, Piano Clark, & Clegg Smith, 2011). Researchers in the field of thermal comfort studies have traditionally employed quantitative approaches in data collection and analysis (Humphreys et al., 2007). The quantitative approach uses a systematic standardized approach and employs methods such as surveys.

Table 4. 1. Difference between Qualitative and Quantitative Methods

S/N	Qualitative	Quantitative
1	Issues are addressed in-depth and not constrained by pre-determined categories of variables.	Use of pre-determined response variables requiring use of standardized measures to which numbers are assigned
2	Values openness and flexibility	Values control
3	Researcher cannot be separated from data collection and analysis	Researcher maintains an objective detached stance
4	Large amount of information from a smaller number of people, thereby reduces generalizability of results.	Statistical data from a great many people results in generalization of findings with more accuracy.

The main advantage of this research method is its richness in use in the comparison of the objective indoor thermal conditions with the corresponding subjective thermal comfort responses of participants (Cândido et al., 2011; Efeoma, 2017). Furthermore, this research approach allows a researcher to study the participants in their normal day-to-day activities (Nicol and Roaf, 2005), and this is important when dealing with children. Figure 4.1 depicts in a bubble diagram the complementary roles of both research methods.

4.2.1 Justification for Adopting Quantitative

The following reasons influenced the adoption of the quantitative approach to data collection in this study are:

- Quantitative method is useful in dealing with precise and systematic measurements of quantities such as climate data.

- A quantitative approach checks the limitations of the qualitative approach and also the likely biases in interpreting data as well as generalization of the research findings by the researcher

- International researchers in the field of adaptive thermal comfort studies often prefer using the quantitative approach.

- Using similar research techniques and adhering to the standardized protocol will be a fair and objective standpoint for comparing results and findings from other thermal comfort findings.

In view of the analysis, the quantitative approach fits this study and is subsequently adopted in this research.

4.3 Field Work Design

The design of the field study commenced by discussing the various research approaches, the research population and the sample size determination.

4.3.1 Research Approaches

Two basic research methods used in field work are longitudinal approach and the transverse approach. In longitudinal surveys, a relatively small number of subjects are polled for their comfort vote repeatedly over an extended period, while in transverse surveys many people are polled just once within a limited survey period (Humphreys et al., 2015). The transverse method is less expensive and consumes less time. The problem with this method is that if the survey is completed in a short time, the subjects won't be available to express their reactions to the variations in temperature. With a longitudinal survey, a large range of air temperatures over a long period makes analysis more robust. Researchers have adopted either of these two methods in their various research works on thermal comfort. For example, by adopting the longitudinal approach in fieldwork, Sharma & Ali (1986) obtained 5100 responses from 18 individuals, while Mustapha et al (2016) collected 303 from 28 individuals. In a transverse survey, Ogbonna & Harris (2008) had a sample size of 200 subjects, Feriadi & Wong (2004) had 525 subjects. These are few examples of the many research works that adopted one of these research approaches. This study adopted longitudinal research approach in order to obtain repeated data from the subjects over a long period of time.

4.3.2 Research Population

A research population is described by Kothari (2004) as constituting all items of consideration in any field of inquiry. Uji (2009), posited that the population of research study consists of a collection or group of individuals or objects of interest with a common characteristic which is of interest to the researcher. The opinion of a particular group of people or individuals (target population) are sought to gather the relevant information towards research findings. The main target population in this study are school children. School teachers are also targeted for comparison of results. Furthermore, the research population includes all the open-space and enclosed plan primary school buildings.

The warm humid states in southeast Nigeria are five in number. The following reasons justify the selection of Imo State as a case study area:

- The state was selected because it is easily reachable from other South-Eastern states
- The state has the highest number of primary school enrolment when compared with the other states in the same zone (Table 4.2)
- Being the home state of the researcher, logistics associated with cost, accommodation, transportation, coordination and time management will be minimal.
- All the public primary school buildings are naturally ventilated as such are ideal for use to evaluate the comfort temperature of a group of people in the tropics.

Table 4. 2. Number of Public Primary School enrolment by State in South East Nigeria (Compiled from Universal Basic Public Education and Key statistics in Nigeria)

State	Number in year 2013			Number in year 2014	
	Male	Female		Male	Female
Abia	120,546	118,030		100,879	97,600
Anambra	419,117	473,992		369,088	386,164
Ebonyi	184,290	186,020		209,921	214,739
Enugu	98,919	95,693		95378	92,438
Imo	796,610	719,989		718,141	672,039

4.3.3 Determining the Sample Size

Sample size determination is an act of choosing the number of observations. The aim of the sample size in an empirical study is to make inferences about a population from the sample. A sample is a 'subgroup of a population' (Latham, 2007), and is described as a representative 'taste' of a group (Berinstein, 2003). The sample should be 'representative in the sense that each sampled unit will represent the characteristics of a known number of units in the population' (Lohr, 2019). There are no rigid specifications as to what an ideal sample size should be, but the number can range from a hundred to a few thousand responses (Mishra & Ramgopal, 2013). It is generally known that the larger the sample size the less the sampling error and vice-versa. Also, one would ensure that the sample includes as much as possible the variances in the characteristics of the population to make generalization possible and large enough to enable valid conclusions to be made.

Various approaches to determine the sample size of a population include using a census for small population, imitating a sample size of similar studies, using published tables, and applying formulas to calculate sample size. Since it is usually rare to cover an entire population (census) when conducting research, because of cost and time constraints, a proportion that is representative of that population (sample size) is selected. Stratified random sampling technique was adopted in this study to divide the population into smaller groups (called strata) using Cochran formula. The researcher then used his judgement to select the final items proportionally from the different strata.

The sample size for the evaluation of indoor thermal comfort conditions of open space and enclosed plan primary school buildings in Imo State was determined using the population of primary school buildings in the 27 LGA of the state as the sampling frame.

The population of 1,272 primary school buildings (Table 4.3) from which respondents were polled for the study, an alpha (α) value of 0.05 was adopted to achieve a confidence level of 95% in choosing the sample population. The confidence interval here equalled (1- α) *100 or 95%, (Kanji, 2006).

For large populations, Goin and Cochran developed the Equation 4.1 to yield a representative sample for proportions (Goin & Cochran, 1963).

$$n_o e^2 = z^2 pq \qquad (4.1)$$

where

n_o is sample size

z takes the value at the desired confidence level 95% (Table 4.4);

e is the desired level of precision (also called sampling error): 5%;

p is the estimated proportion of an attribute that is present in the population (p=0.5 maximum variability); and

q equals 1 – p = 0.5

Note: The confidence level of 95% has a Z value of 1.96 (Table 4.4). This value can also be found in a statistical table which contains the area under the normal curve (Israel, 1992).

Table 4. 3. Approximate Distribution of Primary Schools in each Senatorial Zone.

Orlu Senatorial Zone	**432**
Okigwe Senatorial Zone	427
Owerri Senatorial Zone	413
TOTAL	**1,272**

Table 4. 4. Statistical Guide

Confidence	90%	95%	99%
Z- Value	1.645	1.96	2.575

Substituting values for the formula as follows;

$n_o = (1.96)^2\ (0.5)\ (0.5) / (0.05)^2 = 384$ sample size

(Israel, 1992) also gave the formula for correcting the finite population, if the population is small as follows: (where N is the total population= 1272 and *n* is the corrected value of n_o)

$$n = \frac{no}{1+\frac{(no-1)}{N}} \qquad (4.2)$$

n=384/ (1+ (384-1)/1272)) = 295.

According to Kothari (2004), if *Pi* represents the proportion included in stratum *i* and *n* represents the total sample size, the number of elements selected from stratum *i* is

NxPi **(4.3)**

The study area, Imo State Nigeria, has 27 Local Governments Areas (LGA), 3 senatorial zones and 1,272 public owned primary school buildings. Apparently, any sample with size greater than the threshold of thirty (n>30) should be considered a large sample (Munn & Drever, 1990). Kothari (2004) opined that large populations in the case of cities, states, countries or considerably large geographical areas would be expensive to identify each sampling unit and advocated the use of multi-stage sampling technique.

Furthermore, a four stage multi-stage sampling technique was adopted to arrange this population into strata. The first stage involved listing the 27 LGA (Table 4.5). The second stage involved setting up these 27 LGA into the 3 senatorial zones (Table 4.6). The third stage involved the distribution of the public primary schools according to their number in these three senatorial zones earlier presented in Table 4.3.

Table 4. 5. First stage of the Multi-Stage Sampling Showing the 27 L.G.A. in Imo State

SN	LGA	SN	LGA	SN	LGA
1	**Aboh Mbaise**	10	Isu	19	Okigwe
2	**Ahiazu Mbaise**	11	Mbaitoli	20	Onuimo
3	**Ehime Mbaise**	12	Ngor-Okpala	21	Orlu
4	**Ezinihite Mbaise**	13	Njaba	22	Orsu
5	**Ideato South**	14	Nwangele	23	Oru East
6	**Ideato North**	15	Nkwere	24	Oru West
7	**Ihite Uboma**	16	Obowo	25	Owerri Municipal
8	**Ikeduru**	17	Oguta	26	Owerri North
9	**Isiala Mbano**	18	Ohaji Egbema	27	Owerri West

Table 4. 6. Second Stage of the Multi-Stage Sampling Showing the 3 Senatorial Zones in Imo State

SN	Orlu Zone	SN	Okigwe Zone	SN	Owerri Zone
1	**Ideato North**	1	Ehime Mbano	1	Aboh Mbaise
2	**Ideato South**	2	Ihite/Uboma	2	Ahiazu Mbaise
3	**Isu**	3	Isiala Mbano	3	Ezinihite Mbaise
4	**Njaba**	4	Obowo	4	Ikeduru
5	**Nkwere**	5	Okigwe	5	Mbaitoli
6	**Nwangele**	6	Onuimo	6	Ngor Okpala
7	**Oguta**			7	Owerri Municipal
8	**Ohaji Egbema**			8	Owerri North
9	**Orlu**				
10	**Orsu**				
11	**Oru East**				
12	**Oru West**				
Total	**(12)**	Total	**(6)**	Total	**(9)**

In this study, the sample size of 295, from equation 4.2, was drawn from a population of 1,272 (referring back to Table 4.3) public primary school buildings from the three senatorial zones in Imo State. However, according to Okafor (2016), for the environmental variables of air temperature and relative humidity, a convenient sample of 5% can be used. Literature review of similar works indicate that subjects from one or two schools can provide enough respondents for credible thermal comfort research, especially if longitudinal approach is adopted in the study. At this stage, the researcher used his judgement to pick a school from each of these three senatorial zones, considering as a prerequisite, those schools that have both ‘open-space’ and ‘enclosed-plan’ classrooms.

Thus, a total of 6 classrooms from 3 schools (3 open-space and 3 enclosed-plan) were selected to be surveyed. These 6 classrooms are to be surveyed repeatedly in both seasons (longitudinal) in order to provided enough objective and subjective information for analysis in this study. Furthermore, for the rainy season and dry season surveys in school A, a total of 52 visits are envisaged based on the time frame of the survey in this school. Schools B and C also have appropriate allocations of 56 visits each. Full information about the visits to the schools for the survey is expected to be detailed in Chapter 5.

4.3.4 Justification for Adopting Public Schools instead of Private Schools.

The reasons for selecting public school buildings over the private schools for this study are:

- Public school buildings represent about 80% of primary school buildings in Imo State, while the private schools constitute about 20% (Table 4.7).
- About 380 (30%) of these public schools have an open-space classroom concept (private schools do not have the open concept).
- The open space classrooms have similar architectural characteristics while the enclosed plan classrooms also have their own distinctive architectural characteristics, therefore acting as true representation of the primary school buildings in Imo State, Nigeria.
- The children who attend the public-school come from different socioeconomic backgrounds, as this may widen information regarding their thermal state. Children's background affects their perception of comfort. (Trebilcock et al., 2017; Montazami et al., 2017).

Table 4. 7. Government/ Private Schools in Imo State
(Compiled from Ministry of Education Owerri. Official record 2018).

Government/ Private Schools in Imo State	No of Schools
Government owned (Public) Primary Schools	1,272
Private owned Primary Schools (Approved)	310
% of Public owned Primary schools	80%

Furthermore some other researchers in a similar research setting, such as the work of Mohamed, (2009), justified the choice of government schools over private schools, as case study, by arguing that government schools represent 89% of the total number of schools in Egypt.

4.4 Sampled subjects and Buildings

This section discusses the subjects used to achieve the objectives of this research work. It also discusses the criteria adopted in selecting the case study schools and the characteristics of the selected classrooms.

4.4.1 Subjects

The participants used in this study were, primarily, schoolchildren aged 7-12 years and their teachers. Participation in the field study took place during regular school meetings that cut across two seasons (rainy season and dry season) experienced in Nigeria. The survey was not part of the children's academic work and this was explained to them. To ensure confidentiality, codes were assigned to the children during the survey and their names were not written on the questionnaire. The schoolchildren had no prior information about the nature of the survey, however, they were informed ahead of time that a visitor would come to discuss with them. On the first day of the survey, the researcher was introduced to the children as a graduate student from the University of Salford, UK. Subsequently, the researcher had a series of meetings with some of the teachers where they were trained on how to participate and during which the proposed questionnaires were appraised to ensure they would be properly understood by the children

4.4.2 Classroom Building Selection Criteria

Several factors guided the selection of school buildings as case study in this thesis. A school building is considered for the fieldwork when it has two distinctive architectural features referred in this research study as 'open-space' classroom and 'enclosed-plan' classroom concepts. These two concepts were described in section 3.5 of chapter 3. Other factors unrelated to the indoor environment, such as building related factors (type of building), can influence the perception of comfort by the occupants (Frontczak & Wargocki, 2011). A good number of classroom buildings that have these two distinctive architectural features are found in many public schools in Nigeria. To achieve the research objective (i), the following criteria were considered.

- The case study classrooms in each of the selected schools should contain 'open-space' and 'enclosed-plan' concepts.

- Both classroom types must be naturally ventilated with no heating system

All the classrooms used in this study satisfied these two basic requirements. To achieve research objectives (ii-iv) the following criteria were adopted to ensure compliance with ASHRAE Standard 55 for occupants-controlled spaces (ASHRAE, 2017).

- occupants of the classroom spaces should have control over the ventilation system in place and could be either mixed-mode or naturally ventilated but not mechanically ventilated
- windows had to be easy to access and operate;
- the occupants of the spaces should be engaged in near-sedentary physical activities (metabolic rate should be between 1.0 to 1.3 met); and
- occupants are to be free to adapt their clothing to the indoor and/or outdoor thermal conditions within a range at least as 0.5-1.0 clo.
- the prevailing mean temperature had to be greater than 10°C and less than 33.5°C (ASHRAE, 2017).

All the 'enclosed-plan' classrooms selected for the study met these selection criteria. The 'open -space' classrooms did not meet the criterion ('windows had to be easy to access and operate'), since they do not have operable windows. However, it was adopted for comparison of results with the findings from the enclosed plan classrooms. Some thermal comfort researchers have advocated for buildings that can allow unrestricted access of air especially in tropical climates. For example, Cândido et al., (2010) posited that it is important to investigate other sources of effects of air movement in actual buildings, with or without individual control. Candido further argued that air movement limits imposed by current standards come out with inherent energy penalties and may not be providing occupants with the indoor environment they prefer.

4.4.3 Characteristics of the Selected Classroom Spaces

All the selected primary schools participated in the field study in both seasons; rainy season and dry season. An average of 30 students occupied each of the surveyed classrooms each day the survey was carried out. The 'open-space' classrooms were less densely occupied compared to the 'enclosed-plan; classrooms. This is because the 'open-space' classrooms were found to have a larger size. The participating schools were selected based on the analysis in section 4.4.2. and with the approval from the school and the local ministry of education. All the classrooms were naturally ventilated, and none had any active ventilators such as the air-conditioning system and fan. The entire outside walls of the surveyed classrooms were built with sandcrete block material and nowhere were any metal iron sheets used in the construction, apart from their usage for windows and, in some places. These areas were well shaded from the sun' rays by trees and also by the roof overhangs (eaves) which projected a minimum of 1.2 meters in all the surveyed buildings. All the studied classrooms were fitted with iron panel windows, except the open classrooms that had no window covering. However they were protected from direct solar radiation by the projected eaves. The floors of all the classrooms were covered with a cast in situ concrete and finished with weak cement screed overlay. The thermal impact on the floor will only be significant in places where people are bare feet (Effting et al., 2007). The floor finishing had no impact on the thermal sensation on the school children since they adhere to the strict code of wearing sandals always while in school. The surveyed classrooms were all finished with 'Polyvinyl Chloride' (PVC) ceiling sheets. The roof of the schools were made of corrugated iron sheets resting on timber supports. Further details about each of the surveyed schools are presented below.

School A (Premier School Umuaka)

School A (Figure 4.2) is a naturally ventilated bungalow that accommodates one long 'open-space' classroom, 10 'enclosed-plan' classrooms, and an office. The frontage of the surveyed classrooms (A_{OP} and A_{EN}) has a south-west orientation. The school is set back to the road by 150 meters, and in between the road and the school is a field used by the school children during breaks as a playing ground. The classrooms have ceilings with heights of approximately 3.5 meters. The school is a mixed public one (boys and girls) and was built in the 1950s. The outdoor floor area is not paved or cemented as it has some vegetations and trees which helped to reduce the absorption of the sun's rays by the external walls of the classrooms.

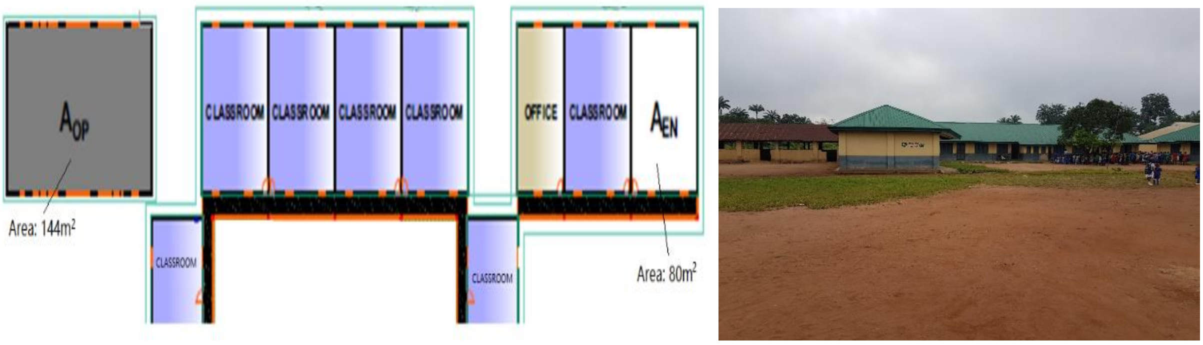

Figure 4.1: Shows the floor plan (left) and front view (right) of school A

School B (Central School Ogbaku)

School B (Figure 4.3) is a naturally ventilated bungalow built in the 1940s and houses one 'open-space' classrooms, 6 'enclosed-plan' classrooms, and one office space. The front elevation of both classrooms has a north-east orientation. The school is set back from a busy main road by 120 meters and in between the main road and the school is a greenfield used for outdoor activities by the children. The classrooms have ceilings with heights of approximately 3.5 meters. The outdoor floor area is not paved or cemented as it has some vegetations and trees which helped to reduce, considerably, the absorption of the sun's rays by the external walls of the classrooms.

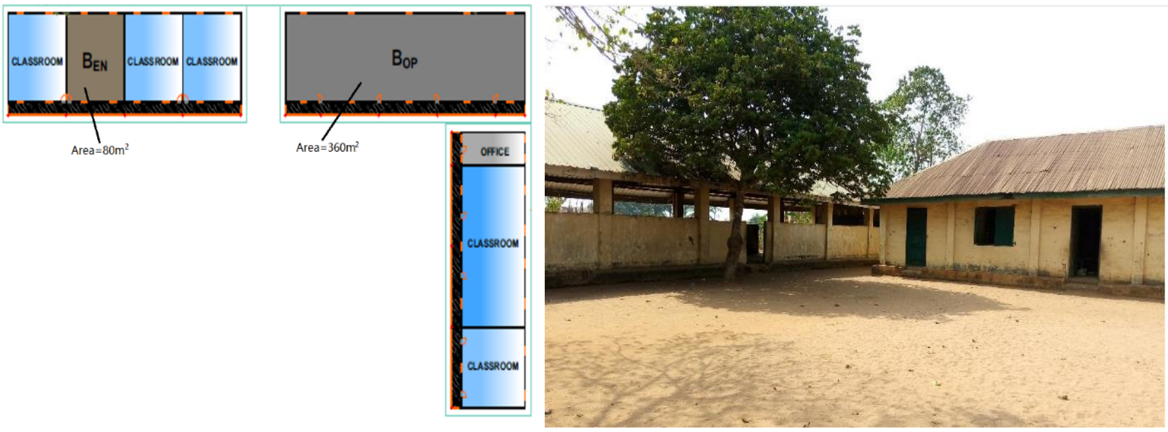

Figure 4.2: Shows the floor plan (left) and front view (right) of school B

School C (Central school Umuduru)

School C (Figure 4.4) is a bungalow built in the 1950s and accommodates 3 'enclosed-plan' classrooms, a long 'open-space' (partitioned into 3 classrooms) and an office. The entrance to the 'open-space' classroom has south-west orientation, while that of the 'enclosed-plan' classroom is oriented towards the south-east. The design concept creates a semi-enclosed courtyard that is used for outdoor activities. The school is set back to the road by only 20 meters. The classrooms have ceilings with heights of approximately 3.5 meters. The outdoor floor area is not paved or cemented as it has some vegetations and trees which helped to reduce, considerably, absorption and reflection of the sun's rays to the external walls of the classrooms.

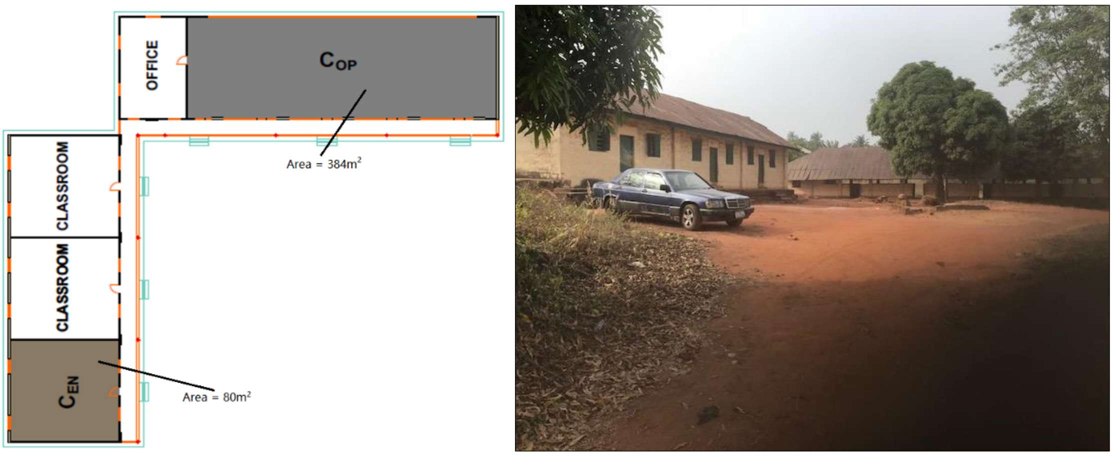

Figure 4.3: Shows the floor plan and front view of school C

4.5 Ethical Considerations in Survey

Ethics is 'the study of science of morals, rules or principles of behaviour' (Aldus et al, 2008). Informal consent, confidentiality, anonymity and courtesy are some of the aspects of ethical issues in research (Nicholas, 2011). Because this study involved children, an approval was obtained from the university of Salford ethics committee prior to the commencement of the survey. Ethical approval was granted by the university's ethics board (Please see Appendix A). Participation was voluntary and confidential. An informed consent form was included in the survey. The researcher attended the meetings organized by the parents-teachers association of each of these surveyed schools where an agreement was reached between the parents and the researcher to use their children for the study, with a condition not to elongate the survey period. This agreement was entered in the minutes of the meeting. Earlier, a written approval had been given by the local ministry of education to survey the selected schools (Appendix E). Literature reviews of the previous similar works guiding in timing and programming the data collection. Hussein & Rahman (2009) in their separate field experiments on children conducted survey in 3 days. (de Dear et al., 2015) had a field work that lasted one week to four weeks in each of the 9 classrooms surveyed. The field work carried out by Mishra & Ramgopal (2015) lasted 5 days, while (Kwok et al.,1998) conducted fieldwork in September and October (hot season) and in January (winter).

Furthermore on ethical considerations, there were days the survey was cancelled because of very low turn up of children and when a tragedy occurred in one of the schools being surveyed. One of the survey days, a car killed a student while crossing the road. The survey was immediately when the news filtered in. The researcher, together with his assistant, followed the school authority to pay condolences to the bereaved family. In that case the survey was skipped the next day being Friday, not only on moral grounds, but also to allow the children to have enough time to be balance emotionally. Furthermore, there were also days some of the children did not attend classes either because of ill-health and a host of other personal reasons and days a good number failed to turn up or went home early. For example, on October 11, 2017, there was a commotion and frantic withdrawal of schoolchildren in most primary schools in south-east Nigeria in the morning hours caused by social media rumour about a 'killer vaccine' being forced on school children. Though the news was later confirmed as false, it took days before the primary schools had a full class again in the state. The survey which was in progress the day the rumour was spread was cancelled.

4.6 Pilot Study

Prior to the commencement of this field work a pilot study was conducted. The pilot study rated the various Indoor Environmental Quality (IEQ) components. The findings from the fieldwork helped in the research direction of this study. Also, the thermal comfort questionnaire for children was modified for a better understanding.

4.6.1 Rating the Components of IEQ

A Post Occupancy Evaluation (POE) was conducted, before the commencement of this research work, to determine the very component of Indoor Environmental Quality (IEQ) that gave the students in the studio classrooms the most concern to classroom work. A university was used for the case study instead of a primary school because ethical approval letter was yet to be granted for the survey on children. The result of the study showed that thermal comfort was considered the number one component of the IEQ components that gave the students the highest concern to comfort indoor comfort. Post-occupancy plays important roles in the investigation of actual thermal comfort, and provides the 'ground-truth' data for the improvement of thermal comfort models (Safarova, Halawa, Campbell, Law, & van Hoof, 2018).

4.6.2 Children's Thermal Comfort Questionnaires Adjustment

Following the protocol adopted by some thermal comfort researchers, the researcher had a meeting with some of the school teachers to appraise the ASHRAE standardized thermal comfort questionnaire usually applied to children. Some words used in the standardized questionnaires were amended so that the children can understand the questions. Wordings such as ‘neutral’ and ‘thermal comfort’ used in the standardized questionnaires were changed to ‘okay’ and ‘temperature’, respectively. Furthermore, ‘slightly warm’ and ‘slightly cold’ were changed to ‘a bit warm’ and ‘a bit cold’, respectively. These changes were reflected in the questionnaire used in this study as shown in Table 4.12.

4.7 Data Collection and Analysis

4.7.1 Objective Data Collection

The indoor air temperature, globe temperature (supplementary addition), the outdoor temperature, the indoor relative humidity, and the indoor air velocity were the objective data. The physical characteristics of the classrooms were also recorded. Nicol et al., (2012) posited that one does not always need a costly instrument set up to be able to conduct a field survey yielding consistent and valuable results. However, efforts were made to obtain reliable instruments to be used in measuring the thermal variables. The instruments used for the survey met the prescriptions of international standards (ASHRAE and ISO). Tinytag Ultra 2 (TGU-4500) was used to measure the indoor air temperature and the indoor relative humidity, while The outdoor temperature was measured with Tinytag Plus 2 (TGP-4017). The outside data logger was well sheltered, avoiding direct sunlight and rainfall. The technical characteristics of these instruments are summarized in Table 4.9. Kestrel 3000 Pocket Wind Meter was used to conduct spot measurements of indoor airspeed according to the specifications of ASHRAE Standard 55. The standard recommends averaging the airspeed surrounding the occupants over an interval not less than one and not more than three minutes (ASHRAE, 2017) page 2.

The literature review in this study revealed several studies that used different height levels for positioning the measuring instruments while researching with children as participants. For example, Hwang et al., (2009), Kwok & Chun (2003), Teli et al., (2013), Trebilock & Figueroa, (2014) and Zeiler & Boxem (2009) took measurements at the height of 1.1 meters above the floor level. Some other researchers such as De Giuli et al., (2012), and Katafygiotou & Serghides (2014) placed their equipment at the height of 0.6 meters, while de Dear et al., (2015) mounted the instrument on the wall between 2.0 m and 2.5 m above the floor level to protect the instrument from damage by the students. Guided by the decision of these researchers and by the prescriptions of ASHRAE standard 55, the instrument in this study was placed at 0.9 meters above floor level. Furthermore, the researcher adopted the same method used by some other thermal comfort researchers such as Kwok et al., (1998), ter Mors et al., (2011), Teli et al., (2013), Trebilock & Figueroa, (2014), Yun et al., (2014) by positioning the measuring instrument at a single central location in each of the surveyed classrooms as permitted by ASHRAE standard 55 (ASHRAE, 2017).

Figure 4.4: Tinytag Ultra 2 (TGU-4500) and Tinytag Plus 2 (TGP-4017)

Table 4. 8. 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 +85ºC	±0.01ºC	±0.3%
	Indoor relative humidity	0% to 100%	±0.3%.	±1.8% RH
WBGT Heat Stress Meter	Globe temperature (supplementary)	0 – 80ºC	-	±0.2ºC
Tinytag Plus 2 (TGP-4017) loggers	Outdoor Temperature	25 to +85 ºC	±0.01ºC	-
Kestrel 3000 Pocket wind meter	Air velocity	0.30 to 40.0m/s	-	±1.66%

4.7.1.1 Indoor Thermal Variables: Indoor thermal variables recorded were the air temperature, relative humidity, mean radiant temperature and air velocity.

Air temperature and relative humidity: For the recording of indoor temperature and indoor relative humidity, Tinytag Ultra 2 (TGU-4500), shown in Figure 4.5, was used. This instrument is ideal for monitoring the efficiency of heating, ventilation and air-conditioning in any indoor space. It is widely used to help assess the performance of building materials such as insulation and help evaluate conditions in environmental refit projects. It has a built-in temperature sensor, 32,000 reading capacity, a delayed start option and a high reading resolution and user program alarm.

Radiant temperature: ASHRAE Standard 55 (2017) section 5.3.4.4 p. 16 specifies that radiant temperature asymmetry that may cause local discomfort can be measured using contact thermometer or infrared thermometer to measure in the affected occupant's locations, with sensor oriented to capture the greatest surface temperature difference. Further steps were taken prior to the start of the survey to check for radiant asymmetry in the surveyed classrooms. Temperatures readings were taken at different heights in the classrooms; 2.8 meters above the floor level (near the ceiling), 1.0 meters above the floor area at the centre of the classrooms, and a distance of 0.6 meters to the external walls using a Touchless Thermometer. All the readings were observed to be similar. The reason attributed to the similarity in the readings was the characteristics of the surveyed classrooms discussed in sections 3.5 and 4.4.3. The theoretical analysis in section 2.3.4.1 also finds some other studies having similarities with the finding in this study.

Air velocity: Air velocity of the classrooms was not logged continuously during field work as was done in temperature and relative humidity. This was because of the non-availability of the equipment to log the air velocity of the spaces on a continuous basis. The instrument available for measuring air movement was a hand-held instrument, Kestral 3000 pocket wind meter. This was used to measure air speed at various spots in the surveyed classrooms.

4.7.1.2 Outdoor Thermal Variables: Tinytag plus 2 (TGP-4017) Gemini loggers (Figure 4,6) measured the corresponding outdoor air temperature of the immediate outdoor environment of the indoor spaces being monitored. The outside data logger was well sheltered, avoiding direct sunlight and rainfall. The instruments used for the survey met the prescriptions of ASHRAE 55 and ISO 7730 standards.

4.7.1.3 Metabolic rate: The metabolic rate of the children was determined for the purpose of calculating the Predicted Mean Votes (PMV) of the studied children. This was determined by observing the participants activity. This will better be understood by knowing the daily activity of the schoolchildren. The school time is Monday to Friday, from 7.30 am to 11.00 am for the morning session, and from 12.00 pm to 1.45 pm for the afternoon session. Break time is 1 hour from 11.00 am to 12.00 pm. School programs for class lessons and breaks are the same for all the schools and cuts across all seasons. Class lessons last for 45 minutes within which the students sit down and engage in reading, writing and listening to the teachers. During breaks, the students are free to engage in different forms of physical activities.

During the survey, the children were mainly seating down and were engaged in reading and writing. These activities were observed to be consistent for most of the period the survey was conducted in all the classrooms. They were observed to be engaged in these activities not less than 30 minutes before the questionnaires were administered. However, a small number of them occasionally stood up to either use the toilet or drink water. Based on the consistent activity of approximately 99% of the children who sat down, their activity was estimated at 1.2 MET representing sedentary activity as suggested by ASHRAE Standard 55 and ISO.

4.7.1.4 Clothing Estimation: The clothing values of the children were estimated to calculate their PMV. The knowledge of the insulation of the clothing is not necessary for an estimate of the comfort temperature in a given situation, however if the results of the survey are to be used to compare observed comfort vote (Actual Mean Votes) vs PMV, then knowledge of the clothing insulation is essential (Nicol et al., 2012).

Public primary school children in the study area wear government-approved uniform and PE in school as a dress code, for both sexes, and the pattern between the boys and girls do not vary significantly as shown in Figure 4.6. Also, the clothing worn does not differ much in the two seasons; rainy season and dry season. However, during the rainy season, extra clothing like a sweater or additional clothes are put on by some of the children when the temperature drops to a lower value. This was observed mostly in the morning hours during the rainy season. Furthermore, children in the study area wear two types of uniforms in a week; normal uniform on Tuesdays, Thursdays and Fridays and Physical Education (PE) uniform on Mondays and Wednesdays. For the girls, normal uniform comprises of white shirts inside with sleeveless blue gown, reaching to the knee. Boys wear white shirts with blue shorts. PE comprises of short sleeve polo with skirts for the girls and short sleeve polo with shorts for the boys. PE comes in five different colours; blue, yellow, red, white, green and purple.

Figure 4.5: Dress code in school (left) and children filling in questionnaire in their classroom (right)

Well known international standards such as ASHRAE 55, and ISO 7730, list the clothing thermal insulation of many individual garments and typical clothing ensembles that are established based on measurements with adults and children were not considered. However, a fieldwork by K. Al-Rashidi, Al-Mutawa, & Havenith (2012) did establish that the adult- based standard tables, from ASHRAE 55 and ISO 9920, can be applied to children. Standing on this finding, children's clothing based on the spot observation and recording of what everyone was wearing during the survey period was conducted. Furthermore, previous thermal comfort findings did not show any tangible difference between two genders (Zomorodian et al., 2016). The differences in clothing can be significant especially in countries where there are clothing restrictions for females. However, there is no clothing restrictions for female in this study area. The clothing observed and recorded during the survey is matched with tabulated values for individual garments given in the existing standards (ASHRAE 55, ISO 7730) as shown in Table 4.10. Clothes not usually worn were excluded from the list to make the estimation simpler. Generally, the clothing the children wore were categorized as light summer clothing typically used in the tropics because of heat, as summarized in Table 4.11.

Table 4. 9. Summary of Clothing values (Clo values)

	$Boys_{clo}$	$Girls_{CLO}$
Underwear Pants (Panties)	0.04	0.04
T-shirt	0.08	0.08
Skirt (Light 15cm below Knee)	-	0.14
Short-sleeve dress shirt	-	0.19
Shorts	0.06	-
Socks	0.02	0.02
Sweater	0.13	0.13
Sandals	0.02	0.02
Wooden chair	0.00	0.00
Metal chair	0.00	0.00

Table 4. 10. Total thermal Insulation provided by clothing ensembles

	Rainy season		**Dry season**	
	Boys	Girls	Boys	Girls
Min	0.18	0.19	0.18	0.20
Max	0.39	0.42	0.38	0.40
Mean	0.38	0.39	0.37	0.38

4.7.2 Subjective assessment

***Survey on Children (Right of a child*)**: It is important to collect information on children's opinions and behaviours directly from them rather than from their gatekeepers as the society is becoming more and more concerned with issues that concerns them. For instance, the United Nations (UN) convention of 1989 reflected in Article 12 the Rights of children to;

- be involved in decisions that affect their lives and have access to information about themselves
- have their views respected, and to have their best interests considered at all times
- use their preferred communication methods and language, considering their ages, ability and level of development and understanding.

Furthermore, the United Nations Convention on the Rights of the Child (UNCRC) commits all signatory states to protecting the right of every child to a safe, healthy environment in which to develop and grow. The African Charter on the Rights and Welfare of the Child (ACRWC) also recognises that the development of a child requires particular care concerning health, physical, mental, moral and social development. According to Borgers, De Leeuw, & Hox (2000), official government agencies, such as statistics Canada, statistics Sweden, and the British economic and social research councils and a host of other organisations from different countries, now acknowledge children as respondents and have developed and implemented special surveys for them. However, some researchers are of the opinion that young children may not be able to respond to structured thermal comfort questions.

Can Children in Imo State Answer Thermal Comfort Questions*?* Generally, some researchers raise doubts whether children can understand the wordings of a questionnaire. Some others argue that children can complete the self-reporting questionnaires. For instance, Christensen & James (2000) argue that children are worthy of investigating and may not need parents or caregivers to guide them. Trebilock & Figueroa (2014), added that children can properly understand the wordings in a questionnaire. Furthermore, Clark & Moss (2011) believe that children are strong, capable, and knowledgeable experts on their lives. Children in the late childhood (9-11 years old) can provide valid responses to structured questionnaire (Korsavi & Montazami, 2020). SHAMILA Haddad, King, Osmond, & Heidari (2012) suggested that even children from the age of 7 may have the capability to complete the self-reporting questionnaires. In North Italy Fabbri (2013) evaluated thermal comfort of children between 4 and 5 years by administering pedagogical questionnaire. Results showed that the children understood the concept of comfort. Also, child psychologists believe that participants in late middle childhood (6-11 years old) do not have trouble differentiating between seven categories (ASHRAE standard 55) of response options, indicating different levels of warmth of the environment (SHAMILA Haddad et al., 2012). Some other field studies such as, Pepler (1972), M A Humphreys (1977), Teli et al., (2013) and Trebilock & Figueroa (2014) conducted thermal comfort studies in classrooms with children 6-11 years of age and found them capable of responding accurately to the structured questionnaires.

However, the success or failure of any research that involves the use of questionnaires to get information from children depends on how the questionnaire is fashioned out to be understood by them. Questionnaires for children should be structured to be brief and clear, devoid of complex wordings or statements that may be difficult for them to understand. A case as an example was an adult who tried to comfort a teenager whose grandfather had died and was seeking to establish how emotionally intimate the relationship had been by asking her ‘were you close’ to which the teenager replied ‘No, he lived in Whitby’ (Kellett, 2011). If that was a fieldwork survey, data collected would have been inaccurate. The way the question was structured led the teenager to think that, maybe, she was being asked ‘if the grandfather lived close to where she is living’. Perhaps, another child could have answered ‘Yes it was closed’ thinking that the question asked if the road was closed. Questionnaires used for adults can also be used for children above 11 years, but to use the same questionnaire design for children less than 11 years of age whom their skills in reading, writing and comprehension of words are still developing without some modifications, may produce data that are not reliable. To mitigate this potential threat, some wordings used in thermal comfort questionnaires such as ‘neutral’, ‘thermal comfort’, ‘just right’, ‘much too humid’ and some statements such as ‘How are you feeling at the moment’? maybe misunderstood or misinterpreted by the children being evaluated. This especially may be the case with those who do not use the English language as their medium of communication. For clarity, the question may need to be modified to state the subject being investigated.

In Nigeria, the English language is the medium of communication and teaching in schools from nursery to the university level. Children ask and answer questions, write figures and essays by using the English language. According to Edem, Mbaba, Udosen, & Isioma (2011), teachers in Nigeria expose children to English as a medium of communication from the beginning of their schooling. There is no taken away the fact that school children aged 7-11 years in Nigeria can fill on their own appropriately worded questionnaire structured in the English language without any guidance. However, it is important not to overlook the likely possibility that some children of a young age may not properly understand the wordings of a thermal comfort questionnaire. Another concern is that some of them may be influenced by their classmates when filling the questionnaires.

However, some thermal comfort researchers have found ways of navigating through this difficult terrain of finding appropriate thermal comfort questionnaires for children. For instance, Sani, Martionson, & Al-Maiyah (2016), & Al-Maiyah, Martinson, & Elkadi (2015) converted the 7-point ASHRAE scale into three categories in their separate thermal comfort study on children. In doing this, the first and last two extreme categories on the scale were merged into one group each in the questions under thermal comfort, while the three central categories formed the ‘moderately comfortable’ group. In other thermal comfort research done for children aged 6-11 years, the same standardized thermal comfort questionnaires used for adults were adopted but some of the studies reduced the number of questions and modified the wording so that the children could understand them better. For example, the original word ‘neutral’ used by Professor Fanger P.O to determine the central category of 7-point ASHRAE scale was modified by Martinez (2007) to the word ‘good’ for better understanding of his respondents. In the survey conducted by Karyono & Delyuzir (2016) the word ‘comfort’ was adopted in place of ‘neutral’, while Teli et al., (2012), Trebilcock et al., (2017), Montazami et al., (2017) and Korsavi & Montazami (2019) used the word ‘Ok’. H. Zhang et al., (2007) used the word ‘keep constant’ instead of ‘no change’ in thermal preference question and ‘temperature’ instead of ‘thermal comfort’ in thermal sensation question. According to Saunders et al (2016), using terms that are likely familiar to, and understood by, respondents can improve the validity of the questionnaire

Furthermore, Karyono & Delyuzir (2016) used the Indonesia language to investigate the thermal comfort conditions of primary school students in Tangerang, Indonesia. In adopting a different language, what is important is ensuring that the language is translated correctly to comply with the ASHRAE standard. While investigating the thermal comfort perception of primary school children Wong & Khoo (2003) left out numbers in the questionnaire arguing that the numbers will confuse the children and Trebilock & Figueroa (2014) adopted this method. ter Mors et al., (2011), suggested that the ASHRAE scale is easier for children to understand because of its simplicity. Previous thermal comfort research works on children conducted by Auliciems, (1969), Kwok et al., (1998), Hwang et al., (2009) and Liang et al., (2012) and the recent ones by, de dear et al (2014) and Shamila Haddad et al., (2014)) adopted the standardized ASHRAE thermal comfort questionnaires used for adults.

Also, Kwok et al., (1998) adopted a 7-scale ASHRAE Standardized questionnaire to investigate the thermal conditions of school students whom their ages ranged from 15-17 years. In one of the questions, respondents were asked to mark x in a box that used a 7-point scale ranged from ‘neutral to hot’ on the right side of the scale and from ‘neutral to cold’ on the left side of the scale to determine their thermal sensation. Ali, Martinson, Al-Maiyah, & Gaterell (2018) while assessing the participants’ perception of comfort in the theatre at the Bayero University Kano, Nigeria converted the 7-point scale into three categories. For the questions under thermal comfort, the first and last two extreme categories on the scale were merged into one group each, while the three central categories formed the ‘moderately comfortable’ group. Al-Maiyah et al., (2015) also adopted the same scale. The questions required approximately 15 minutes to complete and contained six pages. This structure of the questionnaire, though worked for older children, may not be suitable for use by younger children aged 6-11 years because of the time it took to fill in the questionnaires and the wordings used. With long questionnaires, especially lack of motivation and difficulties in keeping up concentration will result in poorer data quality, and Borgers et al., (2000) and Holaday & Turner-Henson (1989), especially if the children are not motivated. It is therefore important to consider these arguments while designing a questionnaire for little children. Teli et al., (2012) sought teachers' feedbacks while drafting questionnaires for children. Furthermore, it is important to keep thermal comfort surveys as short as possible Nicol et al., (2012), especially when dealing with young children because they can get bored easily. Saunders et al (2016) and Ubaidullah (2015) suggested that when designing a questionnaire for children it is best to adopt and adapt similar questions already used in a related study, especially when results are to be compared with others for better accuracy.

***Questionnaire Design for this Thesis**:* For the subjective assessment, questionnaires administered to the children were aimed at evaluating their thermal comfort perception as it relates to their classroom indoor thermal variables and how their perceptions were influenced by the classroom architectural characteristics, with a focus on adaptive thermal comfort. However, it is important not to overlook the likely possibility that some children of a young age may not properly understand the wordings of a thermal comfort questionnaire. Another concern is that while filling the questionnaire, their interactions with the other classmates can potentially influence the responses from those young children who may tend to align their answers with the general feedback. These potential threats were observed and dealt with accordingly during the survey. First, for a better understanding of the questionnaire, the teachers assisted the researcher to review the questionnaires to ensure the language and information were understood by them. The second threat was handled by the presence of the teachers which ensured that the children did not influence one another when filling the questionnaire.

The questionnaire included the subjective perception of participants regarding the indoor thermal environment (temperature, relative humidity, and wind speed). The questionnaire was adopted from the previous commonly thermal comfort questionnaire with minor modifications. The first section, section A, was related to general personal information about the child. Section B asked personal questions about the thermal conditions, while section C required information related to the use of adaptive opportunities.

To get answers to the thermal perception of the children in the case study classrooms, questions were asked to determine their thermal sensation, thermal preference, and thermal acceptability. Thermal comfort scales were adopted to allow the participants to make their own judgment whether the thermal conditions are acceptable to them or not This was done in line with ASHRAE Standard 55, which defines an acceptable thermal environment as the thermal environment where 80% or more of occupants find it to be thermally acceptable (ASHRAE, 2017). To ascertain the correct temperatures deemed as being desirable by the occupants, participants were asked to regularly complete short comfort vote surveys, which include the ASHRAE 7-point thermal sensation and 3-point McIntyre preference scales (Table 4.12). The McIntyre preference scale asks people whether they would prefer to feel warmer or cooler, or whether they deserve no change. The differences in the 'neutral' temperature from ASHRAE thermal sensation scale and the preferred temperature from the preference scale is referred to as the 'semantic offset' (Humphreys et al., 2015).

Question 9**:** The subjects' thermal sensation Vote: For thermal sensation, ASHRAE seven-point rating scale was adopted to find out how they felt to the indoor thermal environment. Many thermal comfort researchers, for example, Wong & Khoo (2003), K. E. Al-Rashidi, (2011), Shamila Haddad (2016), Teti et al (2012) and Yao et al., (2009) used the same seven point rating scale.

Question 10**:** A three-point McIntyre rating scale, widely used in thermal comfort surveys, was adopted for the subjects' thermal preference assessment.

Question 11**:** To determine the subjects' thermal acceptability, the respondents were expected to check a box of 'acceptable' or 'unacceptable'. The word 'temperature' was included alongside 'conditions' for ease of understanding.

Question 12: General Comfort Question**:** This question was asked to determine the general comfort condition of the subjects. This question also helped determine the validity of the answers provided.

Question 13*:* Because the buildings are all naturally ventilated and do not depend on any ventilator to determine thermal comfort other than air infiltrations into the rooms, there was a need to ask some questions about air movement acceptability or not.

Question 14: This question asked the subjects air preference in the classrooms.

Question 15: This question asked the subjects acceptability to humidity in the classrooms.

Table 4. 11. Administered Questionnaire

SECTION B: Personal Thermal Comfort *(Please tick appropriate box)*

9. How are you feeling the temperature in the classroom right now?

Colder	Cooler	A bit cold	Okay	A bit warm	Warmer	Hotter
-3	-2	-1	0	1	2	3

10.Right now I would prefer to be:

Cooler	Okay	Warmer

11.Are the conditions (temperature) in this classroom accepted by you right now?

Acceptable	Unacceptable

12. How comfortable is your classroom right now (General comfort)?

Comfortable	Uncomfortable

13. Do you accept the air movement in your classroom right now?

Acceptable	Unaccepted

14. Right now I would prefer:

More air	No change (okay)	Less air

15. Do you accept the humidity in your classroom right now?

Acceptable	Unacceptable

SECTION C: Personal Controls

16. Which of these controls can you adjust in your classroom? You can tick more than one.

Windows	Doors	Fans	None is available

17. Why do you adjust the control?

Get colder	Get warmer

Questionnaire Administration The academic year in Nigeria runs from September to July and is broken down into three sessions: September-December (1^{st} term), January-March (2^{nd} term) and April-July (3^{rd} term). This field study was conducted from October 2017 to November 2017 and from January 2018 to May 2018 (with some breaks in between) to capture the different climatic periods in the classrooms within the academic year. The survey period was broken down into two seasons; rainy season (Oct to Nov 2017 and May 2018) and dry season (Jan, Feb and April 2018), as summarized in table 4.13 All the holidays, weekends and out-of-term dates were removed. The school time is Monday to Friday, from 7.30 am to 11.00 am for the morning session, and from 12.00 pm to 1.45 pm for the afternoon session. Break time is approximately 45 minutes from 11.00 am to 11.45 pm. School programs for class lessons and breaks are the same for all the schools and cuts across all seasons. Class lessons last for 45 minutes during which the students sit down and engage in reading, writing and listening to their teachers. During breaks, the children are free to engage in different forms of physical activities.

Table 4. 12.Summary of Survey period for the 6 classrooms during both rainy & dry seasons

School	A_{OP}	A_{EN}	B_{OP}	B_{EN}	C_{OP}	C_{EN}
Rainy Season	Oct 13-24/2017	Oct 13-24/2017	Oct 25-Nov3/ 2017	Oct 25-Nov 3/ 2017	May 9-29/2018	May 9-29/2018
Dry Season	Feb 6-28/2018	Feb 6-28/2018	April 2-27/2018	April 2-27/2018	Jan 15-31/2018	Jan 15-31/2018

Note: OP =Open classrooms; EN= Enclosed classrooms

Humphreys et al., (2015) suggested that it is important that measurements and subjective responses be distributed uniformly throughout the day, and not restricted to the warmest period but to also consider the coolest period, to properly capture any likely diurnal swings of indoor temperature. In the morning survey, the questionnaires were distributed and filled at 9.00 am. At that time, the students were either reading or writing and most had entered classroom by 8.00 am. The adaptation time in this survey was set at 60 minutes within which their metabolic rate was assumed to have settled and reached the recommended sedentary level of 1.2 met, which corresponds to light office activity in the ASHRAE Handbook of fundamentals. The ASHRAE adaptive comfort applies to spaces where the occupants are engaged in near sedentary physical activities with metabolic rates ranging from 1.0 to 1.3 (ASHRAE, 2017). The afternoon questionnaire was distributed and filled at 1.00 pm (about one hour after the break). At that time, the children have sufficiently settled down to a sedentary level of activity. The clothing insulation values and the metabolic rate were determined based on ISO 7730, as earlier discussed in section 4.7.1.

The participating children did not change classes in the two seasons the survey was conducted and were assumed to have adapted to their classroom's indoor environment. The questioners were administered with the help of a trained assistant and the class teachers. However, the trained teachers did not participate in full during the survey. This was done based on some observations made by the researcher. The researcher earlier visited some of the schools to familiarize himself with the environment and how the children interacted with the class teachers. The major observation was that children were often afraid of their teachers. It was figured out that if the teachers participate fully during the survey the element of fear might influence the responses to the questions by the school children. The first solution to that was to get a trained assistant who was not part of the school administration. The trained assistant was not part of the school system. To further allay the fears of the children, the researcher gave the assurance that only the researcher or the trained assistant will collect their questionnaires and 'no body, except the researcher will see their responses. Reassurance such as this is important when carrying out research with children, especially in a developing country like Nigeria where children sometimes are afraid of their class teachers.

The participants filled sections B and C on their own. The class teacher and the researcher ticked section A after getting information from them. This was done to save time and to reduce overtaxing the students in filling the questionnaire. Each respondent took approximately 10-12 minutes to complete the question in the first three days the survey started. In subsequent days when they became familiar with the questionnaire the time to complete the questionnaire reduced.

Thermal comfort studies can be conducted using either the longitudinal approach or transverse approach or a combination of the two methods. In longitudinal surveys, a relatively small number of subjects are polled for their comfort vote repeatedly over an extended period, while in transverse surveys many people are polled just once within a limited survey period (Nicol et al, 2003). The transverse method is less expensive and consumes less time. The problem with this method is that if the survey is completed in a short time, the subjects will only be available to express their reactions to the variations in temperature within the period. Longitudinal technique surveys the subjects repeatedly, requiring several visits or follow-ups, thus providing concrete information of the situation on the ground over time. However, the limitation in using a longitudinal method is that it is expensive and consumes more time when compared with a cross sectional survey. Most surveys take some days to complete and the adaptive model tells us that the characteristics of the sample would have changed over this amount of time. So, whilst the conditions may vary, you are in effect measuring a different population with each temperature. Based on this, the longitudinal approach is more appropriate to the adaptive model which champions adaptation.

4.7.3 Data Analysis

The objective data collected through measurement of the various variables were downloaded, entered and safely stored into a spreadsheet of Microsoft Excel. Documented observations were also entered in world documents and in a spreadsheet. The subject's subjective responses to the questionnaire were coded and imported into a spreadsheet. Inconsistent responses and the answers from sick subjects were excluded from the spreadsheets. The data downloaded into the spreadsheets were analysed using both descriptive and inferential statistical techniques.

This statistical approach presents results as a measure of central tendency and a measure of the spread of the variables under consideration. This approach was generally used to statistically present the results of the objectives in this study and have been previously used by researchers to present and describe the results of thermal comfort variables. The results of such surveys are analysed statistically to estimate the temperature at which the average survey participant will be comfortable, usually called the comfort temperature or neutral temperature.(Nicol et al., 2012). Methods adopted in determining the research objectives of this thesis are further discussed below.

A**) *Relationship in the Thermal Performance of the Two Types of Classroom Buildings (Objective i)***

A combination of tabulated presentation of the variables, in the form of tables, graphical and chart descriptions were adopted to provide information about the thermal conditions in the surveyed classrooms. The measures of central tendency and the measures of spread were adopted in this study to describe the data quantitatively by given values to measured variables where it became necessary to assign the values. To determine the degree of relationship between the variables in the two types of classrooms, a correlation analysis and, significance *p*-value tests were conducted to determine the degree of relationship between the respective indoor temperature and their corresponding outdoor temperature that were concurrently recorded. Pearson correlation is a bivariate measure of association that assesses the strength or weakness between two variables. The correlation coefficient (r) vary from 0 (no relationship) to 1 (perfect positive linear relationship) or -1 (perfect negative linear relationship). A positive coefficient indicates a direct relationship, indicating as one variable increases the other variable also increases. Pearson's Correlation and Linear Regression Analysis are widely used by researchers in the field of adaptive thermal comfort studies to investigate the interrelationship among subjective thermal perception and thermal indices (Humphreys et al., 2007).

*B**) Comparing the Relationship Between Measured Indoor Temperature and Subjective Comfort Responses of the Children (objective ii)***

The relationship is compared by matching the comfort votes of the children with the corresponding mean indoor temperatures in the surveyed classrooms.

*C**) Determining the Thermal Perceptions of the Children (objective iii).***

Thermal perception is divided into thermal sensation and described as the objective evaluation of a conscious feeling (hot or cold) (Nakamura & Morrison, 2008). Thermal comfort, indicating the state of mind that express satisfaction with the surrounding environment.

Thermal sensation and Thermal Preference: are determined through linear regression**.** Neutral temperature (or comfort temperature) is the temperature at which people have a neutral thermal sensation to their indoor environment. At neutral thermal sensation, a majority of building occupants do not feel warm or cold by voting for neutral (0) on the seven-point ASHRAE scale (Nicol et al., 2012). Linear regression analysis is one of the popular analysis methods used to determine the subjects' comfort temperature (Humphreys et al., 2015; Nicol et al., 2012; Shamila Haddad, 2016). In this study, a linear regression model of thermal sensation was carried out with respect to weighted indoor operative temperature using Microsoft Office Excel and relating the equation with the simultaneous equation shown in Equation 3.1. A neutral temperature is obtained when the thermal sensation votes equals 0 on the seven-point ASHRAE scale. The neutral temperature can also be obtained from the graph where the mean thermal sensation votes cross with the mean indoor operative temperature in the graph. Furthermore, a statistical test was analysed using SPSS version 17.

$$TSV = aT_{op} + b \qquad (3.1)$$

Where,

***TSV** = is the mean thermal sensation*

***a** =represents the gradient or coefficient*

T_{OP} = represents the operative temperature

b *=represents constant*

Comfort range: of the young children can be determined using thermal comfort indices such as the Predicted Mean Votes (PMV) established by Fanger & Toftum (2002) or the ASHRAE adaptive comfort approach suggested by de Dear & Brager (2002). ASHRAE adaptive model that sets an 80% acceptable temperatures with the range from -0.85 to +0.85 can be used to determine comfort range of building occupants (ASHRAE, 2017 and R. de Dear et al., 2015). This approach was adopted in this study 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.

Acceptability: to temperature was determined from the linear equation based on thermal sensation in the range of -0.85 to +0.85 and 80% acceptable indoor thermal condition also expressed as equation 3.1. The acceptability in the range -0.50 to +0.50, at 90% acceptability level, was also calculated for purpose of comparing the comfort band between these two acceptability (80 % and 90%). Acceptability level was determined based on the acceptability criteria of ASHRAE standard 55.

Sensitivity: the linear regression intercept can be used to determine the gradient coefficient (slope) of the regression line for mean thermal sensation can be used to evaluate the sensitivity of the occupants to indoor temperature

D) Determining Thermal Perception of the Teachers (objective iv)

The same method used in C was adopted.

E) Recommending Thermal Comfort Guidelines (objective v)

A combination of tabulated presentation of the variables of interest was adopted in the recommendation.

4.8 Chapter Summary

Chapter 4 explored the methodology adopted in this research. Firstly, it proposed the research aim summarized in Chapter one which is; to determine the thermal perception of primary schoolchildren (alongside their teachers) and to assess the thermal performance of the classrooms they use for class lessons. Thermal comfort researchers often adopt a standardized method of assessment for ease of comparison of results. Two popular methods of assessment identified are the heat balance model and the adaptive model. However, from the literature review, field study on thermal comfort presents stronger external validity than laboratory experiments. (Nicol, 2004). This research work adopted the adaptive model to address the aims and objectives of this study.

Also, field surveys are central in the research of thermal comfort in naturally ventilated buildings. Literature indicated that a longitudinal approach makes research work more robust because of the wide range of data collected with the approach. The longitudinal approach in the field studies is adopted in this survey to cover the two seasons experience in the study area and to capture a large range of air temperature and relative humidity over this long period.

Researchers further highlighted the importance of designing children's questionnaires to ensure that they are well structured. Furthermore, the importance of involving school teachers while structuring the questionnaire was highlighted.

Finally, objective data collected through the measurement of the environmental variables were downloaded into a spreadsheet of Microsoft Excel. Together with the subjective data from the questionnaire, both are statistically analysed. The results are presented in the next chapter (Chapter 5).

5 Chapter 5: Results

5.1 Introduction

The results of the fieldwork, aimed at determining the thermal performance of two types of classroom buildings and the thermal perception of the subjects in these classrooms are presented in this Chapter. The field surveys took place during the rainy and dry seasons from October 2017 to May 2018. Table 5.1 gives further information. The results are presented in five sections.

Section 5.2 presents results of the thermal performance in ‘open-space’ and ‘enclosed-plan’ classrooms with focus on adaptive thermal comfort (objective i)

Section 5.3 presents results of the relationship between the measured thermal variables and children’s thermal perception (objectives ii-iii)

Section 5.4 presents results of teachers’ perception to indoor thermal environment and compares the perception of the teachers to that of the schoolchildren (objective iv)

Section 5.5 recommends thermal comfort guidelines for the primary school children in the warm and humid climate, Nigeria (objective v).

Section 5.6 summarizes chapter 5

5.2 Thermal Performance in the Classroom Buildings (objective i)

This section presents the results of the thermal performance in the studied classrooms. Thermal comfort surveys can be conducted with the involvement of the building occupants or the measurements can be taken without involving the occupants in the survey (F. Nicol et al., 2012). For this very objective of the study, the measurements in the classrooms were taken without involving the occupants. The period of this survey extended beyond occupied school hours.

5.2.1 Characteristics of the Sampled Classrooms

To achieve objective i of this work, a total of six naturally ventilated classroom spaces, comprising of three ‘open-space’ and three ‘enclosed-plan’ in three schools were investigated. The survey covered two seasons as summarized in Table 5.1.

Table 5. 1: Summary of classroom spaces used for the survey

School	Classroom type	Ventilation type	Survey date	Season
School A	A_{OP}	NV	Oct 12-24 (9days)	Rainy
	A_{OP}	NV	Feb 6-28 (17 days)	Dry
	A_{EN}	NV	Oct 12-24 (9days)	Rainy
	A_{EN}	NV	Feb 6-28 (17 days)	Dry
School B	B_{OP}	NV	Oct 25-Nov 3 (8days)	Rainy
	B_{OP}	NV	April 2-27 (20days)	Dry
	B_{EN}	NV	Oct 25-Nov 3 (8days)	Rainy
	B_{EN}	NV	April 2-27 (20days)	Dry
School C	C_{OP}	NV	May 9-29 (15days)	Rainy
	C_{OP}	NV	Jan 15-31 (13days)	Dry
	C_{EN}	NV	May 9-29 (15 days)	Rainy
	C_{EN}	NV	Jan 15-31 (13 days)	Dry

5.2.2 Measured Thermal Variables (All Day)

Table 5.2 shows the statistical summary of the measured thermal variables characterized according to minimum, maximum, mean and standard deviation values. While tables 5.3-5.5 show the summary of the recorded thermal variables according to classroom type. Thermal variables extracted from the dataloggers during and after the school hours were analysed and presented in this section.

Results shown in Table 5.2 indicate that the indoor air temperature for all the combined classrooms in both seasons were within the range 21.2-35.7°C, with mean value of 29.2°C and SD with value 1.6. According to classroom type, the mean indoor temperature for the combined open-space classrooms all season at the time of the survey was 29.1^{o}C, while that of the combined enclosed classrooms was 29.3^{o}C. The standard deviation in the open space classroom was 1.6K with a coefficient variation of 5.0%, while the enclosed plan classroom recorded a standard deviation of 1.4K with a coefficient variation of 4.7%. The range of the outdoor temperature was between 23.0-37.4^{o}C, with 29.4°C as the mean value for the combined classrooms. The RH at the time of the survey ranged from 23.6-92.9% with mean value of 71.6%. The air velocity in the combined classrooms all season at the time of the survey ranged from 0.11-0.30m/s with mean value of 0.20m/s. In the ‘open-space’ classrooms the range was between 0.11-0.30m/s, with mean value of 0.21m/s, while in the ‘enclosed-plan’ classrooms the range was between 0.11-0.28m/s with mean value 0.19m/s. Figure 5.1 shows the graphical representation of temperatures from the data logger placed in school B.

Furthermore, the highest indoor temperature (35.7°C) was recorded in school A (classroom A_{EN}) and that was during the dry season in February, while the lowest temperature (21.2°C) was also recoded in school A, however this time in classroom A_{OP} and that was during the rainy season in October (Table 5.6). Table 5.6 further shows that the minimum temperature was observed during the school hour period at 8.30 am, while the maximum temperature was observed outside school hours at 4.03 pm. In the same school A (classroom A_{OP}) during the rainy season, the highest difference between the minimum temperature and maximum temperature (13.5K) was observed, while the lowest difference (4.7K) was observed in school B (classroom B_{EN}) and that was during the dry season.

In addition, the highest variation in indoor relative humidity was recorded in classroom B_{EN} (65.5%) and that was in the dry season survey. The lowest variation in indoor relative humidity was equally recorded in school B (16.1%) in the same classroom (B_{EN}) and that was in rainy season survey.

Table 5. 2: Mean, Standard Deviation, Min and Max values of the Environmental Parameters

	All Open-space	All Enclosed- plan	Combined Open and Enclosed
Air Temperature (^{0}C)			
Mean	29.1	29.3	29.2
S.D.	1.6	1.4	1.6
Min	21.2	25.0	25.0
Max	35.6	35.7	35.7
Operative Temp (^{0}C)			
Mean	29.1	29.2	29.2
S.D.	1.6	1.5	1.6
Min	21.3	25.0	25.0
Max	35.6	35.7	35.7
Outdoor Temperature	29.4	29.4	29.4
Mean	2.3	2.3	2.3
S.D.	23.0	23.0	23.0
Min	37.4	37.4	37.4
Max			
Relative Humidity (%)			
Mean	71.8	71.4	71.6
S.D.	13.1	11.8	12.4
Min	23.6	29.3	23.6
Max	92.5	92.9	92.9
Air Velocity (m/s)			
Mean	0.21	0.19	0.20
S.D	-	-	-
Min	0.11	0.11	0.11
Max	0.30	0.28	0.30

Table 5. 3 : Summary of Indoor Air Temperature in the Surveyed Schools

	Classroom Type	Season	Max (°C)	Min (°C)	Mean (°C)	St Dev	Coefficient of variation
A	A_{OP}	Rainy (Oct)	34.7	21.2	28.6	1.2	0.042
		Dry (Feb)	35.6	22.6	29.4	1.5	0.051
	A_{EN}	Rainy (Oct)	34.8	22.9	28.7	1.4	0.049
		Dry (Feb)	35.7	26.8	29.5	1.8	0.060
B	B_{OP}	Rainy (Oct, Nov)	34.2	25.9	28.2	1.4	0.048
		Dry(April)	30.2	22.5	28.9	1.4	0.052
	B_{EN}	Rainy (Oct Nov)	31.5	25.0	28.3	1.6	0.055
		Dry (April)	30.5	25.8	28.9	1.1	0.038
C	C_{OP}	Rainy (May, June)	33.6	23.0	28.7	1.9	0.066
		Dry (Jan)	33.8	26.5	28.8	0.7	0.025
	C_{EN}	Rainy (May, June)	34.8	24.0	29.2	1.8	0.061
		Dry (Jan)	35.1	25.8	29.0	0.7	0.025

Table 5. 4: Summary of Outdoor Temperature in the Schools

School	Classroom	Season	Max (°C)	Min (°C)	Mean (°C)	St Dev (°C)	Coefficient of variation
A	A_{OP} & A_{EN}	Rainy	37.4	23.0	29.2	1.7	0.058
		Dry	36.2	24.0	29.6	1.5	0.051
B	B_{OP} & B_{EN}	Rainy	35.6	25.4	28.6	1.2	0.042
		Dry	33.8	23.7	29.1	1.1	0.038
C	C_{OP} & C_{EN}	Rainy	36.6	24.1	29.4	2.0	0.017
		Dry	31.8	24.3	29.1	1.9	0.066

Table 5. 5: Indoor Relative Humidity

School	Classroom type	Season	Max (%)	Min (%)	Mean (%)	St dv (%)	Coefficient of variation
A	A_{OP}	Rainy	89.6	56.7	76.2	6.87	0.088
		Dry	73.7	29.3	70.5	10.3	0.146
	A_{EN}	Rainy	92.5	60.8	81.3	5.25	0.065
		Dry	81.8	50.2	67.8	6.37	0.094
B	B_{OP}	Rainy	87.5	23.6	70.5	13.70	0.194
		Dry	94.2	67.8	80.6	5.6	0.069
	B_{EN}	Rainy	80.8	27.4	73.4	3.4	0.046
		Dry	92.9	27.4	79.2	9.87	0.124
C	C_{OP}	Rainy	91.6	48.4	78.1	7.3	0.089
		Dry	60.8	39.7	52.2	6.43	**0.123**
	C_{EN}	Rainy	87.8	46.2	74.0	5.2	**0.070**
		Dry	60.8	38.3	51.1	6.93	**0.135**

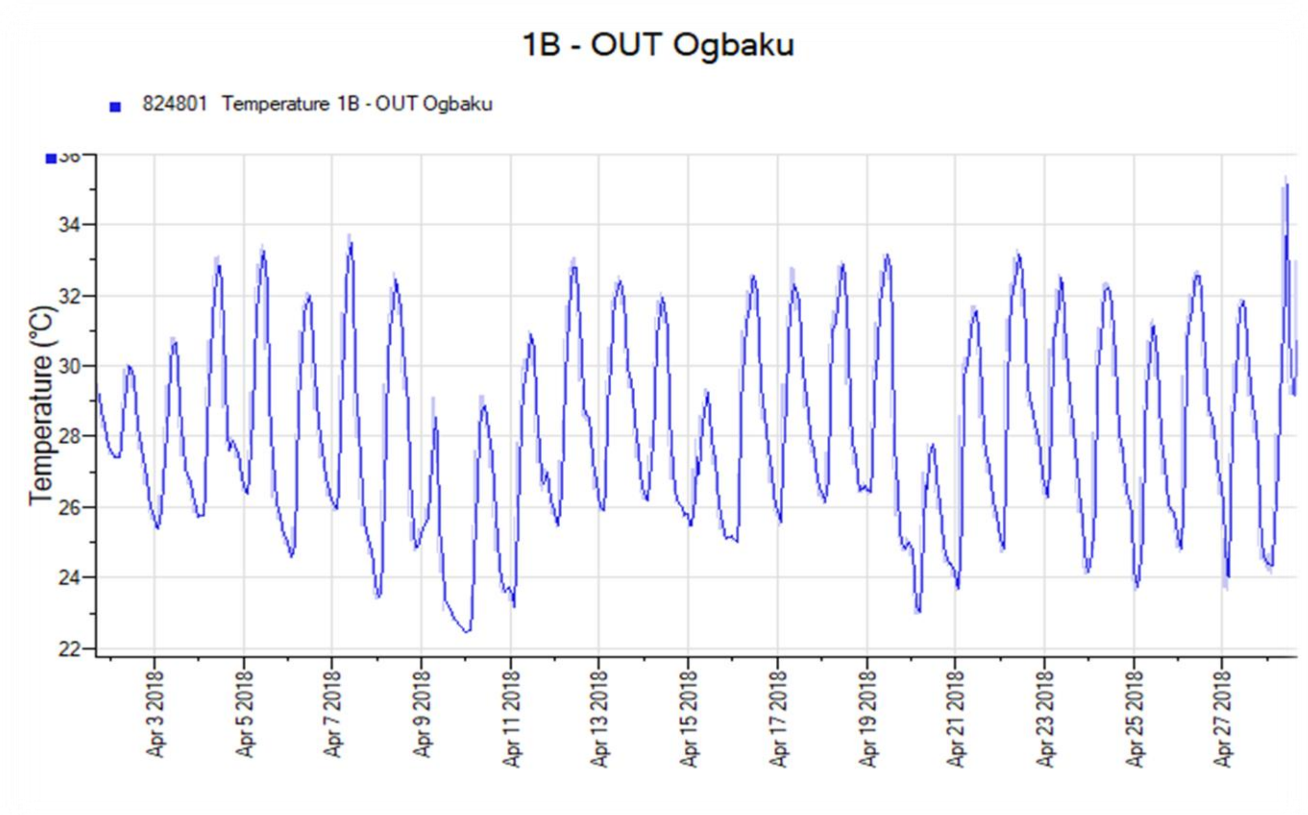

Figure 5.1: Sample of graphical presentation of temperature from data logger

School A

Table 5.6 summarizes the thermal variables extracted from the dataloggers in this school. In both seasons, lower indoor temperatures were observed in the morning hours while higher values were observed in the afternoon hours. The two types of classrooms (A_{OP} and A_{EN}) exhibited some differences and also showed some commonalities in thermal behaviour. There were some days both types of classrooms in both seasons reported minimum (min) and maximum (max) temperatures on the same day, and at the same time in some cases. Also observed was that in some days, the outdoor temperatures of these classrooms followed the same trend exhibited by these two types of classrooms by reporting min and max values in temperatures on the same day. These findings are summarized in Table 5.6 and discussed in Chapter 6. Details about the thermal conditions in school A, in both seasons, are further presented according to classroom type. Figure 5.2 shows the graphical representation of the data logger placed in school A.

Table 5. 6: Outdoor and indoor thermal variables at school

	Classroom Type	Highest Temp (°C)			Lowest Temp (°C)			Highest RH (%)			Lowest RH (%)		
		Data	Date	Time	Data	Date	Time	Data	Date	Time	Data	Date	Time
Rainy season	A_{OP}	34.7	Oct 12	4.40pm	21.2	Oct 16	8.30am	89.6	Oct 16	8.30am	56.7	Oct 12	2.55pm
	A_{EN}	34.8	Oct 12	3.25pm	22.9	Oct 16	8.30am	62.5	Oct 18	7.55pm	60.8	Oct 19	1.55pm
	Outdoor	37.4	Oct 23	3.55pm	23.0	Oct 16	8.40am	-	-	-	-	-	-
Dry season	A_{OP}	35.6	Feb 9	4.25pm	22.6	Feb 21	9.48am	73.7	Feb 7	9.58am	29.3	Feb 2	10.15pm
	A_{EN}	35.7	Feb 16	4.03pm	26.8	Feb 21	9.48am	81.8	Feb 7	9.58am	50.2	Feb 1	9.13pm
	Outdoor	36.2	Feb 3	4.05pm	24.0	Feb 21	10.09am	-	-	-	-	-	-

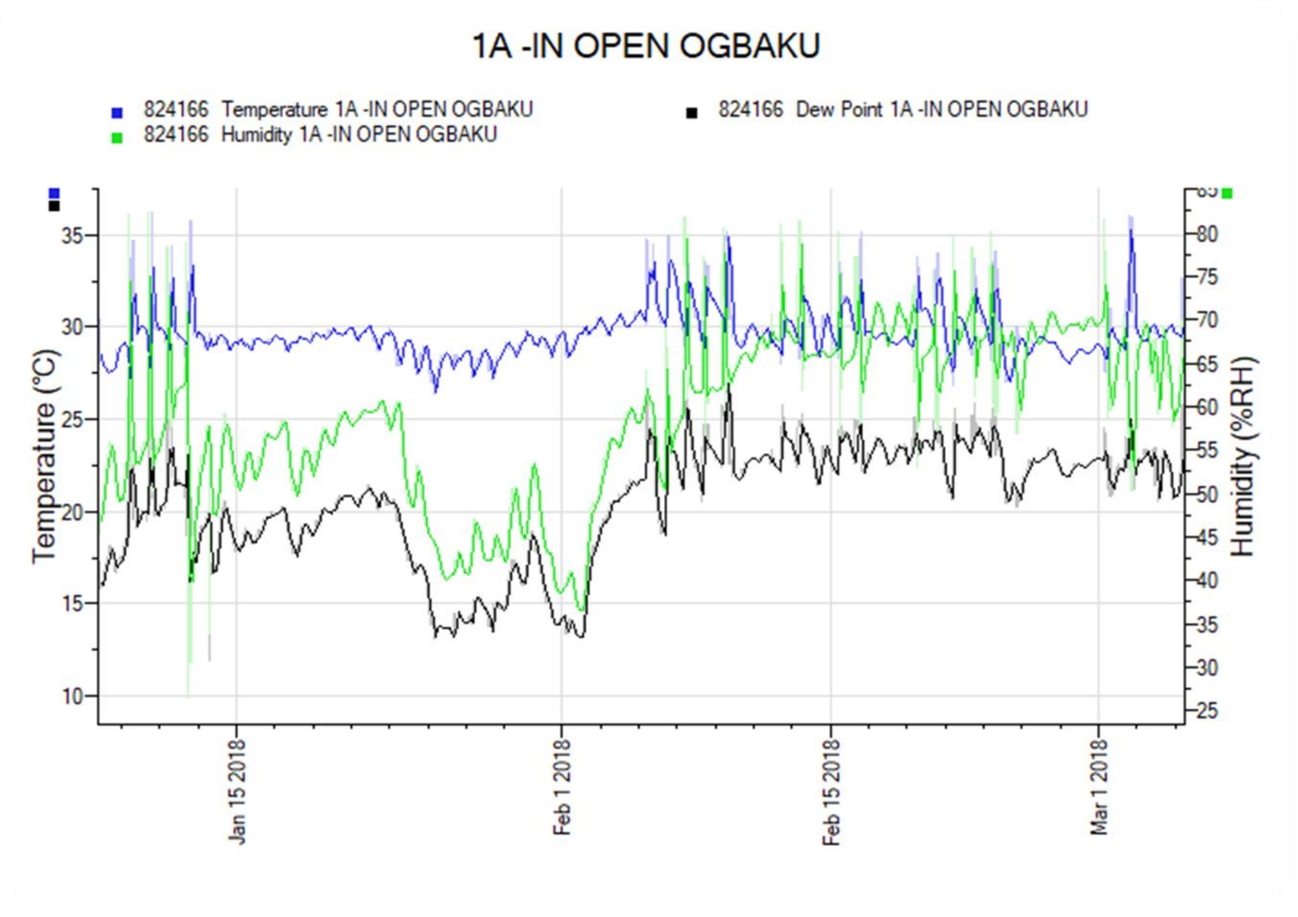

Figure 5.2: Sample graphical representation of operative temperature of School Classroom A_{OP}

Classroom A_{OP}

Rainy Season: In the open-space classroom in school A the indoor temperatures ranged from 21.2°C to 34.7°C during the rainy season survey as shown in Table 5.6. The lowest temperature was recorded in the morning hours of October 16, while the highest temperature was recorded on October 12. The highest daily variation in indoor temperature recorded in the open classroom was 10.4°C on October 24, while the lowest daily variation recorded was 0.6°C on October 16, 2017. Furthermore, the outdoor temperature ranged from 23.0 to 37.4°C, with minimum value observed on Oct 16. The indoor relative humidity ranged from 56.7% to 89.6%. Interestingly, the maximum relative humidity was recorded the same day (October 16), and hour the minimum air temperature was recorded. The lowest RH (56.7%) was reported on Oct 12, 2017 at 2.55 pm. The highest daily variation in indoor relative humidity (32.9%) was recorded on October 16, 2017, while lowest relative humidity variation recorded on October 24 in the open classroom was 1.8%.

Dry Season: In dry season, the indoor temperature in classroom A_{OP} ranged from 22.6°C to 35.6°C. The highest indoor temperature was recorded on Feb 9 at 4.25 pm, while the lowest was recorded on Feb 21 at 9.45 am. The highest outdoor temperature was recorded on Feb 3 at 4.05 pm, while the lowest was recorded on Feb 21 at 9.48 am. Relative humidity ranged from 29.3% to 73.7%. The highest RH was reported on Feb 7 at 9.58 am, while the lowest was recorded at 10.15 pm on Feb 2.

Classroom A_{EN}

Rainy Season: In this classroom, the indoor temperature during the investigation ranged from 22.9 to 34.8°C, with mean value of 28.7°C, (SD=1.4). The maximum indoor temperature was observed on Oct 12 at 3.55 pm, while the lowest temperature was observed on Oct 16 at 8.30 am. The outdoor temperature ranged from 23.0 to 37.4°C with mean value of 29.2°C (SD=1.7). The indoor relative humidity ranged from 60.8 to 92.5% with a mean value of 81.3% (SD =5.25).

Dry Season: In this classrooms, the indoor temperature ranged from 26.8 to 35.7°C with mean value of 29.5°C (SD=1.8). The highest daily temperature was observed on Feb 16, while the lowest value was observed on Feb 21. The outdoor temperature ranged from 24 to 36.2°C with 29.6°C as the mean value (SD =1.5). The indoor relative humidity ranged from 50.2 to 81.8% with 67.8% as the mean value (SD=6.37).

Comparing Thermal Variabilities in Classrooms A_{OP} and A_{EN}

Further results of the thermal performance in these two types of classrooms in school A with a check at the histogram in Figure 5.3 reported some differences. From the figure, the mean indoor temperature in rainy season was as high as 30°C in the open-space classroom on the 12th, 19th and 20th of October. High mean values in indoor temperatures up to 30°C were observed in the enclosed plan classroom on the 12th, 15th and 23rd October. Also, the open-space classroom recorded low mean indoor temperature on the 14th, 15th, and 24th of October.. Furthermore, as shown in Figure 5.4, the mean indoor relative humidity in the enclosed plan classroom in this season were above 80% on the 13th, 14th, 16th, 21st and 22nd October. However, mean indoor relative humidity in the open-space classrooms rarely reached 80% all the days the survey were carried out.

Further check at the histogram in Figure 5.5 shows that in dry season, the mean indoor temperatures in the open classroom exceeded 30°C on the 6th, 16th, 17th and 18th of February.

The lowest mean indoor temperature in the open space classrooms was observed on the 21st and 27th of February. On the other hand, the mean indoor temperature in the enclosed plan classroom exceeded 30°C on the 6th, 15th, 16th, 19th, 20th, 22nd and on 23rd of February.

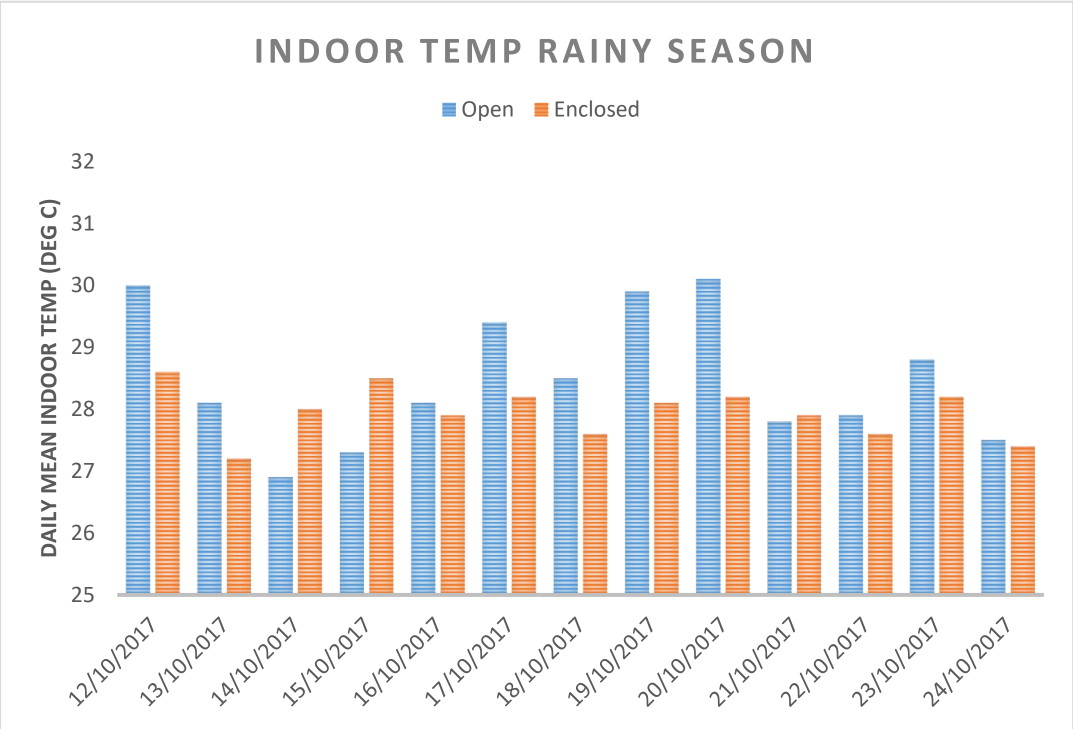

Figure 5.3: Daily means of indoor temperature in rainy season

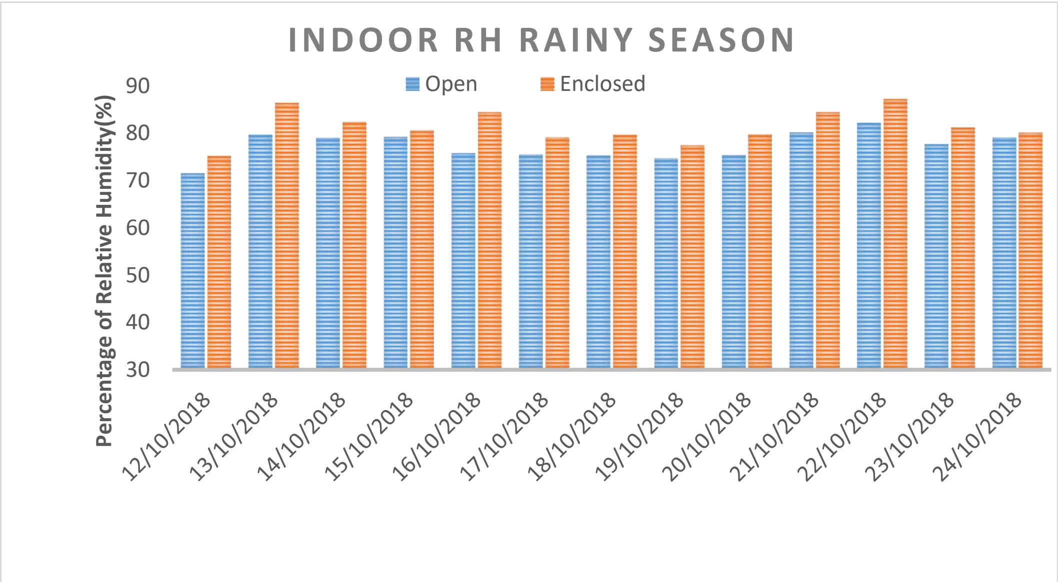

Figure 5.4: Daily mean indoor relative humidity in rainy season

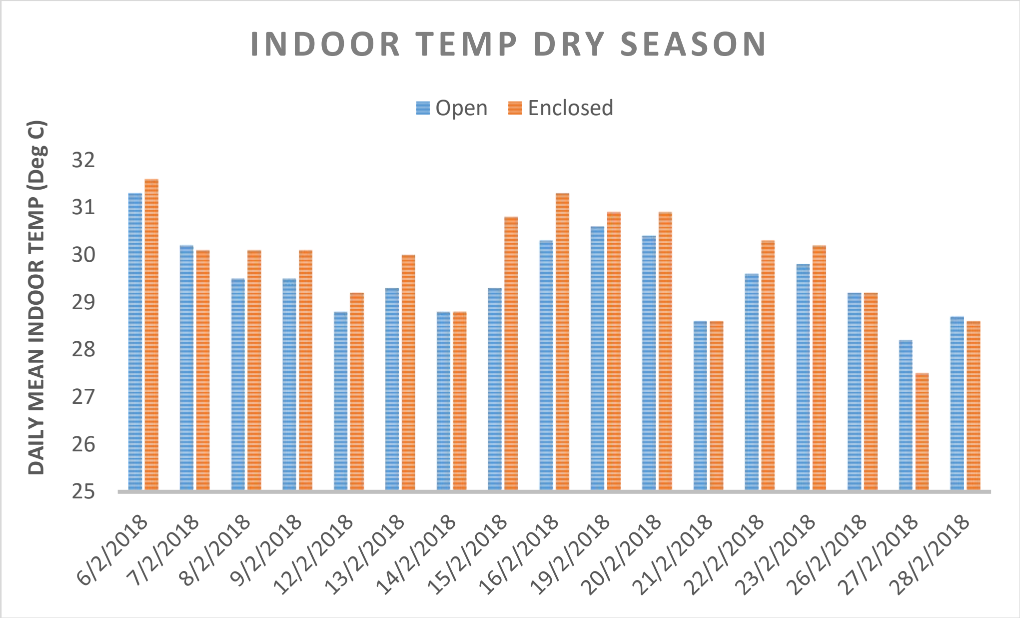

Figure 5.5: Daily means of indoor temperature in dry season

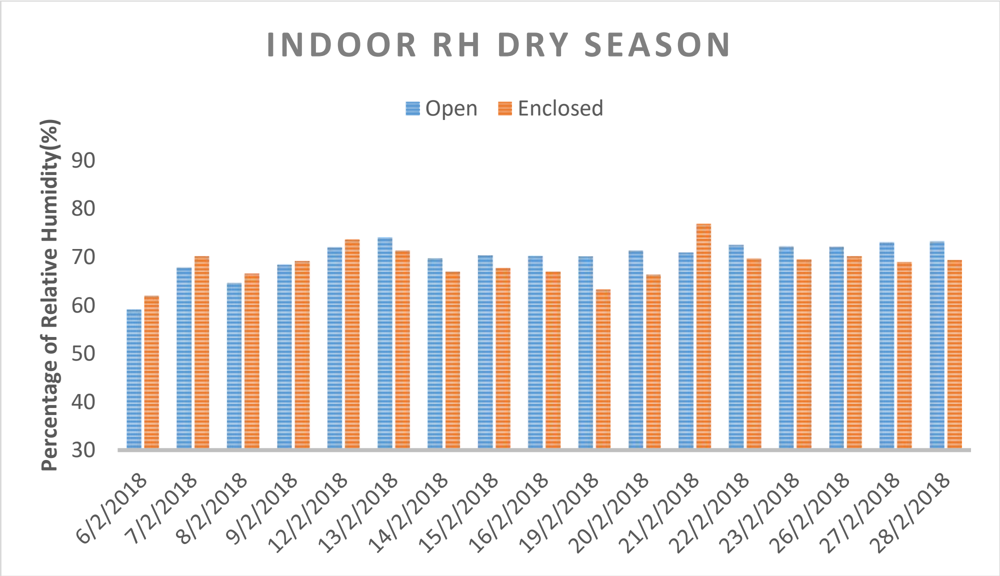

Figure 5.6: Daily mean indoor relative humidity in dry season.

School B

The two surveyed classrooms in this school exhibited the same thermal tendency as was observed in school A, by showing differences and commonalities in thermal behaviour. The findings are summarized in Table 5.7 and further presented according to classroom type and season.

Table 5. 7: Summary of outdoor and indoor thermal variables at school B rainy and dry Season

	Classroom Type	Highest Temp (°C)			Lowest Temp (°C)			Highest RH (%)			Lowest RH (%)		
		Data	Date	Time	Data	Date	Time	Data	Date	Time	Data	Date	Time
Rainy season	B_{OP}	34.2	Oct 25	3.43pm	25.9	Nov1	7.23am	87.5	Nov1	8.18am	23.6	Oct 25	2.03pm
	B_{EN}	31.5	Oct 25	-	25.0	Nov1	7.46am	80.8	Nov1		27.4	Oct 25	
	Outdoor	35.6	Nov 25	2.48pm	25.4	Nov1	7.58am	-	-	-	-	-	-
Dry season	B_{OP}	30.2	April 5	4.08pm	22.5	Apr 9	12:18pm	94.2	-	-	67.8	-	-
	B_{EN}	30.5	April 5	4.19pm	25.8	Apr 9	9:59pm	92.9	-	-	27.4		
	Outdoor	33.8	April 5	-	23.7	Apr 9		-	-		-		

Classroom B_{OP}

Rainy Season: For all the data collected during the rainy season, the indoor temperature ranged from 25.9°C to 34.2°C in classroom B_{OP}, with mean operative temperature of 28.2°C and mean outdoor temperature of 28.6°C. The lowest temperature was recorded on 1st Nov at 07.23 am, while the highest temperature was recorded on Oct 25 at 3.43 pm. The highest variation in indoor temperature of 9.9°C was recorded in this classroom on the 25th Oct, while the lowest variation of 1.9°C was recorded on the 29th of Oct. Relative humidity ranged from 23.6% to 87.5%. The highest RH was recorded on the same day (Nov 1) the lowest temperature was recorded. This maximum RH (with the same value) was recorded three times on the same day in the morning hours at 8.08 am, 8.18 am and at 8.23 am. The highest variation in indoor RH with value 61.6% was recorded on Oct 31, while the lowest variation with value 7.7% was recorded on Nov 3.

Dry Season: During the dry season survey, the indoor temperature in the open classroom ranged from 22.5°C to 30.2°C with a mean indoor operative temperature of 28.9°C. The outdoor temperature ranged from 23.7°C to 33.8°C with mean value 29.1°C. The highest daily variation in indoor temperature recorded in the open classroom in this season was 3.7°C and that was in April 19. The relative humidity ranged from 67.8% to 94.2% with an average relative humidity of 80.6%.

Classroom B_{EN}

Rainy Season: The range of indoor temperature in the rainy season in this classroom was from 25.0 to 31.5°C with mean value of 28.3°C. The lowest temperature was observed on Nov 1, while the highest temperature was observed on Oct 25. The highest daily variation in indoor temperature was on Oct 25 with value 9.8°C, while the lowest daily variation was observed on Oct 28 with value 1.9°C. The outdoor temperature ranged from 25.4 to 35.6°C, with 28.6°C as the mean. Furthermore, the indoor RH ranged from 27.4 to 80.8% with mean value 73.4%. The highest variation of 65.5% RH was recorded on Nov 1, while the lowest variation of 6.0% was recorded on Oct 25.

Dry Season: In this season, the temperature ranged from 25.8 to 30.5°C with 28.9°C as the mean. The lowest temperature was recorded on April 9, while the highest temperature was recorded in April 5. The outdoor temperature ranged from 23.7 to 33.8°C with mean value of 29.1°C, while the range for the RH was between 27.4 to 92.9% with mean value 79.2%.

Comparing Thermal Variabilities in Classrooms B_{OP} and B_{EN}

Further results of the comparison of the thermal performance in these two types of classrooms in school B are presented in Figures 5.7 to 5.10. According to the histograms, the daily mean indoor temperatures during the rainy season in the open space classrooms were less than 30°C in all the days the survey was conducted. In the enclosed plan classrooms, the daily mean indoor temperature exceeded 30°C on the 25th, 30th and 31st of the surveyed month (Oct.). During the dry season survey, the daily mean indoor temperature in both the open space and the enclosed plan classrooms did not exceed 30°C. Furthermore, the highest value in daily mean indoor during the rainy season occurred on the 25th and 30th of Oct, while in the enclosed plan classrooms the highest daily mean indoor temperature occurred on the 25th, 30th and 31st of Oct. During the dry season, the highest daily mean indoor temperature occurred on April 4, 5, 7, 18 and 19, while the highest daily mean indoor temperature occurred in the enclosed plan classroom on April 4, 5, 7, 18 and 19.

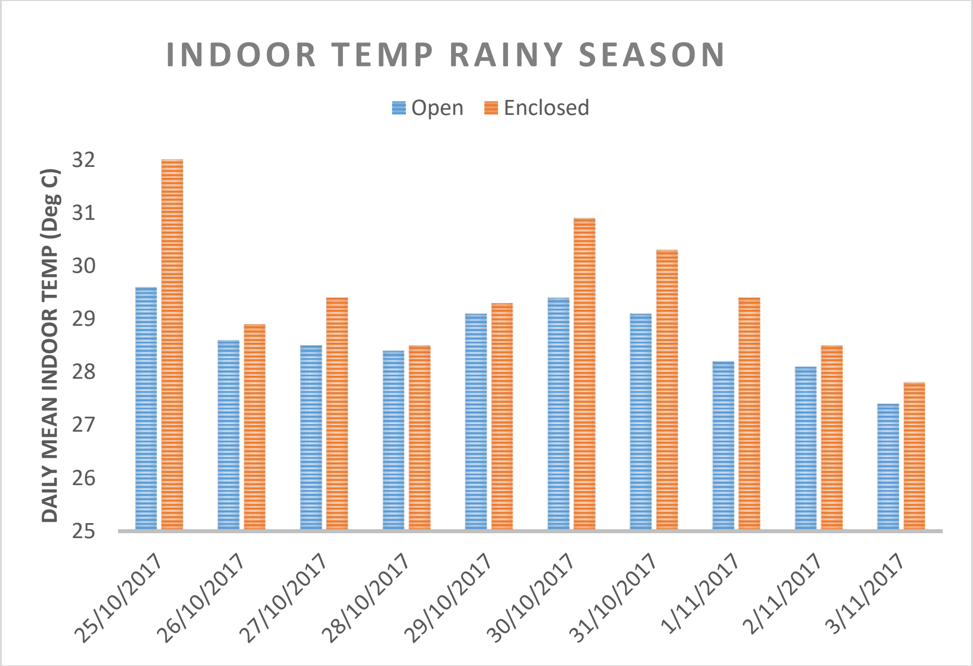

Figure 5.7: Daily means of indoor temperature in rainy season

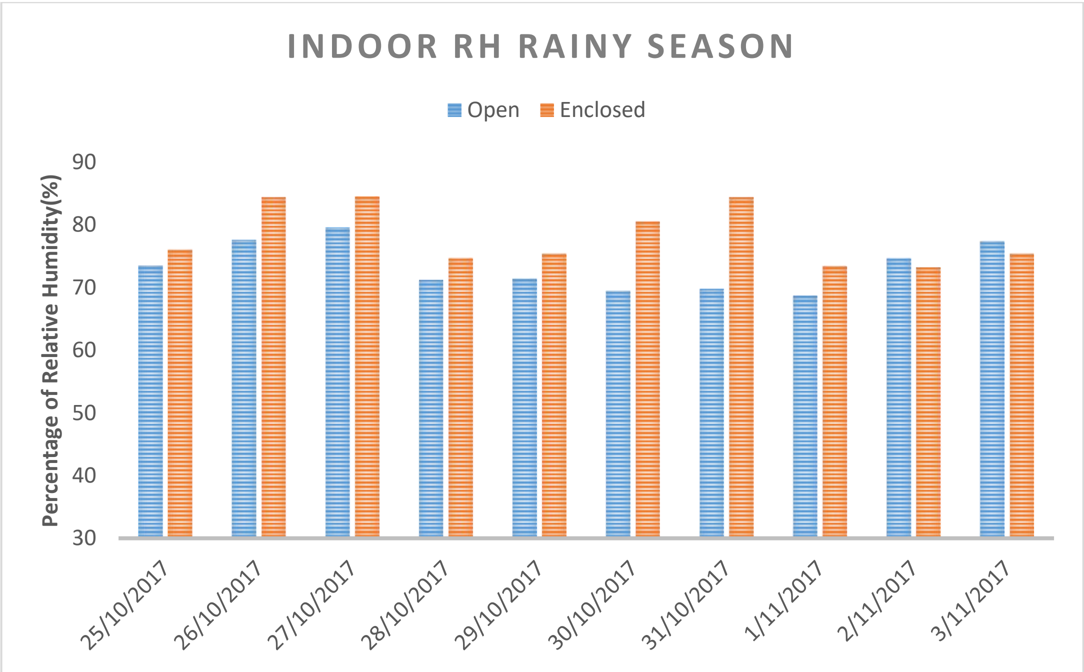

Figure 5.8: Daily mean indoor relative humidity in rainy season

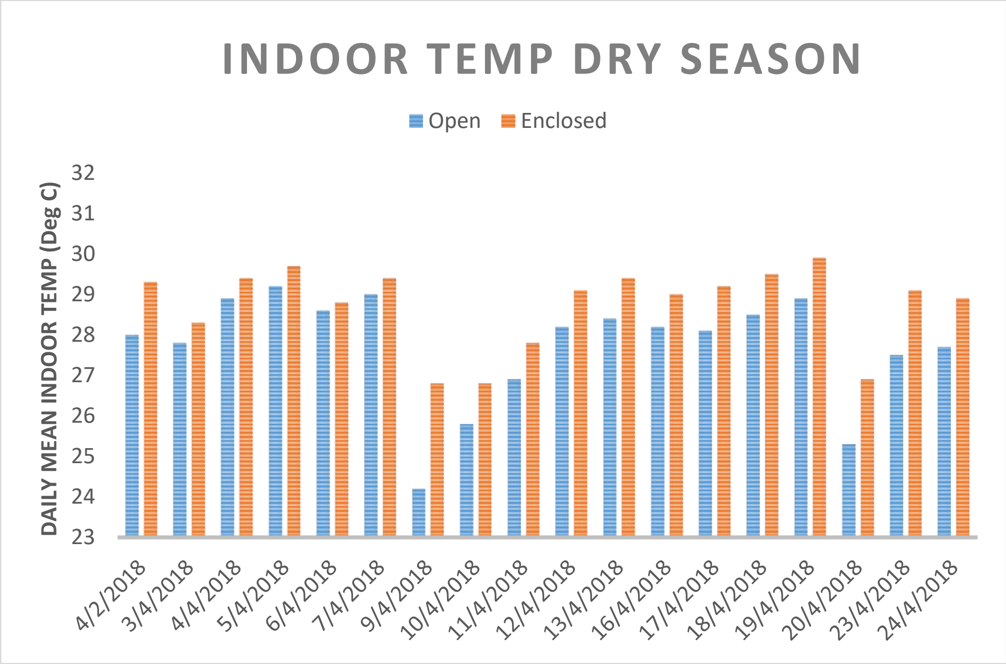

Figure 5.9: Daily means of indoor temperature in dry season

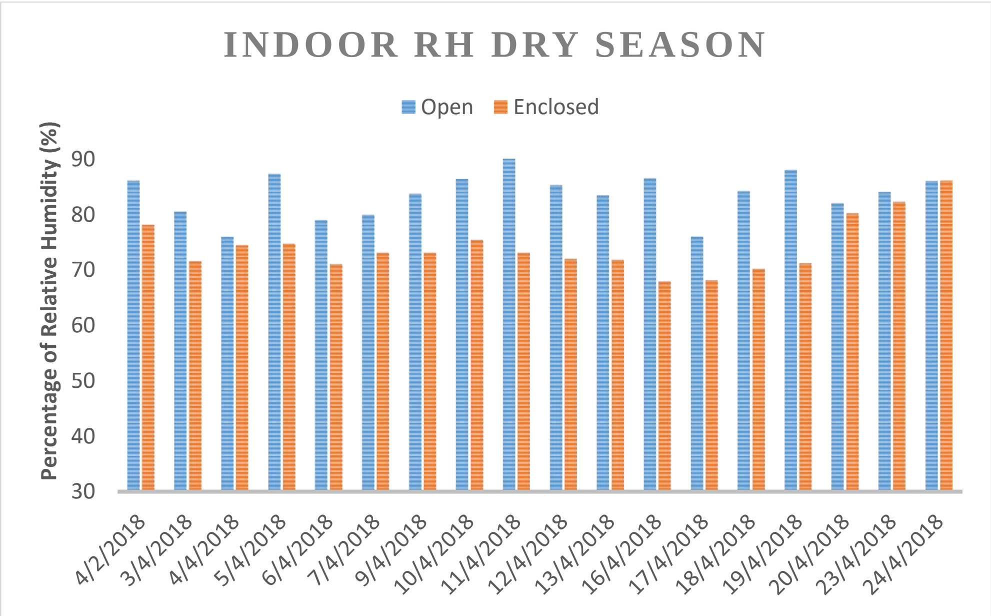

Figure 5.10: Daily mean indoor relative humidity in dry season

School C

Table 5.8 shows the detailed summary of the indoor and outdoor thermal variables in school, while Figures 5.11 and 5.12 show the graphical depiction of the indoor temperature and indoor relative humidity during the rainy season and dry season, respectively. During the rainy season survey, the indoors of the two types of classrooms and their outdoor recorded max temperatures on the same day. The trend repeated itself in the dry season where max temperatures were also observed in both classrooms. The results in this school are further presented according to classroom type and season.

Classroom C_{OP}

Rainy Season: During the rainy season, the temperatures in this classroom ranged from 23.0 to 33.6°C with mean value of 28.7°C. The minimum temperature was observed on May 10`at 6.38 pm, while the maximum temperature was observed on May 23 at 3.20 pm. The outdoor temperature ranged from 24.1 to 36.6°C with mean value 29.4°C. The maximum outdoor temperature was observed on May 23 at 3.15 pm while the minimum outdoor temperature was observed on May 9 at 8.29 pm. Relative humidity ranged from 48.4% to 91.6% with mean value 78.1%.

Dry Season: During the dry season, the indoor temperatures in the open classroom ranged from 26.5°C to 33.8°C with mean value 28.8°C. The outdoor temperature ranged from 24.3 to 31.8°C with mean value 29.1°C. Relative humidity ranged from 39.7% to 60.8% with mean value of 52.2%.

Classroom C_{EN}

Rainy Season: During the rainy season, the temperatures in the open classroom ranged from 24.0°C to 34.8°C with mean value of 29.2°C. The outdoor temperature ranged from 24.1 to 36.6°C with mean value 29.4°C. Relative humidity ranged between 46.2% to 87.8% with mean value 74.0%.

Dry Season: During the dry season, the indoor temperature in the open classroom ranged from 25.8°C to 35.1°C with mean value 29.0°C. The maximum temperature was observed on January 28 at 4.00 pm. However, that was recorded outside the school hours. The outdoor temperature ranged from 24.3 to 31.8°C with mean value 29.1°C. Relative humidity ranged between 38.3% to 60.8% with mean value 51.1%.

Table 5. 8: Summary of thermal variables in the surveyed schools

Season	Class	Highest Temp (°c)			Lowest Temp (°c)			Highest RH (%)			Lowest RH (%)		
		Data	Date	Time	Data	Date	Time	Data	Date	Time	Data	Date	Time
Rainy season	C_{OP}	33.7	May 23	3.20pm	23.0	May 10	6.38pm	91.6			48.4		
	C_{EN}	34.8	May 23		25.0			87.8			46.2		
	Outdoor	36.6	May 23	3.15pm	24.1	May 9	8.29pm	90.3			30.5		
Dry season	C_{OP}	33.8	Jan 28	4.34pm	26.5	Jan 15	9.54pm	60.8			39.7		
	C_{EN}	35.1	Jan 28	4.00pm	25.8			60.8	82.1		38.3	-	-
	Outdoor	31.8	Jan 28		34.3								

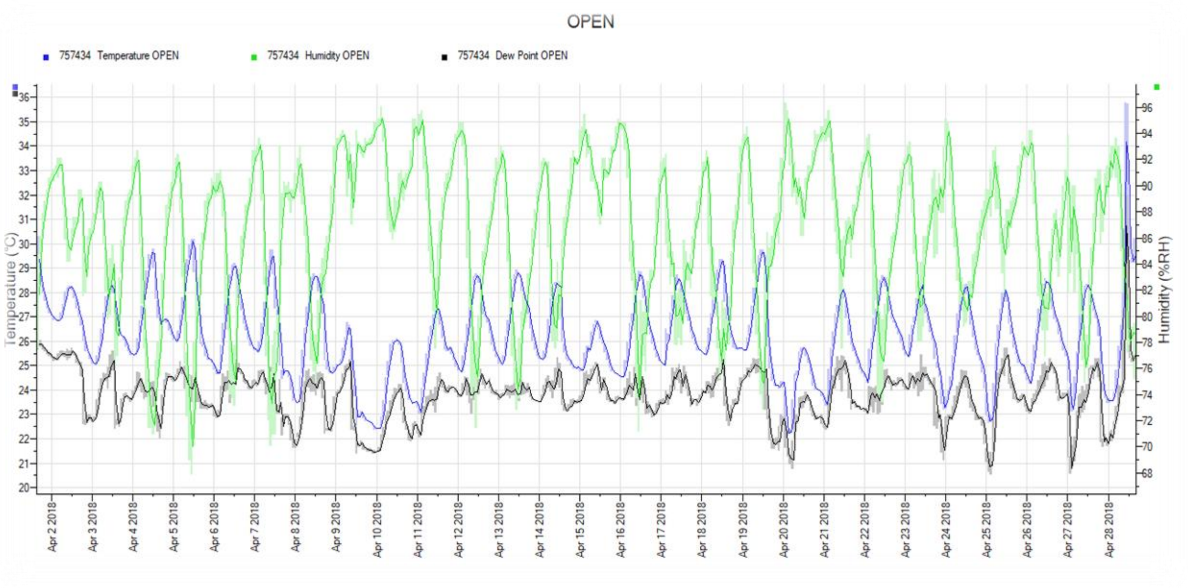

Figure 5.11: Indoor temperature and RH of school C during the rainy season

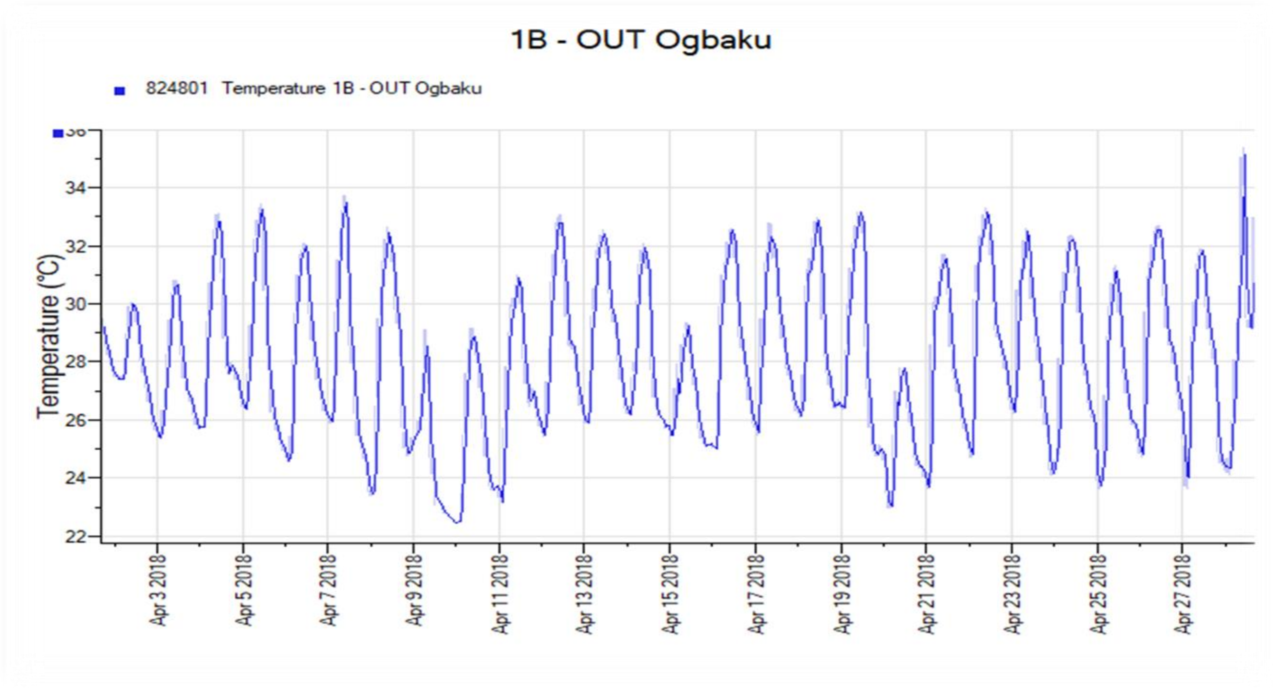

Figure 5.12: Outdoor temperature of school C during the rainy season

5.2.3 Determining Classroom's Compliance with ASHRAE Standard 55

The adaptive thermal comfort model is based on the relationship between the indoor temperature and the outdoor temperature. Adaptive model suggests that these two variables mostly determine the comfort temperature of building occupants. Indoor air movement is another variable that can influence the thermal performance of a building. ASHRAE Standard 55 sets 80% and 90% acceptable comfort ranges of indoor spaces based on these variables (ASHRAE, 2017).

To determine the thermal performance in each of the surveyed classrooms, the prevailing mean outdoor temperature (T_{out}) of each classroom space was plotted against the corresponding daily mean indoor operative temperature (T_{OP}) putting into consideration the prevailing mean indoor air velocity. The result was compared with the 80% and 90% acceptable comfort ranges of the ASHRAE Standard 55-2017 (ASHRAE, 2017). The ASHRAE Thermal Comfort Tool is permitted to be used to ensure compliance (ASHRAE, 2017). Some other researchers who used the Centre for the Built Environment Thermal Comfort Tool to ensure compliance to the standard are (Hoyt, Schiavon, Piccioli, Moon, & Steinfeld, 2013 and Efeoma, 2017). Where the classroom under investigation does not comply with the requirements of the standard, the variables are further analysed using the Centre for Built Environment (CBE) thermal comfort tool. ASHRAE Standards 55 allows the use of a CBE thermal comfort tool to enhance thermal comfort by increasing airflow to more than 0.3m/s provided that the mean outdoor temperature in the space does not exceed 33.5°C (ASHRAE, 2017). For this study, the mean outdoor temperature in the surveyed classrooms did not exceed 33.5°C (Tables 5.2 and 5.4).

School A

Classroom A_{OP}

Rainy Season: The prevailing mean indoor operative temperatures were plotted against the corresponding mean outdoor temperatures obtained from the field work. Each point represents one measurement carried out during the survey. The result is overlaid with the adaptive model of ASHRAE Standard 55. These can be compared with the 80% and 90% acceptable comfort ranges on the ASHRAE 55 adaptive comfort model (Hoyt et al., 2013). The result indicated that all the points were within the 80% comfort range and almost all the points falling within the 90% comfort range. Thus, classroom A_{OP} complied with the ASHRAE Standard 55 adaptive comfort standard with 28.6°C as the mean indoor operative temperature and 29.2°C as the mean outdoor temperature. Because of the compliance, no further analysis was needed. Figure 5.13 shows the mean indoor operative temperature plotted against the prevailing mean outdoor temperature.

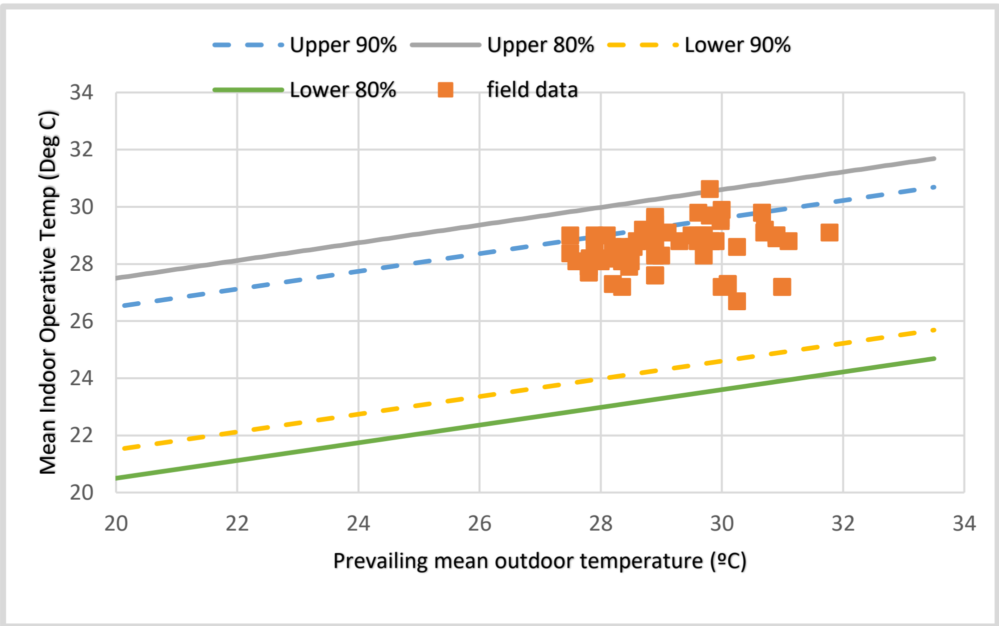

Figure 5.13: Mean indoor T_{OP} plotted against the prevailing mean T_{out}

Dry Season: However, during the dry season, in the same classroom, some of the points were outside the 80% and 90% adaptive comfort range as shown in Figure 5.14 at the mean indoor operative temperature of 29.4^{o}C, mean outdoor temperature with value 29.6^{o}C and at the prevailing indoor air velocity. The thermal condition in the classroom in this season was further analysed to determine its compliance with the ASHRAE Standard, by increasing the indoor air velocity using the CBE comfort analysis tool. By increasing the air velocity to 0.3m/s, the classroom complied with the ASHRAE Standard 55 adaptive standard as shown in Figure 5.15.

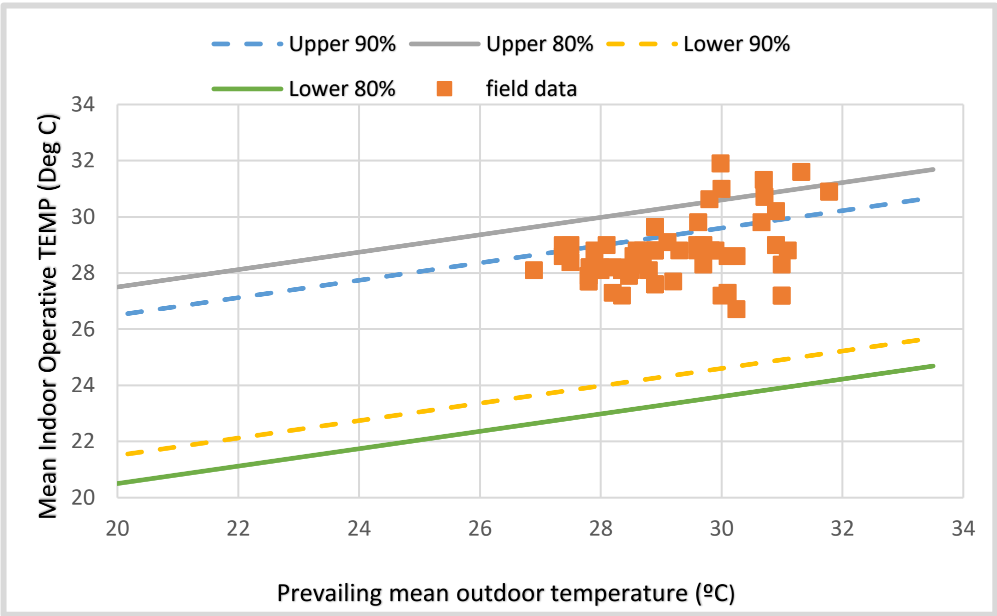

Figure 5.14 Mean indoor T_{OP} plotted against the prevailing mean T_{out}

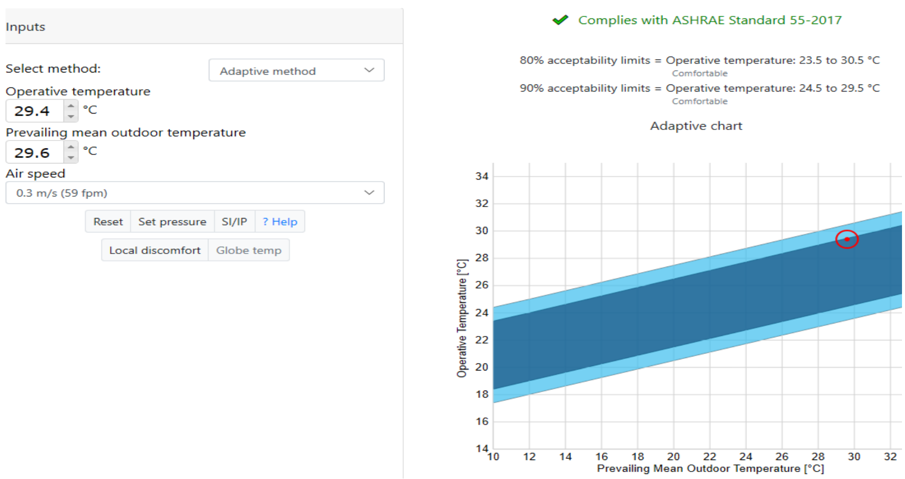

Figure 5.15: Analysis of classroom A_{OP} with air velocity of 0.3m/s using CBE Thermal Comfort Tool.

Classroom A_{EN}

Rainy Season: Results of the measured indoor OT were plotted upon the corresponding outdoor temperature and compared with ASHRAE adaptive standard 55 as shown in Figure 5.16. Results indicated that almost all the points were within the 80% and 90% range of the standard with a mean indoor operative temperature of 28.7°C and the corresponding mean outdoor temperature of 29.2°C. This suggested that classroom A_{EN} in the rainy season complied with the requirement of the standard. As a result, there was no need for further analysis.

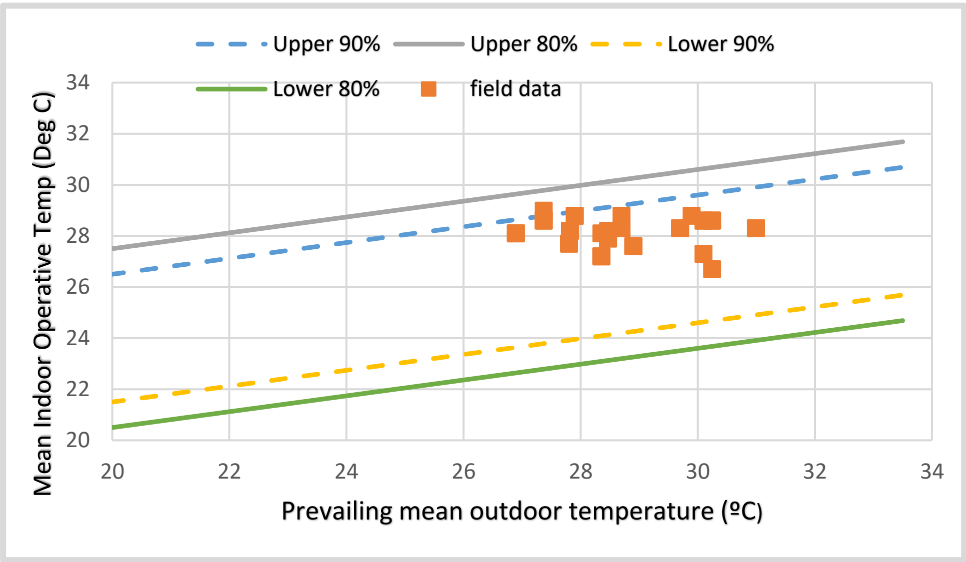

Figure 5.16 Mean indoor T_{OP} plotted against the prevailing mean T_{out}

Dry Season: However, during the dry season survey, some of the points were outside the 80% comfort range as shown in Figure 5.17 This indicated some discomfort in the classroom during the dry season at a mean OT of 29.5°C with 29.6°C as the mean outdoor temperature. The thermal condition in the classroom during the dry season was further analysed using the Centre for the Built Environment thermal comfort analysis tool by increasing the air velocity beyond the one recorded during the survey. As shown in Figure 5.18, with a higher air velocity of 0.3m/s the classroom complied with the Standard, based on 80% acceptability only. According to the CBE comfort tool, with 90% acceptability, the users of the classroom space would feel very warm even at a higher air velocity of 0.3m/s. However, the users of the indoor space can only be comfortable at air velocity of 0.6m/s for the 90% acceptability as shown in Figure 5.19.

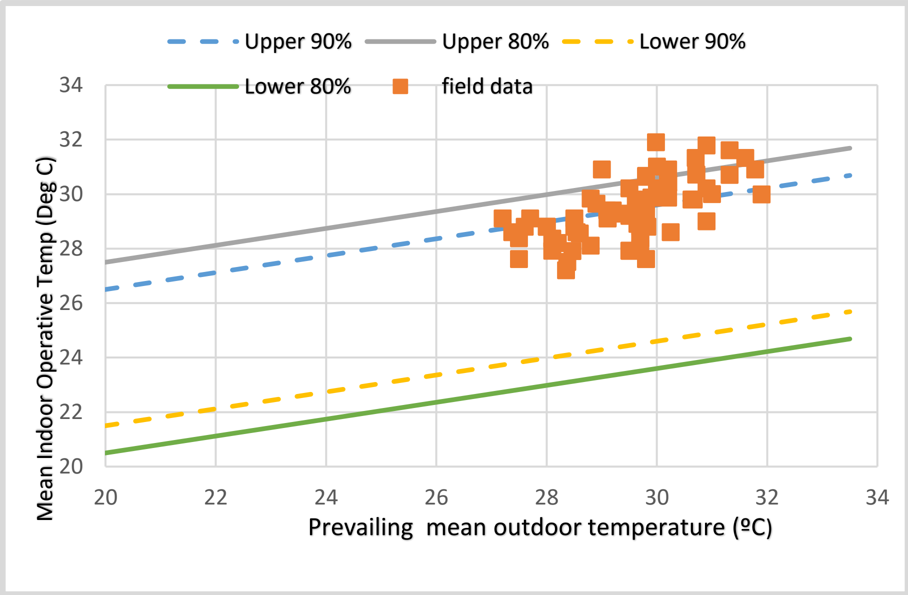

Figure 5.17: Mean indoor T_{OP} plotted against the prevailing mean T_{out}

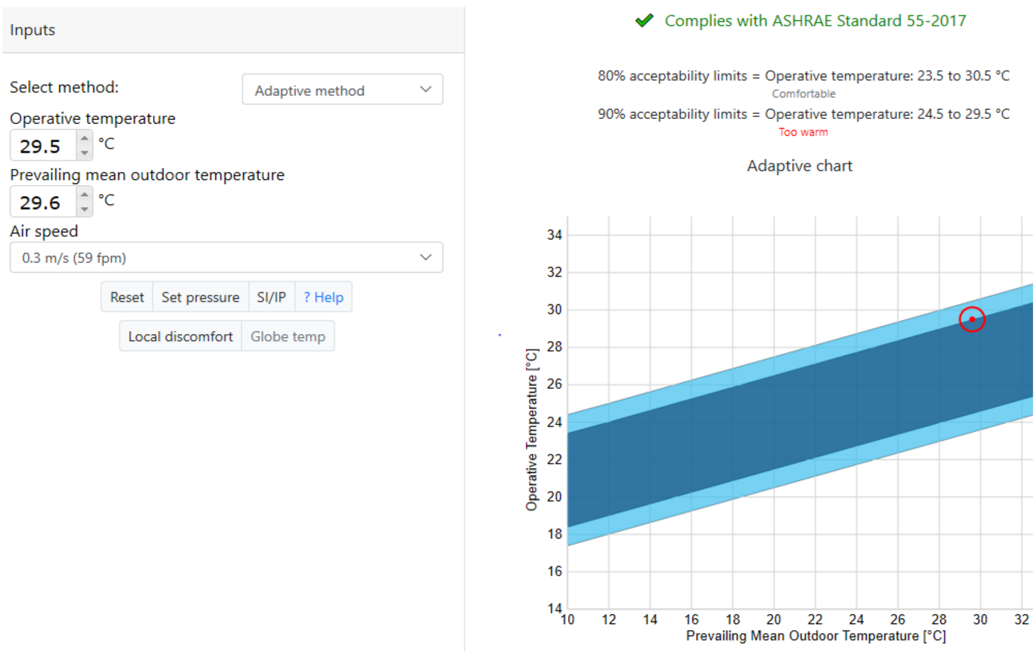

Figure 5.18: Analysis of classroom A_{EN} with air velocity of 0.3m/s using CBE Thermal Comfort Tool.

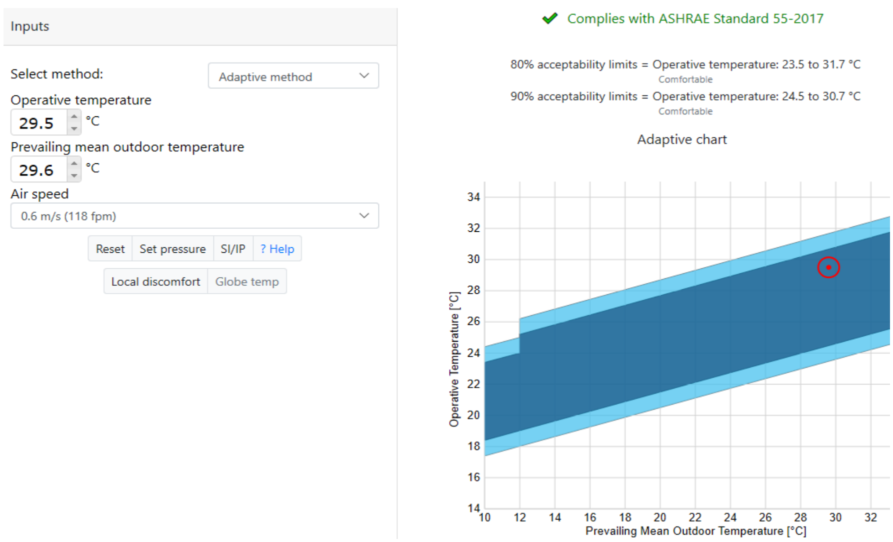

Figure 5.19: Analysis of classroom A_{EN} with air velocity of 0.6m/s using CBE Thermal Comfort Tool.

School B

Classroom B_{OP}

Rainy Season: Figure 5.20 shows the result of the regression of the mean indoor operative temperature against the mean outdoor temperature in classroom B_{OP} in the rainy season. The classroom complied with the standard at the mean indoor operative temperature and mean outdoor temperature of 28.2°C and 28.6°C, respectively considering both 80% and 90% acceptability criteria.

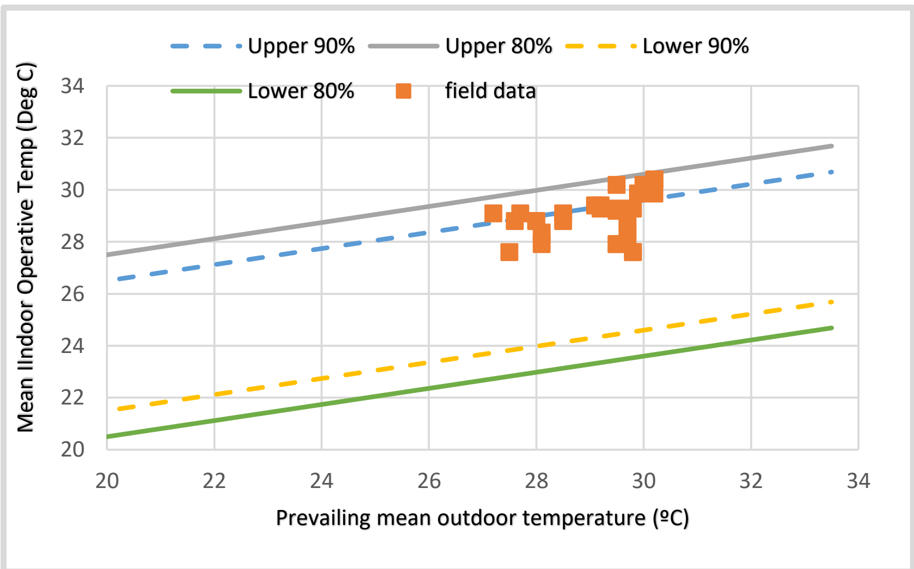

Figure 5.20: Mean indoor T_{OP} plotted against the prevailing mean T_{out}

Dry Season: Figure 5.21 shows the result of the regression of the mean indoor operative temperature against the mean outdoor temperature in classroom B_{OP} in the dry season survey. The votes were within the 80% and almost all the points were within the 90% acceptability criteria at a mean indoor OT of 28.9°C with mean outdoor temperature of 29.1°C. There was no need for further analysis.

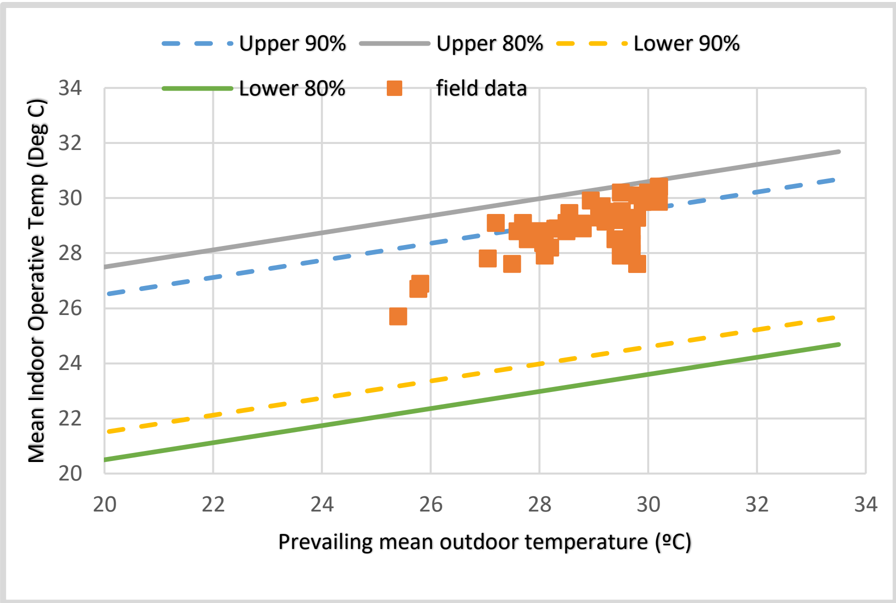

Figure 5.21 Mean indoor T_{OP} plotted against the prevailing mean T_{out}

Classroom B_{EN}

Rainy Season: Figure 5.22 shows the result of the regression of the mean indoor operative temperature against the mean outdoor temperature in classroom B_{EN} in the rainy season survey. The votes were within the 80% and 90% acceptability criterion at a mean indoor OT of 28.3°C with mean outdoor temperature of 28.6°C.

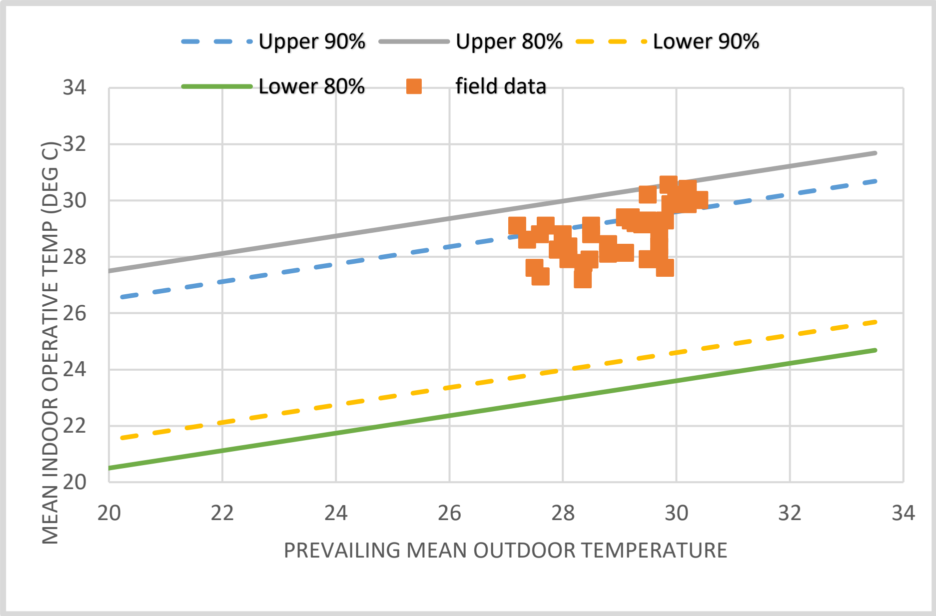

Figure 5.22. Mean indoor T_{OP} plotted against the prevailing mean T_{out}

Dry Season: Figure 5.23 shows the result of the regression of the mean indoor operative temperature against the mean outdoor temperature in classroom B_{EN} in the dry season. The votes were within the 80% and the 90% acceptability criteria. Thus, the classroom complied with the standard at a mean indoor OT of 28.9°C with mean outdoor temperature of 29.1°C

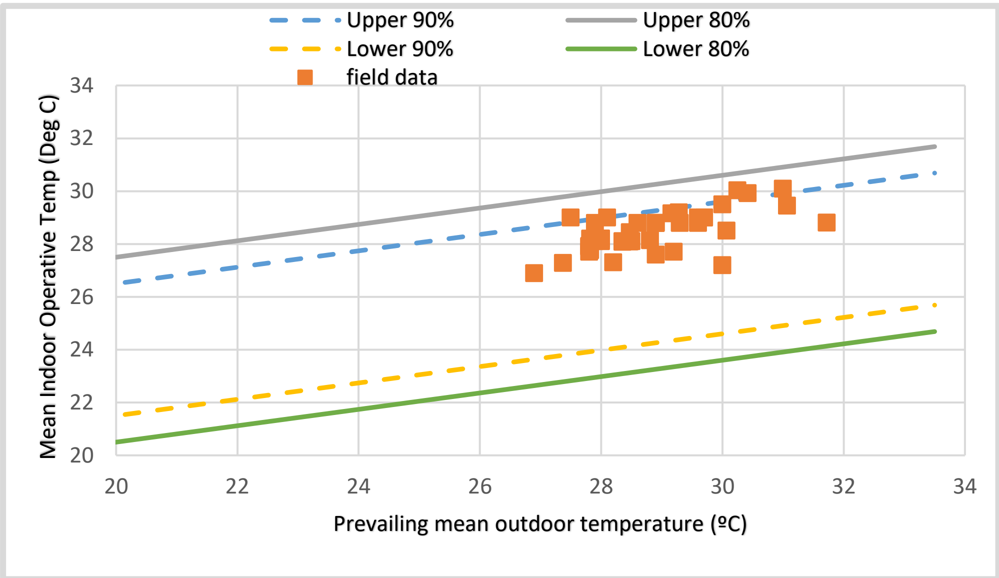

Figure 5.23: Mean indoor T_{OP} plotted against the prevailing mean T_{out}

School C

Classroom C_{OP}

Rainy Season: As seen in Figure 5.24, with the indoor mean temperature of 28.7°C and outdoor mean temperature of 29.4°C, the points were within the 80% comfort zone. However, the very few points that tended towards the periphery of the 80% comfort zone were further analysed using comfort tool by assuming a higher air velocity of 0.3m/s (Figure 5.25). At this increased air velocity, the classroom complied with both the 80% and 90% acceptability range.

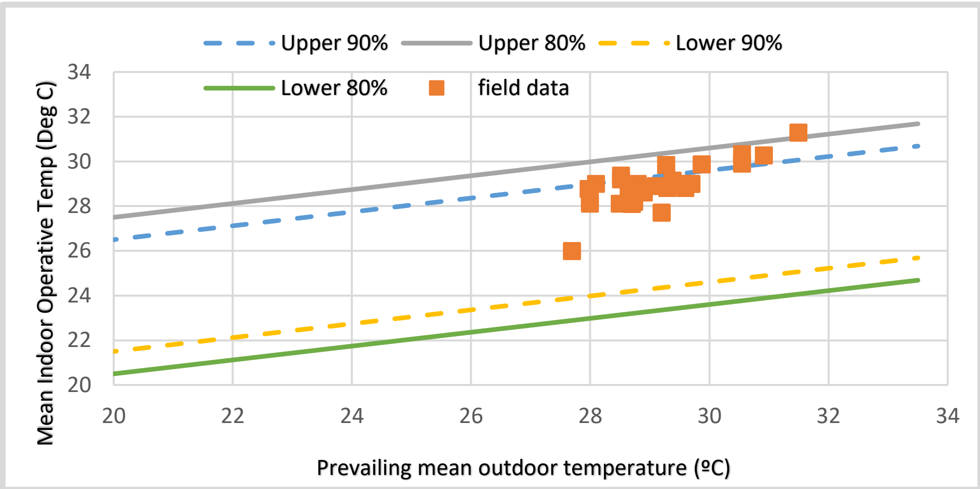

Figure 5.24: Mean indoor T_{OP} plotted against the prevailing mean T_{out}

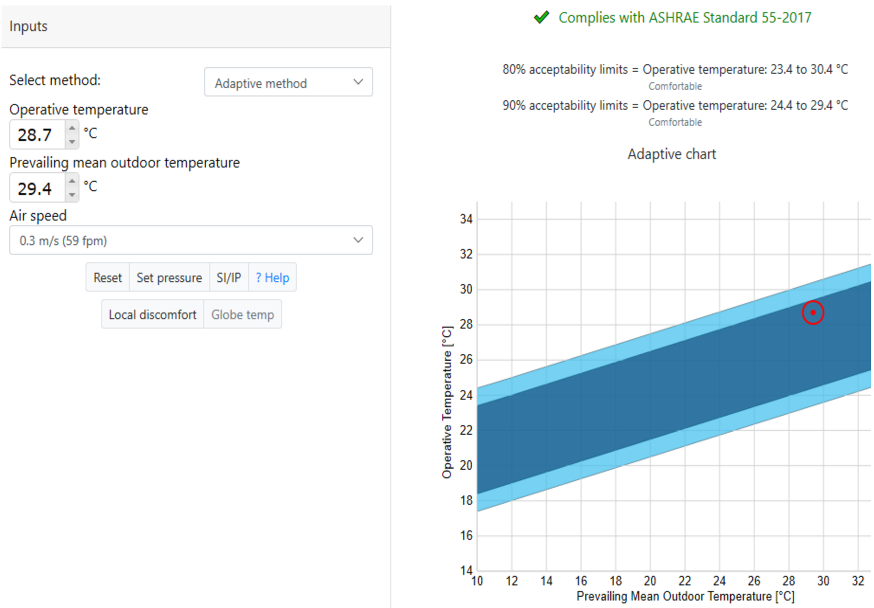

Figure 5.25: Analysis of classroom C_{OP} with air velocity of 0.3m/s using CBE Thermal Comfort Tool.

Dry Season: As seen in Figure 5.26, with the indoor mean temperature of 28.8°C and outdoor mean temperature of 29.1°C, the points were within the 80% comfort zone. Though, some few points tended towards the periphery of the 90% comfort zone however this classroom was deemed to have complied with the ASHRAE standard 55.

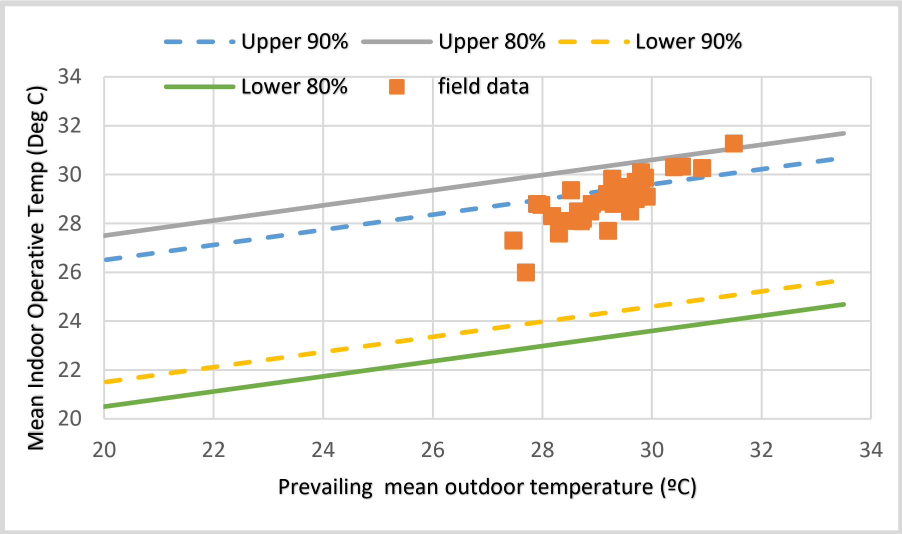

Figure 5.26: Mean indoor T_{OP} plotted against the prevailing mean T_{out}

Classroom C_{EN}

Rainy Season: As seen in Figure 5.27, with the indoor mean temperature of 29.2°C and outdoor mean temperature of 29.4°C, the points were within the 80% comfort zone. However, the very few points that tended towards the periphery of the 80 % and 90% comfort zones were further analysed using comfort tool by assuming a higher air velocity of 0.3m/s (Figure 5.28). With this, the points were within the 80% and 90% criteria

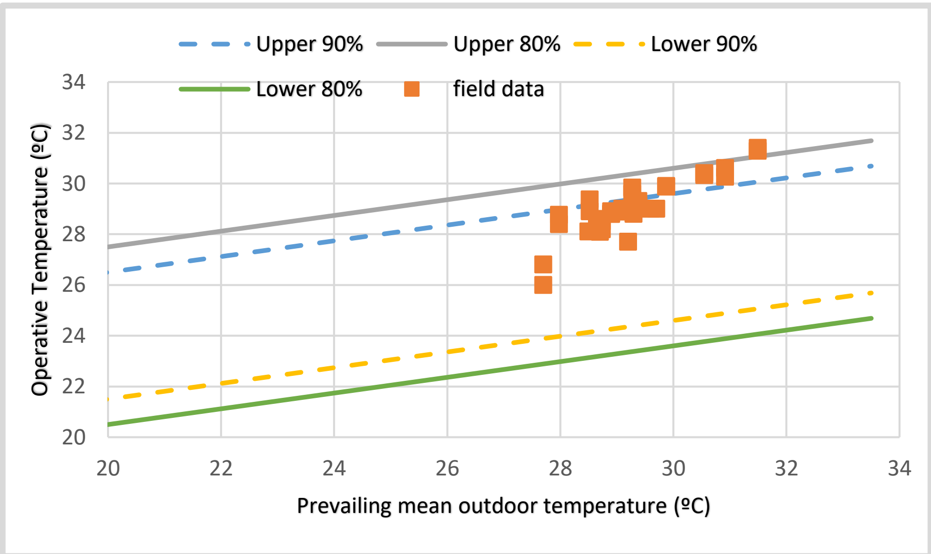

Figure 5.27: Mean indoor T_{OP} plotted against the prevailing mean T_{out}

Figure 5.28: Analysis of classroom C_{EN} with air velocity of 0.3m/s using CBE Thermal Comfort Tool.

Dry Season: As seen in Figure 5.29, with the indoor mean temperature of 29.0°C and outdoor mean temperature of 29.1°C, the points were within the 80% comfort zone. However, the very few points that tended toward the periphery of both the 80% and 90% comfort zones were further analysed using comfort tool by assuming a higher air velocity of 0.3m/s (Figure 5.30. With this increase the classroom complied.

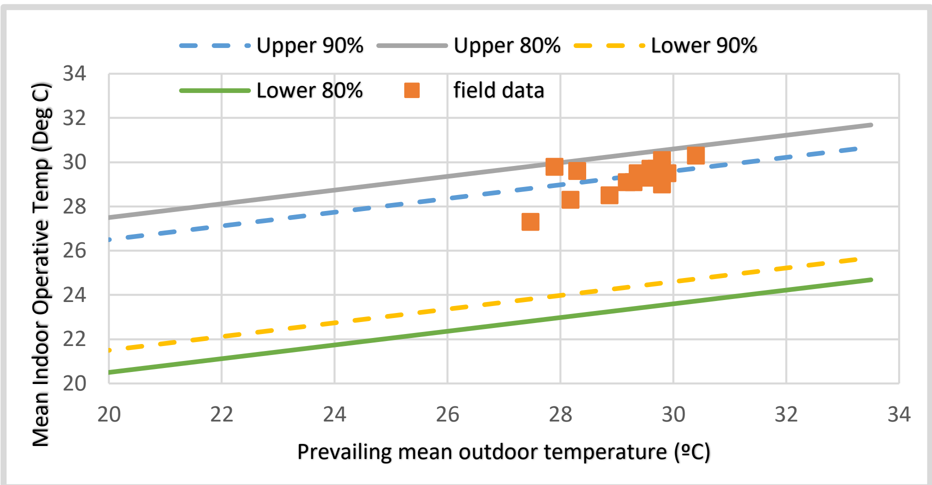

Figure 5.29: Mean indoor T_{OP} plotted against the prevailing mean T_{out}

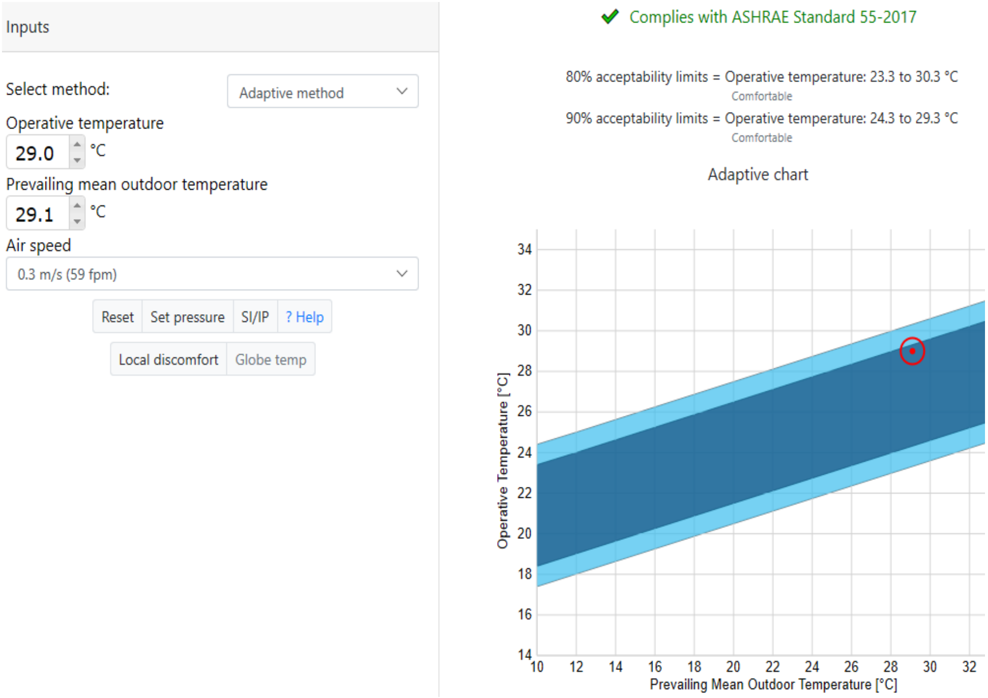

Figure 5.30: Analysis of classroom C_{EN} with air velocity of 0.3m/s using CBE Thermal Comfort Tool.

5.2.4 Comparison Between Indoor operative temperature and Outdoor Temperatures

Referring back to Table 5.2, the combined outdoor mean air temperature was by 0.2K higher than the indoor operative temperature of the combined classrooms all season. For all the classroom spaces surveyed, the indoor operative temperatures were lower than the corresponding outdoor temperature as earlier shown in Tables 5.3 and 5.4. Furthermore, the indoor operative temperatures in all the ‘open-space’ classrooms were lower than that found in all the neighbouring ‘enclosed-plan’ classrooms.

Table 5.9 presents the results of the paired *t*-test and correlation analysis between the indoor operative temperature and the outdoor air temperature in the combined classrooms and in each of the classrooms. The essence was to check the strength of relationship between these two variables of interest (indoor and outdoor temperatures) in the surveyed classrooms. The adaptive model relates the indoor operative temperature to the outdoor temperature in considering the thermal comfort of building occupants in naturally ventilated buildings. Usually correlation between these two variables are run to determine their degree of relationship. The findings were further discussed in Chapter 6.

Table 5. 9 : Paired sample *t*-test and bivariate correlations between T_{OP} and outdoor temperature

School	Class	Season	Indoor temperature vs outdoor temperature				
			Mean Indoor OT (°C)	Mean Outdoor Temp (°C)	Differ in Mean (°C)	Sign (2-tail)	Pearsons Corr
A	A_{OP}	Rainy	28.6	29.2	-0.6	0.000	.888
		Dry	29.4	29.6	-0.2	0.001	.729
	A_{EN}	Rainy	28.7	29.2	-0.5	0.000	.802
		Dry	29.5	29.6	-0.1	0.042	.497
B	B_{OP}	Rainy	28.2	28.7	-0.5	0.000	.947
		Dry	28.9	29.1	-0.2	0.008	.493
	B_{EN}	Rainy	28.3	28.6	-0.3	0.000	.918
		Dry	28.9	29.1	-0.2	0.000	.760
C	C_{OP}	Rainy	28.7	29.4	-0.7	0.000	.547
		Dry	28.8	29.1	-0.3	0.060	.771
	C_{EN}	Rainy	29.2	29.4	-0.2	0.000	.697
		Dry	29.0	29.1	-0.1	0.205	.257
ALL		Both	29.2	29.4	-0.2	0.030	.822

5.3 Thermal Variables and Children's Thermal Perception (Objectives ii-iii)

This section presents the results of the measured thermal variables and the thermal perception of the school children in six naturally ventilated classrooms. The surveys were conducted twice a day during the class lesson periods. The first survey of the day was conducted at 9.00 am, one hour after the children have settled to writing or listening to their teachers. The time of the second survey varied from 1.00 pm to 1.45 pm, at least one hour within which the children have settled after physical activities. The number of participants in each of the surveyed classrooms, for most of the days the survey was conducted, was not consistent. The number of participants was averaged to the nearest figure from the actual recording of the number that participated in each period the survey was conducted. Prevailing mean outdoor temperature above 33.5°C or below 10.0°C are not covered by ASHRAE standard 55 (ASHRAE, 2017; Jindal, 2018). The prevailing mean outdoor temperature obtained in this study satisfies this requirement as summarized in Tables,5.12 and 5.14. To determine if the thermal perception of the subjects can be explained by physiological approach, the results from the field study, that considered an adaptation, and psychological factors, were compared with the predictions of the PMV model that did not consider those two variables.

Furthermore, it is important to consider thermal comfort perception of building occupants according to time of year (seasonal) and to know the temperature people are likely to expect in a particular kind of building (Nicol & Stevenson, 2013). This study also attempted to consider the comfort perception of the subjects, not only on seasonal basis, but also according to time of the day. There are limited field surveys that considered variations in thermal perception according to time of the day.

5.3.1 Descriptive Measures

General Characteristics of Samples

Table 5.10 shows that the sample constituted returned responses from 7050 valid returned questionnaires drawn from 330 primary school children aged 7-12 years in the rainy season and dry season. In each of the surveyed classrooms, the sampled children were in the same age group and were homogeneous in cultural background and heterogenous in social status. A total of 164 visits were made to the surveyed schools; rainy season 64 visits and dry season 100 visits. 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.

Table 5.10 shows that the typical number of children in each classroom ranged from 25-30. However, some days of the survey some classrooms constituted children as small as 20 or as large as 35. A set of 158, representing 47.9% of the children participated during the dry season survey, while 172 children, representing 52.1%, participated during the rainy season survey. Further details show that the number of female participants was more (58%) compared to the male (42%) during both seasons. According to the season, females constituted; 55.1% and 61.0% for the rainy season and the dry season, respectively, against 44.9% and 59.0% for the rainy season and dry season respectively for men. Most of the participating children (56.0%) were within the age range of 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. A majority of them (96%) was born in the study area (Imo state) and have lived in the state throughout their life. After the collection of fieldwork data, the administered questionnaires were checked and rechecked against any possible inconsistent responses from the participants and those who answered questions when not healthy. Cases where children found the classroom hot (+3) or cold (-3), which according to ASHRAE Standard 55 are expressions of discomfort, and still they preferred to be hotter or cooler respectively, are considered inconsistent responses and therefore not included in the final data. This method of eliminating inconsistent responses were also applied by notable researchers in their various field works (Teli et al., 2013; Montazami et al., 2017; Korsavi & Montazami, 2019). This research adopted the same procedure resulting in a total of 374 invalid questionnaires consisting of inconsistent votes, responses from sick children, and uncompleted questionnaires. The invalid questionnaires represented 5% (approximately) of the total number of collected questionnaire (7424), which adhered to the minimum response rate requirement of ASHRAE Standard 55 for indoor environmental evaluation (ASHRAE, 2017) pp. 16.

Table 5. 10: Summary of children's responses

Classroom type	**Num of Children (Appro)**	**Survey date**	**Season**	**Administered Questionnaire**			
				Expected Number	Actual collected	Valid response	Invalid Response
AOP	25	Oct 12-24 (9days)	Rainy	450	380	370	10
AOP	25	Feb 6-28(17 days)	Dry	850	745	713	32
AEN	30	Oct 12-24 (9days)	Rainy	540	420	411	9
AEN	30	Feb 6-28(17 days)	Dry	850	740	708	32
BOP	25	Oct 25-Nov 3(8days)	Rainy	400	343	330	13
BOP	25	April 2-27(20days)	Dry	1,000	885	817	68
BEN	30	Oct 25-Nov 3(8days)	Rainy	480	415	404	11
BEN	30	April 2-27(20days)	Dry	1,200	961	880	81
COP	25	May 9-29(15days)	Rainy	750	620	595	25
COP	25	Jan 15-31(13days)	Dry	650	520	508	12
CEN	30	May 9-29(15 days)	Rainy	900	785	716	69
CEN	30	Jan 15-31 (13 days)	Dry	780	610	598	12
Total	330	164 visits		8850	7424	7050 (95%)	374(5%)

Table 5. 11: Summary of Children's background

		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%
Classrooms		12	100%	6	50%	6	50%

5.3.2 Measured Thermal Variables (School Hours)

Tables 5.12-5.15 give 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 2.45 pm. As shown in Table 5.12, the indoor temperature extracted from the dataloggers for all the combined classrooms in both seasons was within the range 22.5-35.6°C The studied children experienced a mean indoor temperature of 29.1°C (SD1.7), with 5.8% as the coefficient of variation.

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 varied from 24.0 to 94.2% with a mean value of 71.8% (SD=12.4). The mean relative humidity was similar between the two types of classrooms; however, it was slightly higher in the open space classroom.

The three enclosed classrooms recorded a higher mean indoor operative temperature (29.3°C), while the three open classrooms recorded 28.9°C as the mean value, indicating a difference of 0.4°C. Spots checks of the airflow in the classrooms shows that the maximum air velocity in the combined classrooms all season was 0.30m/s, with a mean value of 0.19m/s. The mean air velocity of 0.19m/s and 0.14m/s were observed in the combined open classrooms and combined enclosed classrooms, respectively. Further results of the recorded thermal variables in each of the surveyed schools are presented in subsequent section.

Table 5.12: Mean, standard deviation, min and max values of the main environmental parameters and0 mean thermal sensation votes .

Classroom	All Open	All Enclosed	Combined Open and Enclosed
Air Temperature (^{0}C)			
Mean	28.8	29.3	29.1
S.D.	1.6	1.5	1.7
Min	22.5	22.9	22.5
Max	35.6	35.1	35.6
Operative Temperature (^{0}C)			
Mean	28.9	29.3	29.1
S.D.	1.6	1.5	1.7
Min	22.5	22.9	22.5
Max	35.6	35.1	35.6
Outdoor Temperature (^{0}C	29.6	29.6	29.6
Mean	1.7	1.7	1.7
S.D.	23.0	23.0	23.0
Min	37.4	37.4	37.4
Max			
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
Thermal Sensation			
Mean	0.09	0.29	0.16
S.D.	.60	.70	.66
Min	-1.7	-1.5	-1.7
Max	1.7	1.8	1.8

Table 5. 13: Statistical detail of indoor operative temperature (rainy and dry Season)

School	Classroom type	Season	Max (ºC)	Min (ºC)	Mean (ºC)	St Dev	Coefficient of variation
A	**AOP**	Rainy (Oct)	34.7	22.5	28.6	1.2	0.042
		Dry (Feb)	35.6	22.6	29.6	1.5	0.051
	AEN	Rainy (Oct)	33.8	22.9	29.0	1.4	0.049
		Dry (Feb)	35.1	25.9	29.8	1.8	0.060
B	**BOP**	Rainy (Oct, Nov)	34.2	25.0	28.6	1.4	0.049
		Dry (April)	30.2	22.5	27.9	1.4	0.052
	BEN	Rainy (Oct Nov)	30.6	25.0	28.9	1.6	0.055
		Dry (April)	30.5	25.8	28.7	1.1	0.038
C	**COP**	Rainy (May, June)	33.7	23.0	28.7	2.0	0.070
		Dry (Jan)	33.8	26.5	28.8	0.7	0.025
	CEN	Rainy (May, June)	34.8	24.0	29.2	1.8	0.061
		Dry (Jan)	35.1	25.8	29.1	0.71	0.025

Table 5. 14: Outdoor temperature in the schools

School	Classroom	Season	**Max (ºC)**	**Min (ºC)**	**Mean (ºC)**	**St Dev (ºC)**	**Coefficient of variation**
A	**AOP & AEN**	Rainy	37.4	23.0	29.0	1.6	0.055
		Dry	36.1	24.0	29.9	1.5	0.050
B	**BOP & BEN**	Rainy	36.5	25.4	28.9	1.3	0.045
		Dry	33.4	23.7	28.8	1.1	0.038
C	**COP & CEN**	Rainy	37.3	24.1	29.1	1.8	0.061
		Dry	31.6	26.2	29.2	1.9	0.065

Table 5. 15: Indoor relative humidity

School	Classroom type	Season	Max (%)	Min (%)	Mean (%)	St dv (%)	Coefficient of variation
A	**A_{OP}**	Rainy	90.6	56.7	76.2	6.87	0.090
		Dry	73.7	29.3	70.5	10.3	0.146
	A_{EN}	Rainy	93.5	60.8	81.3	5.25	0.065
		Dry	81.8	50.2	67.8	6.37	0.094
B	**B_{OP}**	Rainy	87.5	24.0	70.5	13.70	0.194
		Dry	94.2	67.8	80.6	5.6	0.069
	B_{EN}	Rainy	80.8	64.7	73.4	3.4	0.046
		Dry	92.9	27.4	79.2	9.87	0.124
C	C_{OP}	Rainy	93.6	48.4	78.1	7.3	0.093
		Dry	60.8	39.7	52.2	6.43	**0.123**
	C_{EN}	Rainy	87.8	46.2	74.0	5.2	**0.070**
		Dry	60.8	38.3	51.1	6.93	**0.135**

School A

According to Season: Figure 5.31 illustrates the distribution of the indoor operative temperature (T_{op}) recorded during the survey period for the combined surveyed classrooms in school A in both seasons at occupied school hours. Each bar of the histogram, binned at 2°C, represents the percentage of survey samples falling within each range of indoor operative temperature. As shown in Figure 5.31, the indoor operative temperature within the range 26-30°C occurred most frequently, accounting for 76% of the whole time the survey was conducted in both seasons. 11% of the indoor operative temperature within the range 24.0-26.0°C was recorded during the rainy season, while only 2% of temperature in the same range was recorded during the dry season. For recorded operative temperatures below 24.0°C, only 1% was observed in the school and that was during the rainy season. Indoor operative temperatures within the range 28.0-30.0°C were more prevalent during the dry season, while during the rainy season they prevailed more within the range 26.0-28.0°C. Furthermore, at occupied school hours, the frequency of indoor temperature that exceeded 34°C was 0%.

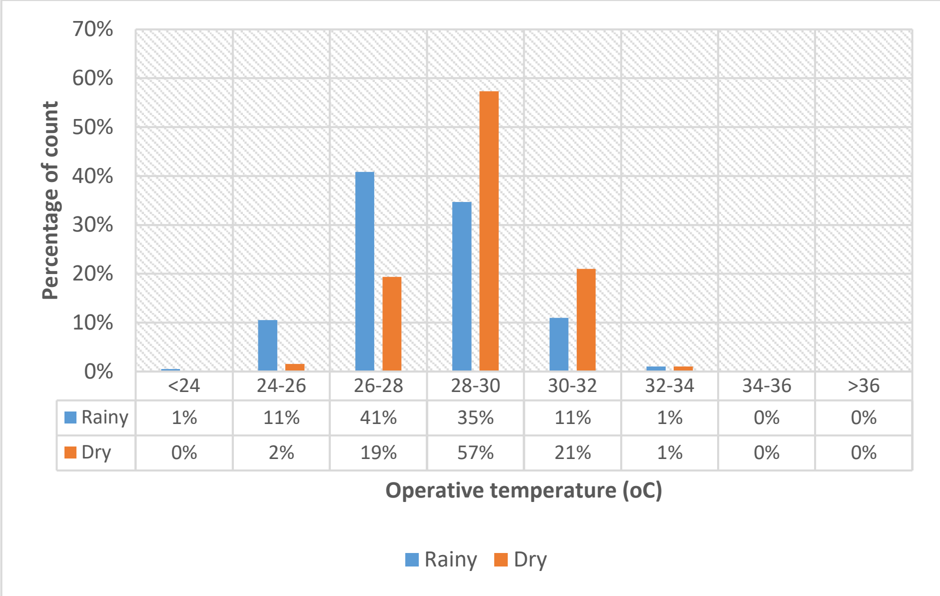

Figure 5.31: Histogram of T_{OP} at occupied time in combined classrooms in School A binned at 2°C.

According to Time of Day: As shown in Figure 5.32, the open-space classrooms in school A recorded lower values in indoor operative temperatures in the morning hours and higher values in the afternoon hours, irrespective of the season or classroom type. For example, in the open space classroom, the mean indoor operative temperature in the morning hours during the rainy season was 26.6°C, while in the afternoon hours in the same season it was 29.4°C. Furthermore during the dry season (shown in Figure 5.33), the indoor temperature in the same classroom was 28.6°C and 30.1°C in the morning hours and afternoon hours, respectively. The enclosed classrooms followed the same trend by recording lower mean values in indoor operative temperatures in the morning hours compared to the afternoon hours.

Furthermore, the mean outdoor temperature in the morning hours was also lower compared to the afternoon hours in both seasons, irrespective of the classroom type. In addition, the histogram in Figures 5.32 shows that during the rainy season, the outdoor temperature reported higher variation between the morning hours and afternoon hours (3.2°C), when compared to the difference between the mean indoor temperature in the morning and afternoon in the two classrooms; 2.8°C and 2.0°C for the open and enclosed classrooms, respectively. However, during the dry season (Figure 5.33), the mean indoor temperature in the two classrooms reported higher variation compared to the outdoor. The possible reason for the low difference in temperature in the classroom is discussed in Chapter 6.

0However, higher mean values in the indoor relative humidity were recorded in the morning hours compared to afternoon hour in both classrooms in the two seasons. The RH was generally higher in the morning hours compared to afternoon hours through ought the survey period.

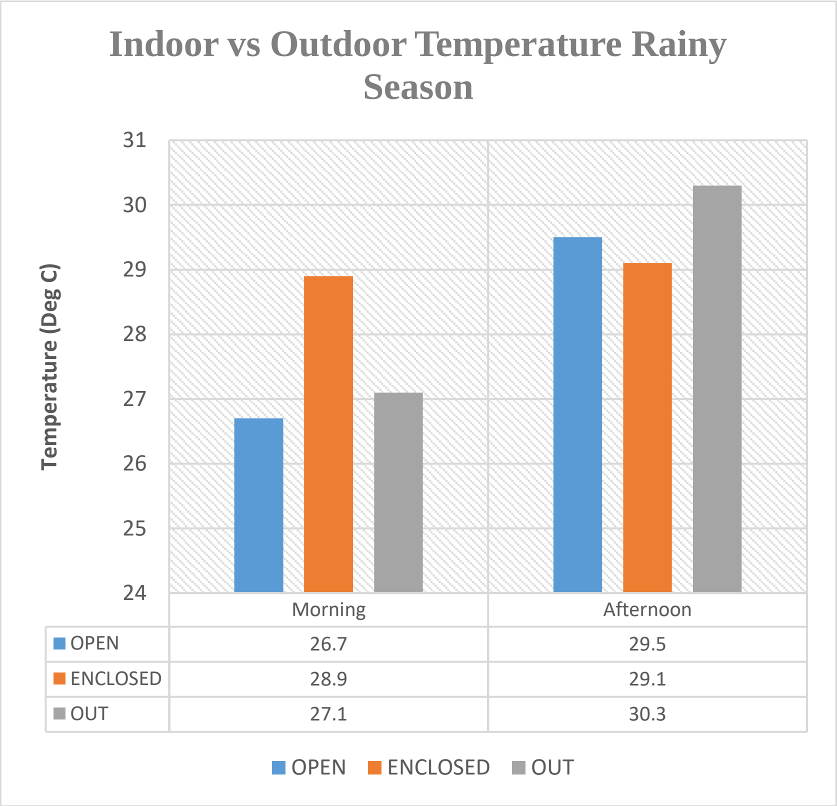

Figure 5.32: Results of the mean T_{out} and indoor T_{OP}

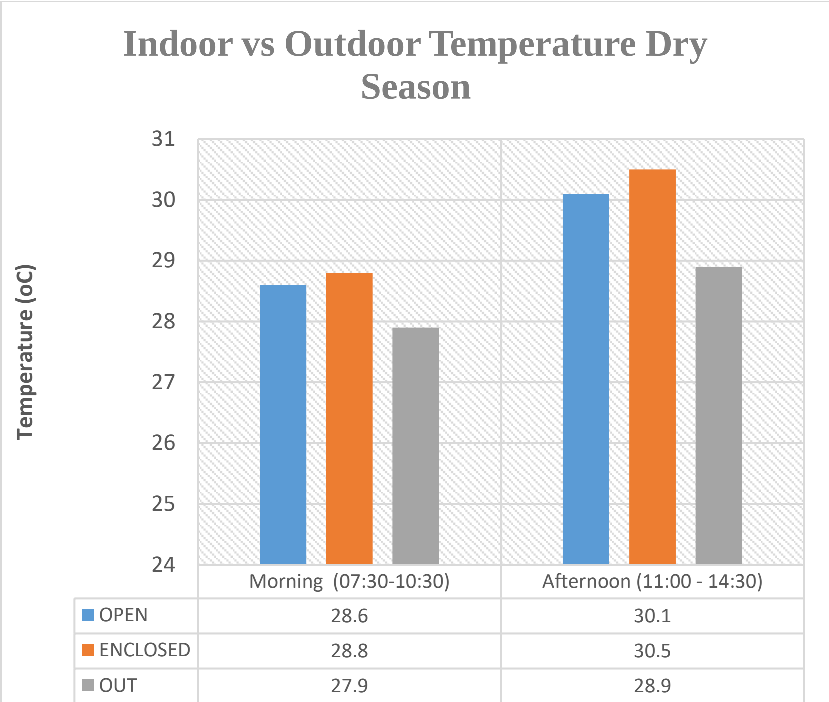

Figure 5.33: Results of the mean T_{out} and T_{OP}

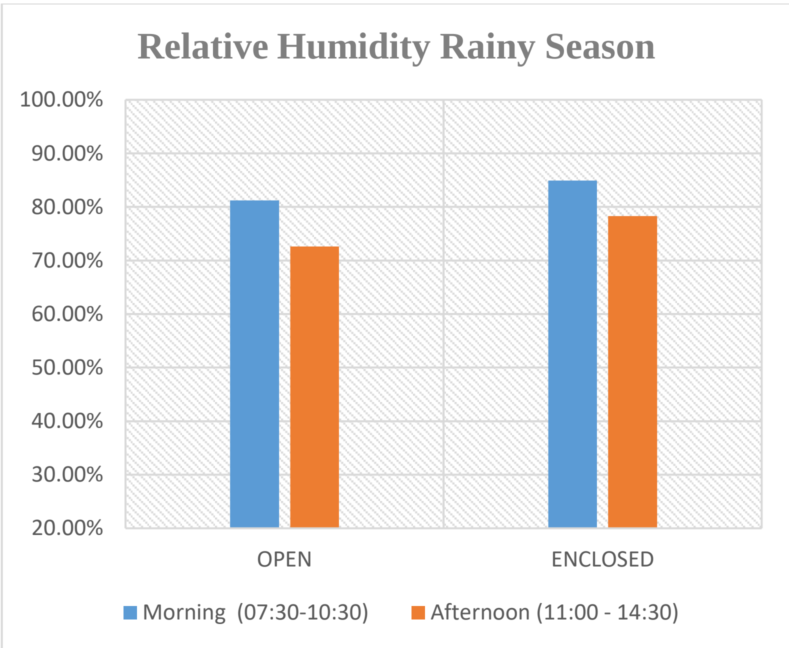

Figure 5.34: Results of the mean indoor relative humidity in rainy season

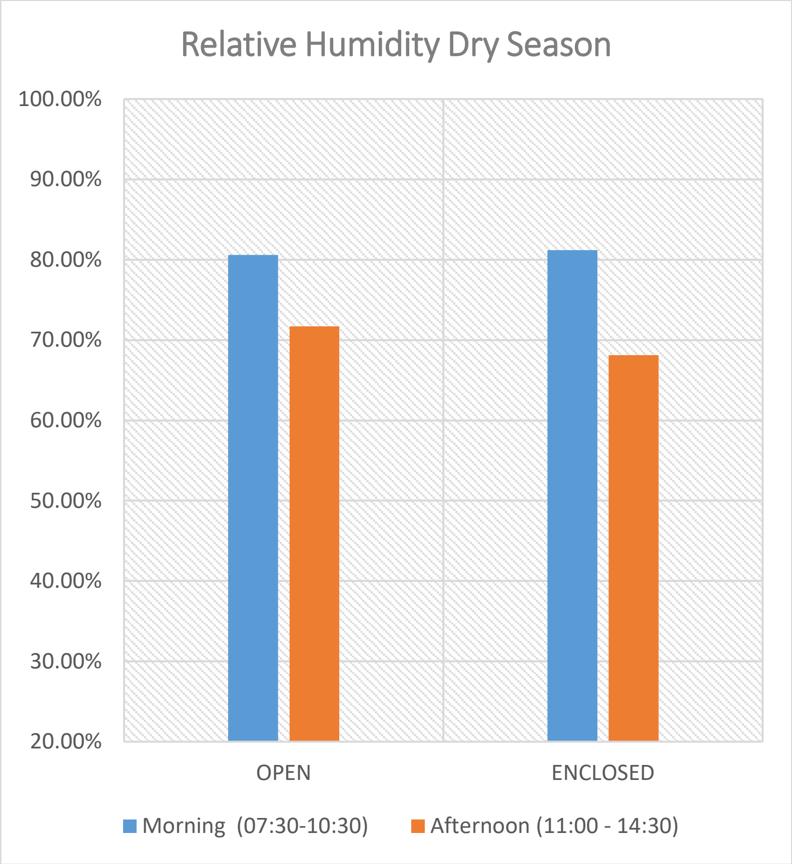

Figure 5.35: Results of the mean relative humidity in dry season

Classroom A$_{OP}$

Rainy Season: As earlier shown in Table 5.13, during the rainy season, the indoor operative temperature in this classroom ranged from 22.5°C to 34.7°C with an average temperature of 28.6°C. The outdoor temperature varied from 23.0 to 37.4°C with 29.0°C as the mean value, 1.7 and 0.058 as SD and CV, respectively (Table 5.14). The indoor RH varied between 56.7-90.6% with mean value of 76.2%, (SD=6.87) and CV of 0.090 (Table 5.15). Figure 5.32 presented further information about the relationship between the mean indoor operative temperature in this open classroom and the corresponding outdoor temperature according to the time of the day in the rainy season. According to the report obtained from the data loggers and represented in the histogram, the morning hours reported lower mean indoor operative temperature compared to the afternoon hours. The indoor temperature within which the children in this classroom operated during the survey period averaged 26.7°C in the morning hours and 29.5°C in the afternoon hours. However, the reverse was the case with the indoor

RH which reported higher values in the morning hours compared to the afternoon hours as shown in Figure 5.34.

Dry Season: As earlier shown in Tables 5.13-5.15, during the dry season, the indoor operative temperature ranged from 22.6 to 35.6^{o}C with an average temperature of 29.6^{o}C. The outdoor temperature ranged from 24.0 to 36.1^{o}C with 29.9^{o}C as the mean value and 1.5 and 0.050 as SD and CV, respectively. The indoor RH ranged from 29.3 to 73.7% with mean value of 70.5%, SD of 10.3 and CV of 0.146. Figure 5.33 provided further information on the relationship between the mean indoor operative temperature of this classroom and the corresponding outdoor temperature according to the time of the day. According to the report obtained from the data loggers, morning hours reported lower mean indoor operative temperature compared to the afternoon hours. Generally, the mean indoor temperature the children operated in the morning and afternoon periods were 28.6^{o}C and 30.1^{o}C, respectively. The outdoor temperature followed the same pattern, as the indoor temperature, by reporting cooler values in the morning hours compared to afternoon hours.

Classroom A$_{EN}$

Rainy season: As earlier shown in Table 5.13-5.15, during the rainy season, the indoor operative temperature ranged from 22.9^{o}C to 33.8^{o}C with an average temperature of 29.0^{o}C, SD was 1.4 and CV was 0.049. The outdoor temperature ranged from 23.0-37.4^{o}C with 29.0^{o}C as the mean value and 1.6 and 0.055 as SD and CV, respectively. Figure 5.33 showed further information about the relationship between the mean indoor operative temperature of the combined enclosed classrooms and the corresponding outdoor temperature according to the time of the day. According to the report obtained from the data loggers, morning hours reported lower mean indoor operative temperature compared to the afternoon hours. The indoor temperature within which the children in this classroom operated during the survey period averaged 28.9^{o}C in the morning hours and 29.1^{o}C in the afternoon hours showing a difference of 0.2^{o}C.

The indoor RH presented higher values in the morning hours compared to the afternoon hours. The indoor RH range from 60.8-93.5% with a mean value of 81.3%, SD of 5.25 and CV of 0.065. The frequency of relative humidity above 70% occurred in more than 90% in the recording retrieved from the data logger. RH averaged 84.9% in the morning hours and 78.3% in the afternoon hours.

Dry Season: In this classroom during the dry season, the indoor temperature ranged from 25.9 to 35.1°C with a mean value of 29.8°C, SD (1.8) and CV (0.060). The corresponding outdoor temperature ranged from 24.0 to 36.1°C with 29.9°C as the mean temperature, SD (1.5) and CV (0.050). The indoor RH ranged from 50.2% -81.8% with mean value of 67.8%, SD (6.37) and CV (0.094). Furthermore, the morning hours reported lower values in temperature compared to afternoon periods. As shown in Figure 5.33, the morning hours reported mean indoor temperature of 28.8°C, while the afternoon hours reported mean indoor temperature of 30.5°C, showing a difference of 1.7°C between these two periods. The outdoor temperature followed the same pattern with the indoor temperature by reporting a lower mean value (27.9°C) in the morning hours compared to afternoon hours (28.9°C). The RH also reported different values between these two periods. However, unlike the indoor temperature the RH reported higher values in the morning hours with lower values in the afternoon periods.

School B

According to season: Figure 5.36 shows the distribution of the indoor operative temperature (T_{op}) recorded during the survey in both seasons at occupied time for both the open and enclosed classrooms. Each bar represents the frequency of recorded temperature. It can be observed that temperature ranged from of 28 to 30°C was recorded highest in both seasons. The indoor operative temperatures in school B did not exceed 34°C, at occupied time, in both seasons. For recorded operative temperatures below 24°C, only 2% was observed in the school and that was during the dry season. The distribution frequency of the indoor operative temperature within the range 26-30°C was relatively high, and occurred in approximately 78% of the whole time the survey was conducted during the rainy season, and 81% of the time during the dry season

The indoor relative humidity followed the same trend with the relative humidity in school A, by reporting higher values in the morning hours than in the afternoon hours.

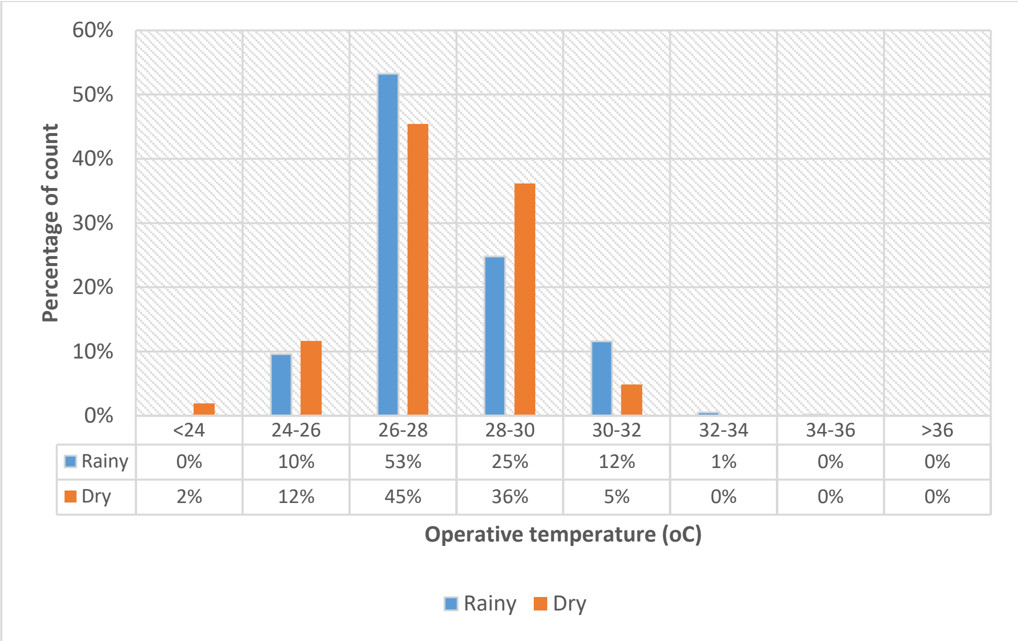

Figure 5.36: Histogram of T_{OP} in school B binned at 2ºC.

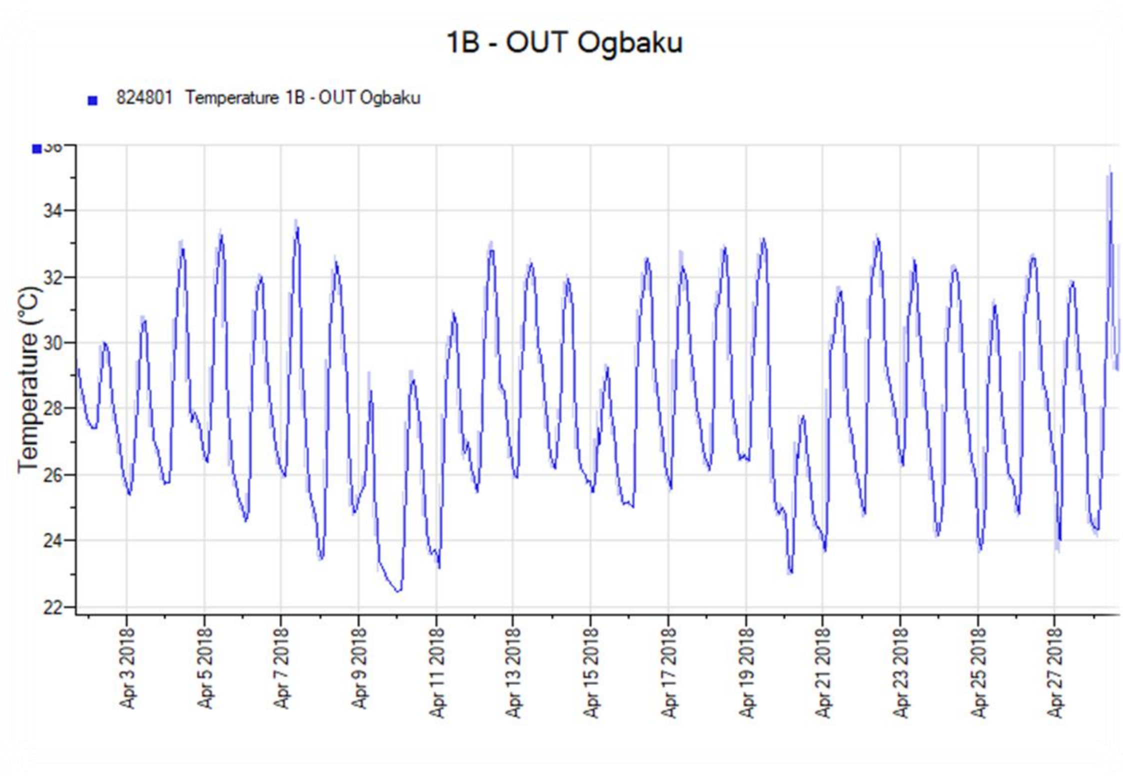

Figure 5.37: A sample graph

According to Time of Day: According to time of the day (as shown in Figures 5.38 and 5.39) the open classroom in school B recorded lower values in mean indoor operative temperatures in the morning hours during the rainy season and dry season (27.2°C rainy season and 27.8°C dry season) compared to the afternoon hours in both seasons (29.9°C rainy season and 27.9°C dry season). The enclosed classrooms followed the same trend with the open classroom by recording lower mean indoor operative temperature in the morning hours compared to afternoon hours in both seasons. Furthermore, the mean outdoor temperature in the morning hours was also lower compared to the afternoon hours during the rainy season. However, during the dry season the outdoor temperature was higher in the morning hours compared to afternoon hours. Higher mean values in the indoor relative humidity were recorded in the morning hours compared to the afternoon hour in both classrooms in the two seasons, unlike what was obtainable in the temperature readings. The RH was generally higher in the morning hours compared to afternoon hours through ought the survey period.

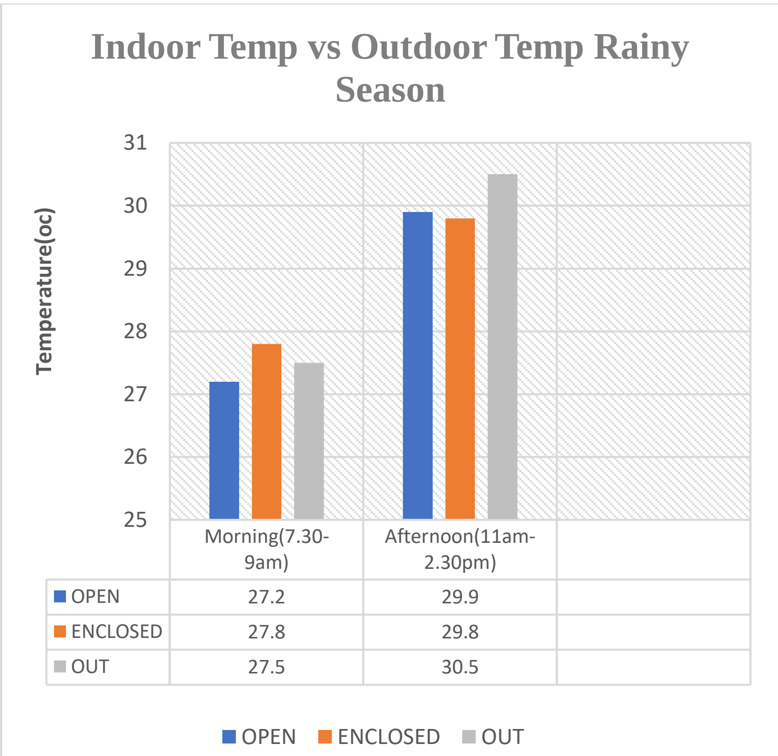

Figure 5.38: Results of the mean outdoor temperature and T_{OP} in rainy season

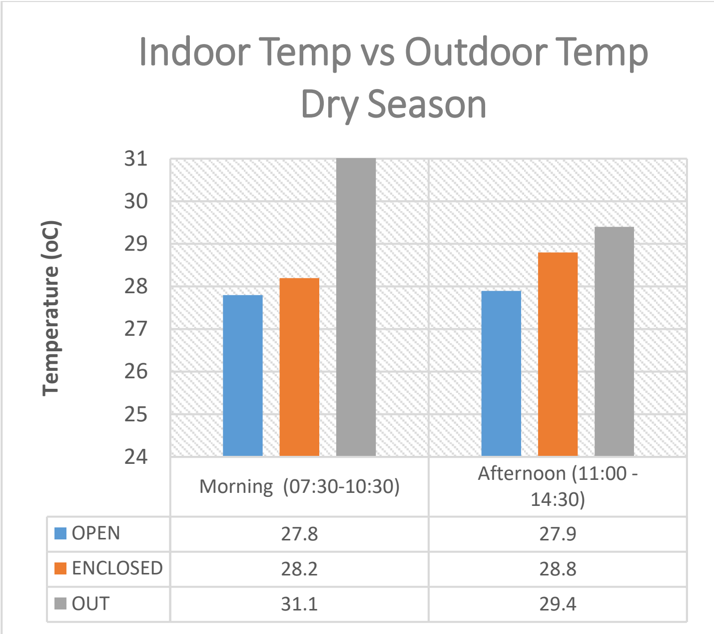

Figure 5.39: Results of the mean outdoor temperature and T_{OP} in dry season

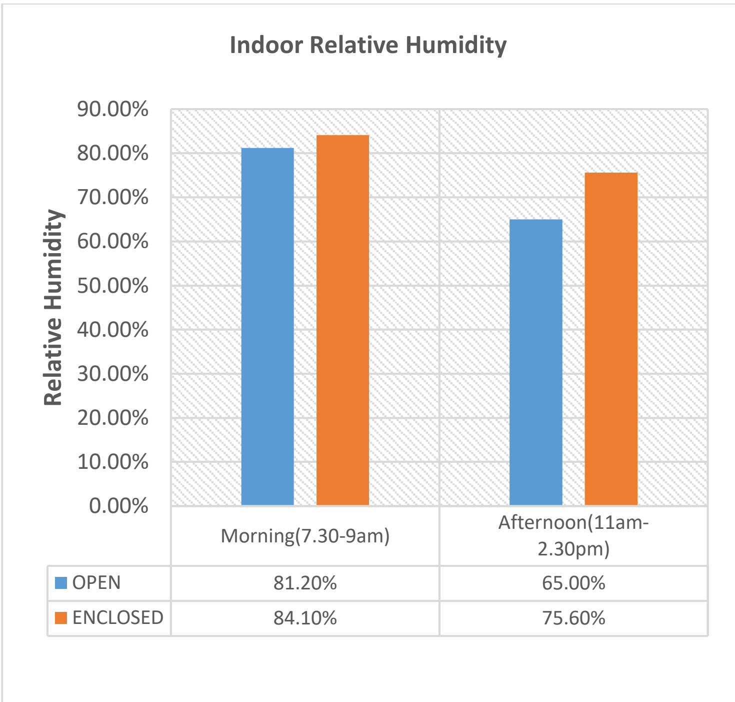

Figure 5.40: Results of the average relative humidity

Classroom B_{OP}

Rainy Season: As earlier shown in Table 5.13, the indoor operative temperature in this classroom ranged from 25.0 to 34.2°C, with mean value of 28.6°C (SD =1.4) and (CV =0.049). The outdoor temperature ranged from 25.4 to 36.5°C with 28.9°C as the mean value (SD =1.3) and (CV =0.045). The RH ranged from 24.0 to 87.5% with mean of 70.5% (SD =13.7) and (CV =0.194). According to Figure 5.36, the indoor temperatures retrieved from the data loggers show that the indoor temperatures varied from 26.0 to 30.0°C approximately 78% of the survey period. The daily indoor temperature averaged 27.2°C in the morning hours, and in the afternoon hours it averaged 29.9°C. The outdoor temperatures averaged 27.5°C and 30.5°C in the morning hours and afternoon hours, respectively.

Dry Season The indoor operative temperature in this classroom varied from 22.5 to 30.2°C, with mean value of 27.9°C (SD =1.4) and CV with value of 0.052 (Table 5.13). The outdoor temperature varied from 23.7 to 33.4°C with 28.8°C as the mean value (SD =1.1) and (CV =0.038). The RH ranged from 67.8% to 94.2% with mean of 80.6% (SD=5.6) and (CV=0.069). The indoor temperatures retrieved from the data loggers show that the indoor temperatures is within the ranged from 26.0 to 30.0°C approximately 81% of the survey period (Figure 5.36). The daily indoor temperature averaged 27.8°C in the morning hours, and in the afternoon it averaged 27.9°C. The mean outdoor temperatures averaged 31.1°C and 29.4°C in the morning hours and afternoon hours, respectively (Figure 5.39). *:*

Classroom B_{EN}

Rainy Season: The indoor operative temperature ranged from 25.0 to 30.6°C with an average temperature of 28.9°C, with a SD of 1.6 and CV of 0.055 (Table 5.13). The indoor operative temperatures were within the range from 26.0-30.0°C approximately 74% of the survey period (Figure 5.36). The daily temperature within which the occupants operated averaged 27.8°C in the morning and 29.8°C in the afternoon showing a difference of 2.0°C (Figure 5.38)

The outdoor temperature ranged from 25.4 to 36.5°C with 28.9°C as the mean value, with the value of 1.3 as the SD and 0.045 as the CV. In the morning hours, the outdoor temperature averaged 27.5°C, while it averaged 30.6°C in the afternoon hours. The RH ranged from 64.7% to 80.8% with an average of 73.4%. RH averaged 84.1% and 75.6% in the morning hours and afternoon hours, respectively.

Dry Season: In this classroom during the dry season, the indoor temperature ranged from 25.8 to 30.5°C with a mean value of 28.7°C, SD (1.1) and CV (0.038) (Table 5.13). The corresponding outdoor temperature ranged from 23.7 to 33.4°C with 28.8°C as the mean temperature, SD (1.1) and CV (0.038). The indoor RH varied from 27.4%-92.9% with mean value of 79.2%, SD (9.87) and CV (0.124). Furthermore, the morning hours reported lower values in temperature compared to afternoon hours. As shown in Figure 5.39, the morning hours reported a mean indoor temperature of 28.2°C, while the afternoon hours reported a mean indoor temperature of 28.8°C, showing a marginal difference of 0.6°C between these two periods.

School C

According to Season: Figure 5.41 shows the distribution of the indoor temperature recorded during the survey in both seasons in the open and enclosed classrooms. Each bar represents the frequency of recorded temperature. It can be observed that the indoor temperatures in the range from 28 to 30°C occurred more frequently in both seasons. The indoor temperatures in school C did not exceed 34°C. According to Figure 5.41, for operative temperatures below 24°C, the frequency of occurrence was 0%. Also, approximately 74% of the operative temperatures were within the range of 26-30°C during the rainy season, while during the dry season 93% of the temperatures were within the same range of 26-30°C. Furthermore, the indoor operative temperature within the range (26 to 28°C) prevailed more in the surveyed classrooms.

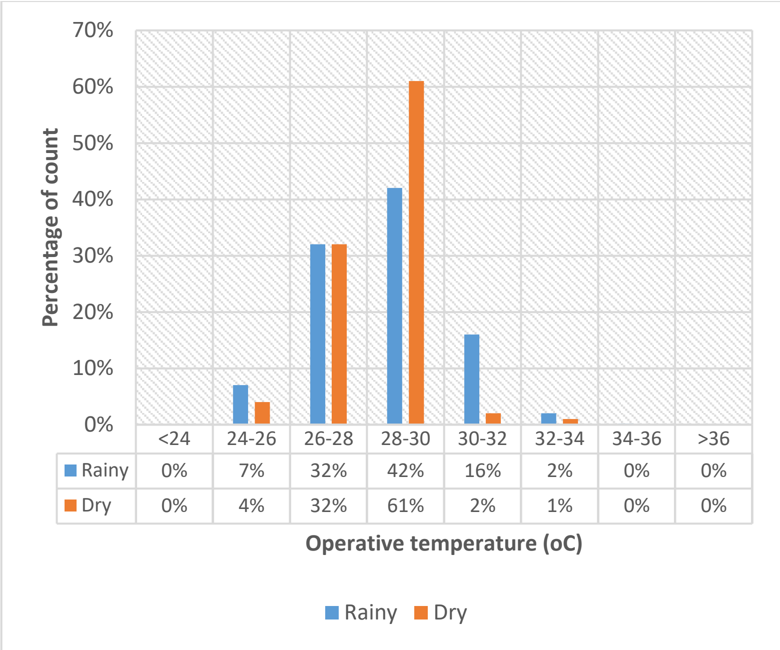

Figure 5.41: Histogram of indoor operative temperature in school C binned at 2ºC interval

According to Time of Day: According to time of day as shown in Figure 5.42, the open-space classroom in school C recorded lower values in mean indoor temperature in the morning hours during the rainy season and dry season (28.6ºC rainy season and 28.8ºC dry season) compared to the afternoon hours in both seasons (29.5ºC rainy season and 30.5ºC dry season). The enclosed classrooms followed the same trend with the open classroom by recording lower mean indoor temperature in the morning hours compared to afternoon hours in both seasons. Furthermore, the mean outdoor temperature in the morning hours was also lower compared to the afternoon hours in both season. The indoor relative humidity had a higher mean value in the morning hours compared to afternoon hour in both classrooms in the two seasons.

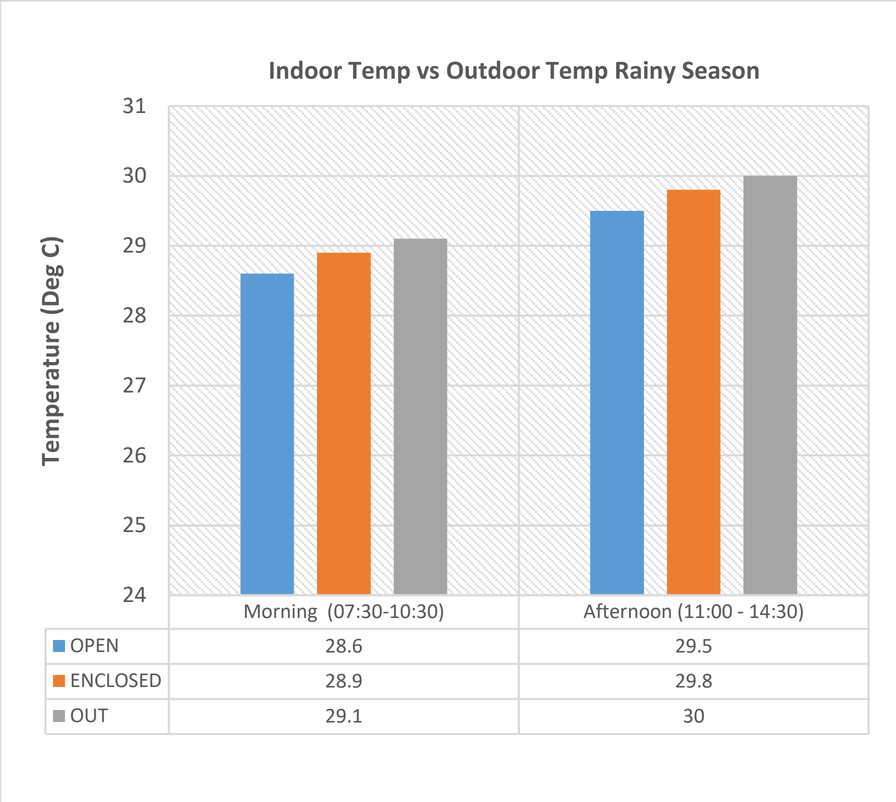

Figure 5.42: Results of the mean indoor operative temperature and Tout in rainy season

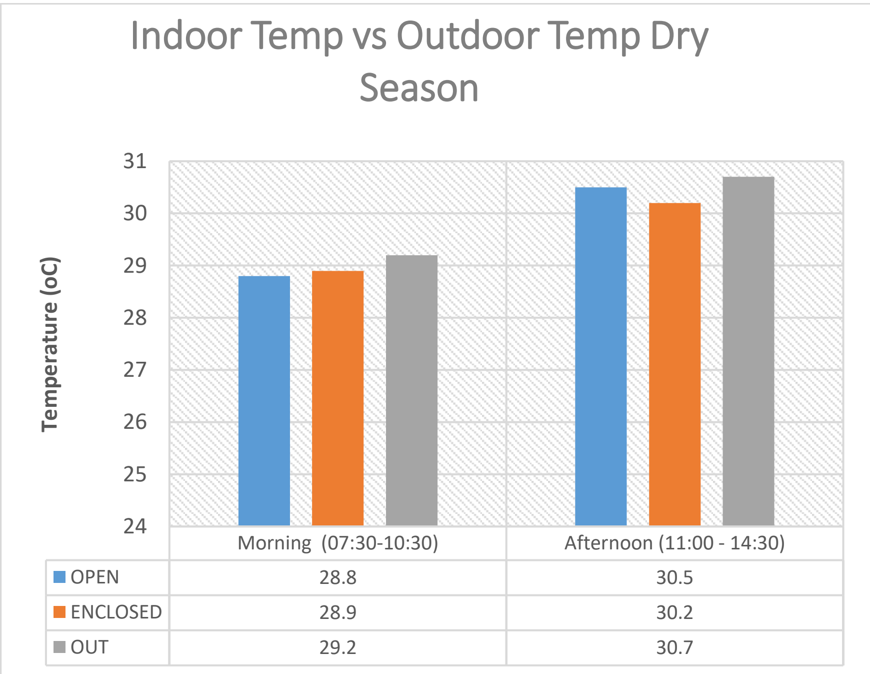

Figure 5.43: Results of the mean indoor operative temperature and Tout in dry season

Classroom C_{OP}

Rainy Season: As earlier shown in Table 5.13, the indoor operative temperature in this classroom ranged from 23.0 to 33.7°C, with mean value of 28.7 (SD =2.0) and (CV =0.070). The outdoor temperature ranged from 24.1 to 37.3°C with 29.1°C as the mean value (SD =1.8) and (CV=0.061). The indoor RH ranged from 48.4% to 93.6% with a mean of 78.1% (SD=7.3) and (CV=0.093). Removed. Furthermore, the indoor temperature remained within the range 27.0-30.0°C from 7.00 am to 1.00 pm for most of the time the surveys were carried out.

Dry Season: The indoor operative temperature in this classroom ranged from 26.5 to 33.8°C, with mean value of 28.8°C (SD=0.7) and (CV=0.025). The outdoor temperature ranged from 26.2 to 31.6°C with 29.2°C as the mean value (SD =1.9) and (CV=0.065). The indoor RH ranged from 39.7%-60.8% with mean of 52.2% (SD=6.4) and (CV=0.123). Furthermore, the indoor temperature remained within the range 27.0-30.0°C from 7.00 am to 1.00 pm for most of the time the survey was conducted.

Classroom C_{EN}

Rainy Season: As summarized in Table 5.13, the indoor operative temperature in this classroom ranged from 24.0 to 34.8°C, with mean value of 29.2°C (SD=1.8) and (CV=0.061). The outdoor temperature ranged from 24.1 to 37.3°C with 29.1°C as the mean value (SD=1.8) and (CV=0.061). The indoor RH ranged from 46.2% to 87.8% with a mean of 74.0% (SD=5.2) and (CV=0.070). Furthermore, the indoor temperature remained within the range 27.0-30.0°C for most of the period from 7.00am to 1.00pm.

Dry Season: As shown in Table 5.13, the indoor operative temperature in this classroom ranged from 25.8 to 35.1°C, with mean value of 29.1 (SD=0.7) and (CV=0.061). The outdoor temperature ranged from 26.2 to 31.6°C with 29.2°C as the mean value (SD=1.9) and (CV=0.066). The indoor RH ranged from 38.3% to 60.8% with mean of 51.1%, SD (6.9) and CV (0.135). Furthermore, the indoor temperature remained within the range 27.0-30.0°C for most of the period from 7.00 am to 1.00 pm.

5.3.3 Thermal sensation of the children

For the subjective thermal sensation of the participating children, the questionnaire adopted the ASHRAE 7- point thermal sensation scale (-3=colder, -2=cooler, -1= a bit cold, 0=okay, +1= a bit warm, +2=warmer, +3= hotter), to assess the occupant’s degree of satisfaction with their thermal environment. Following Fanger’s approach, the central three categories of the scale which represent the range of ‘a bit cold’ (-1) to ‘a bit warm’ (+1), are taken to indicate the sensations at which an occupant will be ‘satisfied’ with the thermal environment. This approach was adopted to determine the thermal sensation of the subjects. Voting outside these 3-central categories (-3, -2, +2, +3) are assumed to indicate ‘dissatisfaction’, with the most extreme ratings of ‘colder’ (-3) and ‘hotter’ (+3) suggesting highest level of dissatisfaction. Thermal sensation of a group of people assumes that the three central categories (-1, 0, 1) of ASHRAE 7-point scale represents acceptability and the voting outside these 3-central categories are unacceptable or an indication of discomfort.

The thermal preference uses the McIntyre binary scale to evaluate the thermal preference of people. This scale directly assesses the ideal conditions since the subjects are asked to indicate how they would ideally prefer to feel (warmer, okay or cooler) to their indoor temperature. Thus, the preferred temperature is the temperature that the subjects want to be feeling other than neutral temperature. Apart from using the preferred temperature to assess the optimum comfort conditions defined in terms of preferred temperature, it is used to compare simultaneous votes of thermal sensation and preference to determine whether ‘neutrality’ represents the optimal thermal responses of a group of subjects (Kwok et al., 1998). The comfort zone is defined in terms of thermal environments that are ‘acceptable’ to at least 80% of the occupants (ASHRAE, 2017).

Table 5.16 summarizes the thermal sensation votes of the children in the six surveyed classrooms. With the mean thermal sensation vote of +0.16 all season in combined classrooms, the mean sensation lay between ‘okay’ and ‘a bit warm’. However, it tended more towards ‘okay’ with sensation range from -2.0 to 1.8 (SD=0.66). The mean thermal sensation votes in the combined ‘open-space’ classrooms all season was +0.09 and ranged from -1.7 to 1.7, SD (0.60). At this mean thermal sensation, the subjects in the combined ‘open space’ classrooms found the indoor thermal condition of their classrooms ‘a bit warm’ and close to the neutral thermal sensation (0). The children in the combined ‘enclosed plan’ classrooms felt ‘warmer’ by expressing a mean thermal sensation vote of +0.29, with a range from -1.5 to +1.8, SD (0.706).

Table 5. 16: Children's mean, standard deviation, min and max values of the main environmental parameters and mean thermal sensation votes

Thermal sensation votes					
		Aver	**Min**	**Max**	**Std**
All Open	Rainy	-.09	-1.74	+0.9	.608
	Dry	+.27	-1.4	+1.7	.582
	All season	+.09	-1.7	+1.7	.60
All Enclosed	Rainy	+.11	-1.5	+1.8	.78
	Dry	+.45	-1.0	+1.8	.588
	All season	+.29	-1.5	+1.8	.706
All classrooms types	All Rainy	-0.01	-2	+1.8	.67
	All Dry	.31	-1.4	+1.8	.65
	All season	+.16	-2.0	+1.8	.660

The results of the thermal sensation votes in the classrooms are further presented in Table 5.17 and illustrated in relative frequency distribution shown in Figure 5.44. The percentage of children's votes that fell on neutrality (0) was 51% for the combined classrooms all season. The percentage of the children that voted on ASHRAE three central categories (-1, 0, 1) of the thermal sensation scale was 82%. The percentage of votes on the two extreme ends of the ASHRAE scale that indicates discomfort (-2, -3 and +2, +3) totalled 18%. However, the discomfort was more on the warmer side (15%) than on the colder side (3%). Results of the thermal sensation votes according to the season, time of day and according to classroom-type are presented in the next section.

Table 5.17: Detailed thermal sensation votes by season in the two types of classroom buildings

Classroom	Season	Votes								
		-3 Colder	-2 Cooler	-1 Bit cold	0 Okay	1 Bit warm	2 Warmer	3 Hotter	-1,0,1	Total
All Open	Rainy	2	76	203 (15%)	826(64%)	144 (11%)	36	8	90%	1295
	Dry	16	15	227 (11%)	1128(55%)	373 (18%)	158	121	85%	2038
All Enclosed	Rainy	15	44	272 (18%)	540 (35%)	418 (27%)	179	63	80%	1531
	Dry	13	20	103 (5%)	1094 (50%)	509 (23%)	297	150	78%	2186
All Open	Both	18 (1%)	91 (3%)	430 (13%)	1954(59%)	517 (16%)	194 (6%)	129 (4%)	88%	3333
All Enclosed	Both	28 (1%)	64 (2%)	375 (10%)	1634(44%)	927 (25%)	476 (13%)	213 (6%)	79%	3717
All building	Both	46 (1%)	155 (2%)	805 (11%)	3588(51%)	1444 (20%)	670 (10%)	342 (5%)	83%	7050

Op= Open classroom; En=Enclosed classroom; (-1 0 1) = votes around the three central points on ASHRAE scale

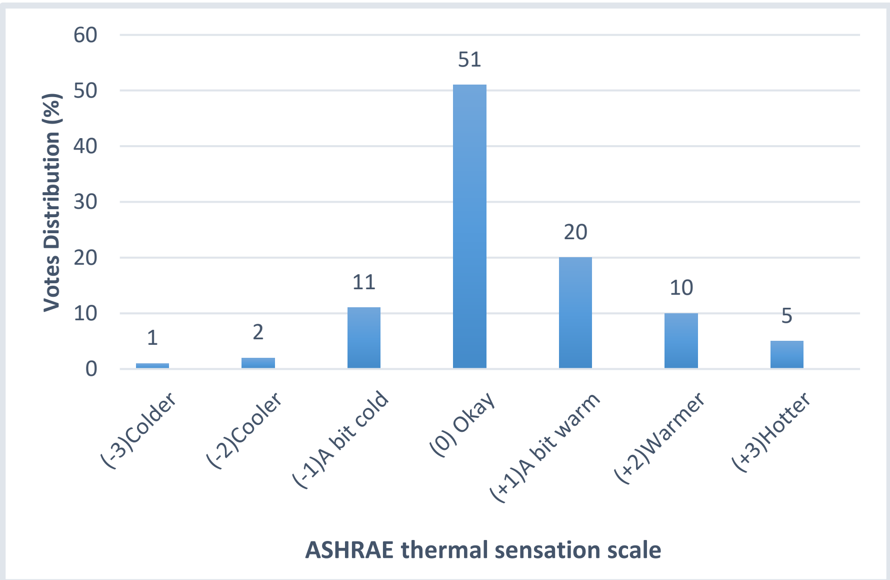

Figure 5.44: Distribution of the children's votes on ASHRAE scale in combined classrooms

*According to Season***:** A further breakdown of the thermal sensation votes according to season indicates that the subjects felt cold in rainy season at the mean thermal sensation with the value of -0.01. As shown in Table 5.16, the range was from -2 to 1.8, SD (.67). The vote was slightly above neutral (0), an indication that the subjects found the indoor thermal conditions comfortable in rainy season. During the dry season, the thermal sensation votes was between 'okay' and 'a bit warm', with a mean value of +0.31, and ranged is from -1.4 to 1.8, SD (.56). This suggests that the subjects felt warmer in dry season compared to the rainy season. However, the mean value of the vote suggested that they were comfortable with the indoor thermal conditions. Furthermore, the lowest (min) thermal sensation vote in rainy season was -1.7, while in dry season the lowest was -1.4. Irrespective of the classroom type, the highest in the rainy season was +1.8 while the highest in the dry season was equally +1.8. These findings are further discussed in Chapter 6.

According to Time of Day: Table 5.18 shows the distribution of the mean thermal sensation votes of the school children in combined classrooms categorized according to morning and afternoon periods of the survey. Results indicated that the studied children during the morning hours of the survey in both seasons (irrespective of the type of classroom) expressed their indoor temperature to be 'slightly cold' with a mean thermal sensation vote of -0.18 on the ASHRAE 7-point thermal sensation scale. The range of thermal sensation in the morning hours was from -2 to 1.48, SD (0.55). In the afternoon period in combined classrooms (irrespective of the classroom type) the mean thermal sensation of the same school children was +0.49 with thermal sensation range from -1 to 1.8, SD (.57). The table further revealed that the studied children felt colder in the morning hours of the rainy season than in the morning hours of the dry season. The morning hours reported a thermal sensation with a value of -0.38 during the rainy season, while at the same period during the dry season it reported a mean thermal sensation with value of -0.01. Further insight is given on how the children felt in the morning hours of the rainy season and the morning period of the dry season. It can be observed that in the morning hours in rainy season, some of the children voted towards the extreme point of ASHRAE thermal sensation vote (-2.0) which indicated cold discomfort. However, in the morning hours of the dry season, the minimum thermal sensation vote was -1.0. These are further discussed in Chapter 6.

Table 5. 18: Thermal sensation according to time of day

Season	Time of day	Mean thermal sensation votes			
		Average	Min	Max	Stdev
Rainy season	All Morning	-.38	-2.0	1.09	.55
	All Afternoon	.36	-1	1.8	.57
Dry season	All Morning	-.01	-1.4	1.48	.49
	All Afternoon	.51	-1.0	1.8	.54
All season	All Morning	-.18	-2	1.48	.55
	All Afternoon	.49	-1	1.8	.57

According to Building Type: A flashback on Table 5.16 shows that the children in the combined enclosed classrooms by expressing +0.29 as their mean thermal sensation votes all season was an indication that they felt warmer in their classrooms compared to those in the combined open classrooms. The children in the combined open classrooms expressed their thermal sensation with value +0.09. The range of thermal sensation in the enclosed classroom all season was from -1.5 to 1.8, SD (.706) while in the open classroom the same season the range was from -1.7 to 1.7 SD (.60). A further breakdown shows that in the rainy season, the mean thermal sensation in the open classroom vote was -0.09, with a range from -1.7 to 0.9, SD (.60), while the thermal sensation votes in the corresponding enclosed classrooms in the same season was higher (+.11), with a range from -1.5 to 1.8, SD (.78). In the dry season, the expression of the thermal sensation followed the same trend as that expressed during the rainy season. The subjects in the combined enclosed classrooms expressed their thermal condition warmer (+.45) compared to the occupants in the combined open classrooms (+.27). The mean thermal sensation vote in the combined open classrooms the same dry season was +0.27.

Furthermore, referring back to Table 5.17, the percentage of votes on the central categories of the ASHRAE thermal sensation scale (-1, 0, +1) was 88% for the combined open-space classrooms all season. According to the season, during the rainy season in the open-space classroom the voting within the three central categories was 90%. However, during the dry season, the voting was down by 6% (84%). In the enclosed-plan classroom the voting during the rainy season was 80%, while in dry the season it was 78%. Table 5.17 showed that the percentage of subjects who voted on thermal sensation in the combined open-space classrooms was cantered on neutral (okay) with 59% of the children's votes. For the combined enclosed-plan classrooms, it was cantered on neutral by 44%. Considering the percentage of subjects votes on the three-central categories (-1,0,+1), 88% voted in the combined open classrooms, while 79% voted in the combined enclosed classrooms. Furthermore, the votes of the occupants of both classrooms tended towards the warmer-than the-neutral side of the scale, where a total vote on that section (+1, +2, +3) was 22% and 44% for the combined open-space classrooms and the combined enclosed classrooms, respectively. Lower values of 18% and 14% for the open-space classroom type and the enclosed-plan classroom type, respectively were observed in the voting on the neutral-than-cooler side of the ASHRAE 7-point thermal sensation scale. Generally, the occupants of the enclosed-plan classrooms evaluated their classrooms warmer than those who occupied the open-space classrooms.

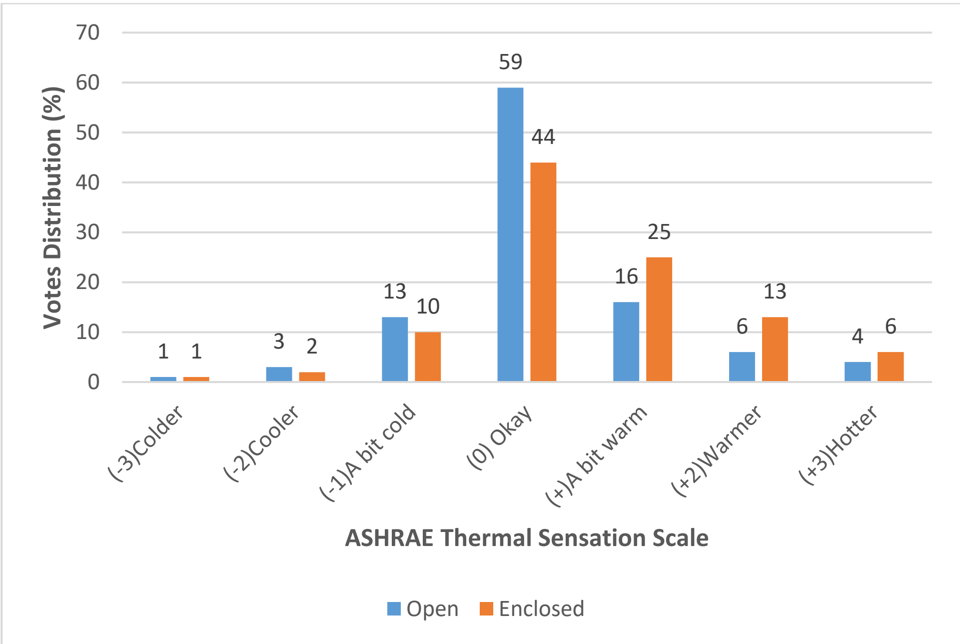

Figure 5.45: Distribution of the children's votes on ASHRAE scale according to classroom type

Relating Thermal Sensation to Indoor Operative Temperature

According to Season: Figure 5.46 shows the regression analysis of the mean thermal sensation votes upon the mean indoor operative temperatures according to season. The analysis shows that the studied children expressed colder thermal sensation in the rainy season compared to the dry season, when matched at the same indoor operative temperature.

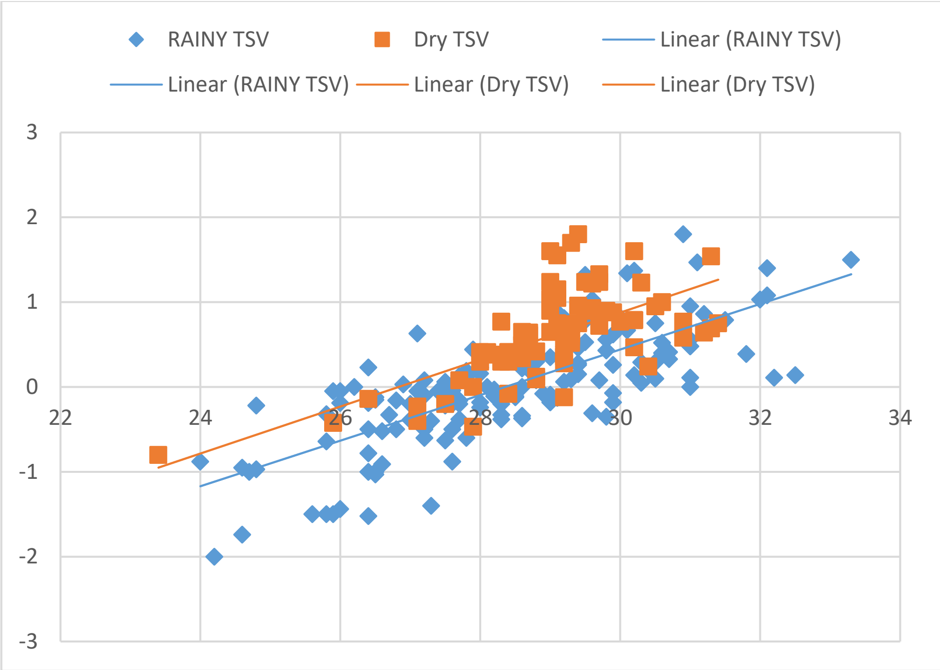

Figure 5.46: Regression analysis of thermal sensation upon Top according to season

According to Time of Day: The mean thermal sensations according to time of the day (Table 5.18) were matched with the mean indoor operative temperatures according to the time of the day (Figures 5.33, 5.38, 5.39. 5.42). The overall subjects mean vote in the morning hours, irrespective of the classroom type, was -.18 at the average temperature of around 27°C in the morning hours. In the combined afternoon hours, the mean vote was +.51, at the average temperature of around 30°C in the same period. Further breakdown according to time of day showed that in the morning hours of the rainy season, the mean votes was -.38 at the temperature of approximately 27°C. In the afternoon hours of the same season, the mean votes was +.36 at the indoor temperature of approximately 30°C. Furthermore, in the morning hours of the dry season, the mean vote was -.01, while in the afternoon hours of dry season, the mean vote was +.63. Generally, from the result of the voting, the studied young children expressed warmer thermal sensations in the afternoon hours compared to the morning hours. This is further presented graphically in the regression analysis in Figure 5.47. The reason can be linked to the higher mean indoor temperatures recorded in the afternoon hours compared to the morning hours survey (as earlier explained). This is further discussed in Chapter 6.

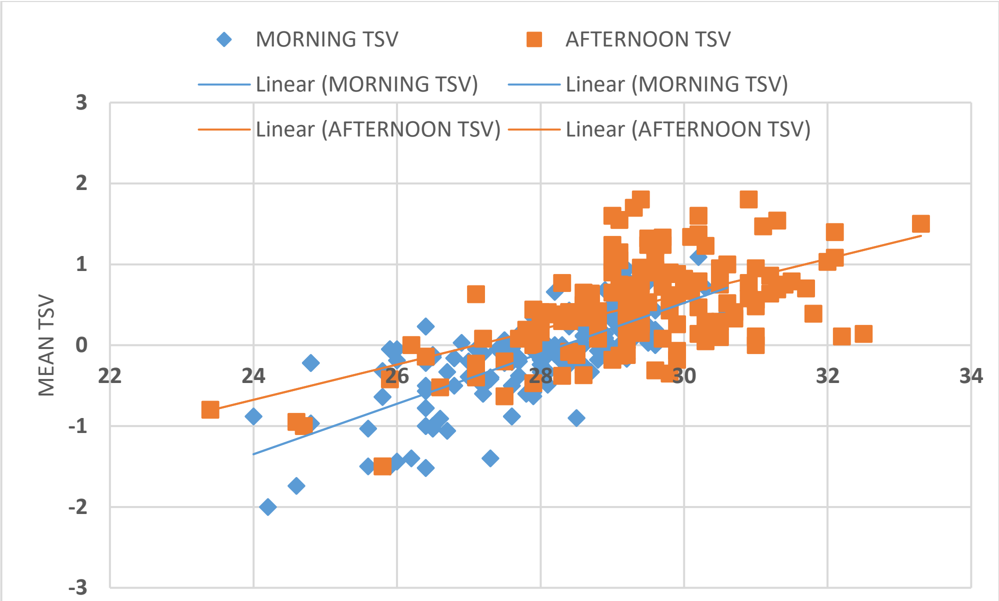

Figure 5.47: Regression analysis of thermal sensation upon Top according to time of day

According to Building Type: The subjects mean thermal sensation votes in the combined enclosed classrooms was +0.29, in both seasons, with 79% of the subjects voting at the mean indoor operative temperature of 29.3^{o}C. In the combined open classrooms, the vote on the three central categories of ASHRAE scale equalled +0.09, all season with 88% of the subject's votes on the three central points at the mean indoor temperature of 28.9^{o}C.

5.3.4 **Thermal Preference of Children**

The McIntyre scale was adopted to evaluate the thermal preference of the children in the classrooms they use for class lessons. Preferred temperature is the temperature that the subjects want to be feeling other than neutral temperature. The subjects were asked whether they would prefer 'warmer, 'cooler; or 'okay' (no change) to their indoor thermal conditions. Apart from using the preferred temperature to assess the optimum comfort conditions defined in terms of preferred temperature, it is also used to compare simultaneous votes of thermal sensation and preference to determine whether 'neutrality' represents the optimal thermal responses of a group of subjects (Kwok et al., 1998)

The thermal preference of the studied children illustrated in the histogram in Figure 5.48 shows that in the combined classrooms all seasons, 50% (half of the entire children) preferred to be cooler than what the existing indoor thermal condition presented. 37% of the entire class preferred the thermal condition to remain in the condition they found it, while 13% preferred a a warmer condition. 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. This is fully discussed in Chapter 6.

However, a closer look at Table 5.19, on a micro-level of each classroom, reveals that the high preference for a cooler environment was not the case in all the classrooms. The preference for a warmer indoor thermal condition depended on the time of the day the survey was conducted. For instance, the preference for warmer conditions, rather than cooler conditions, was a more popular choice of the children in some of the classrooms and that was in the morning hours. Preference according to the season and time of the day is further discussed.

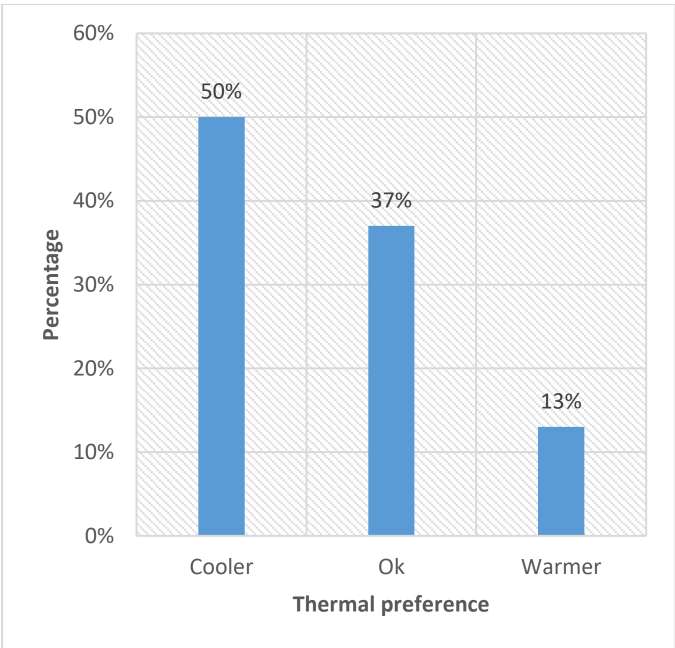

Figure 5.48: Distribution of subjects’ thermal preference votes

According to Season: The preference for a cooler indoor thermal condition was higher in the dry season compared to the rainy season survey (Table 5.19) with almost double the percentage of the children who preferred a cooler environment in the rainy season (36%), preferring warmer conditions in the dry season (60%). This showed that 24% more of the subjects in rainy season preferred a warmer indoor thermal conditions in the dry season. Furthermore, near half the entire class (45%) were satisfied with their thermal conditions in the rainy season and would rather prefer the thermal state to remain as they found it. A significant percentage (69%) were not satisfied with the thermal state during the dry season and would prefer the thermal condition to be either warmer or cooler. The preference for a cooler indoor thermal condition was higher during the dry season compared to the rainy season. For instance, during the dry season, 63% of the children in the combined enclosed classrooms preferred cooler thermal conditions, while the preference for the cooler environment during the rainy season, for the same subjects, was 36%. The trend was the same in the combined open classrooms where 56% of the children preferred a cooler environment in the dry season, compared to the 27% vote in the rainy season.

A higher percentage of the subjects votes were on ‘okay’ during the rainy season, while lower percentage of the subjects votes on ‘okay’ were lower during the dry season, irrespective of the classroom type. The highest percentage of subjects on ‘okay’ was found in the open classrooms in rainy season with more than half of the entire class (55%) preferring the indoor thermal conditions to remain the way they met it. The lowest percentage of subjects who voted ‘okay’ was in the enclosed classrooms, during the dry season, with only 26% of the subjects preferring the indoor thermal conditions to remain the way they met it. Of the 19% of the children who preferred warmer condition during the rainy season, only 8% of them preferred that during the dry season. Also, of the 20% of the children in the combined enclosed classrooms who preferred to be warmer during the rainy season, only 11% of them preferred that thermal state in the dry season survey. Generally, Table 5.19 shows that a greater majority of the surveyed children preferred to be ‘cooler’ rather than ‘warmer’ irrespective of the type of classroom and the season the survey was conducted. However, a further check on the table reveals that a greater majority of the children would prefer to be cooler rather than warmer in dry season survey compared to rainy season survey. The likely reasons for the swings in the thermal preference are further explained in Chapter six.

Table 5. 19: Thermal Preference votes according to season

Season	Classroom Type	Cooler	Okay	Warmer
All Rainy	Open	356(27%)	706(55%)	234(18%)
	Enclosed	667 (44%)	571 (37%)	293(19%)
All Dry	Open	1147(56%)	732(36%)	160 (8%)
	Enclosed	1376(63%)	566(26%)	246(11%)
All Rainy	All	1022 (36%)	1277(45%)	527(19%)
All Dry	All	2522(60%)	1297(31%)	406(9%)
Both Rainy and Dry	All	3544 (50%)	2574 (37%)	932 (13%)

According to Time of Day: Table 5.20 and the histogram in Figure 5.49 present the thermal preference of the children according to time of the day. The Table and the histogram show that in the afternoon period, more than half (59%) of the entire class in all classrooms preferred the indoor thermal condition to be cooler than they found it, while 32% preferred the thermal state to remain the way it was. This suggests that at that period of the day, the children found the indoor thermal environment uncomfortable and would prefer a cooler environment that would make them comfortable. The percentage of the school class who preferred a warmer indoor thermal condition in the morning hours was 42%, while 41% preferred the indoor thermal conditions to remain the way they met it. The preference between these two periods of the day show that more children preferred a cooler indoor thermal condition in the afternoon hours compared to the morning hours.

In the afternoon hours of the dry season a higher percentage of the children preferred a cooler thermal condition. Less than one quarter (21%) would rather prefer the indoor thermal condition to remain in the state they met it. Also, in the morning hours of the dry season, in the same enclosed classrooms, more than half of the class (56%) would preferred a cooler environment.

Table 5. 20: Thermal preference responses according to season, time of the day and classroom type.

Classrooms		Morning			Afternoon		
		Cooler	**Okay**	**Warmer**	**Cooler**	**Okay**	**Warmer**
A_{OP}	Rainy	35	110	41	14	158	14
	Dry	155	166	36	258	90	9
A_{EN}	Rainy	28	140	38	50	106	50
	Dry	221	89	45	297	56	2
B_{OP}	Rainy	50	54	62	104	50	12
	Dry	208	133	68	266	123	21
B_{EN}	Rainy	98	75	40	114	61	27
	Dry	195	145	101	220	141	80
C_{OP}	Rainy	47	182	69	107	153	38
	Dry	115	120	19	145	101	8
C_{EN}	Rainy	133	132	94	245	68	46
	Dry	194	96	15	250	40	9
A_{OP}+B_{OP}+C_{Op}	Rainy	66 (20.2%)	173 (53.4%)	86 (26.4%)	123 (34.7%)	181 (55.7%)	32 (9.6%)
	Dry	478 (46.9%)	419 (41.1%)	123 (12.0%)	669 (65.6%)	313 (30.7%)	38 (3.7%)
A_{EN}+B_{EN}+C_{EN}	Rainy	258 (33.7%)	337 (44.0%)	171 (22.3%)	409 (53.4%)	235 (30.6%)	123 (16.0%)
	Dry	1219 (55.8%)	330 (30.1%)	155 (14.1%)	1532 (70.1%)	236 (21.6%)	91 (8.3%)
A_{OP}+B_{OP}+C_{OP}	All season	609 (36%)	764 (46%)	294 (18%)	893 (54%)	674 (40%)	100 (6.0%)
A_{EN}+B_{EN}+C_{EN}	All season	868 (47%)	666 (36%)	325 (17%)	1175 (63%)	471 (25%)	214 (12%)
All Classrooms	All season	1477 (42%)	1430 (41%)	619 (17%)	2068 (59%)	1145 (32%)	314 (9%)

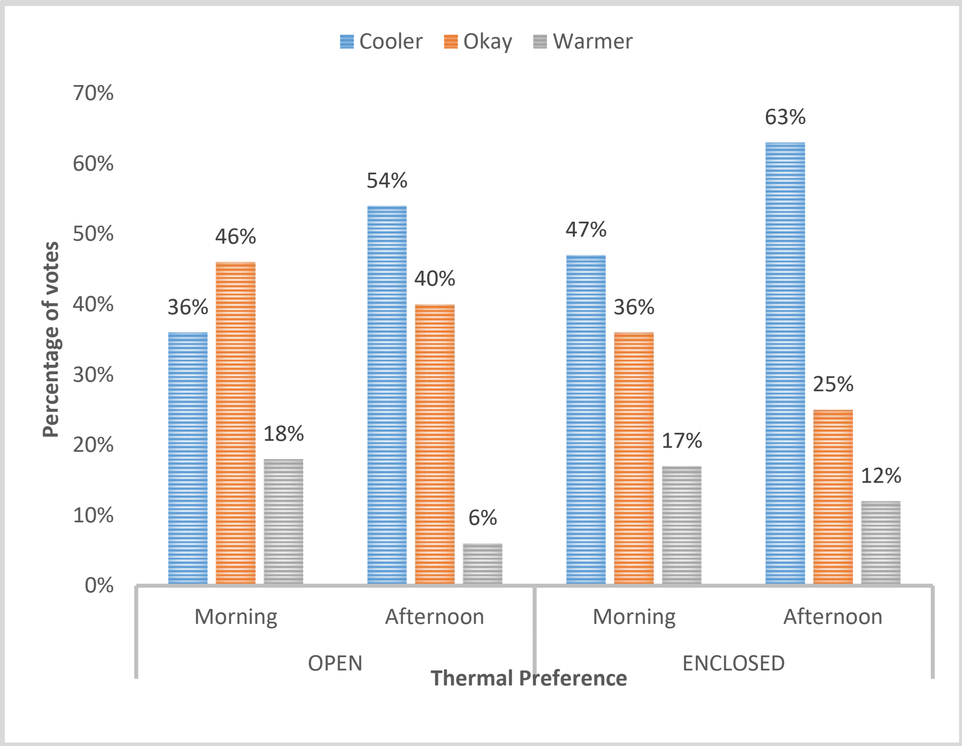

Figure 5.49: Distribution of subjects' thermal preference votes according to time of day

According to Building Type: A flashback to Table 5.19 shows that the preference for a cooler indoor thermal condition was higher in the enclosed classrooms compared to the open classrooms. While 63% of the entire class preferred a cooler environment, in the enclosed classrooms in dry season, 56% of the entire class in the open classrooms in the same season preferred a cooler indoor environment. This showed that the subjects in the enclosed classrooms felt warmer than those in the open classroom, resulting to a higher percentage of the subjects in the enclosed classrooms preferring a cooler environment. In the rainy season survey, the trend in the preference was the same with that found during the dry season, with 44% of the subjects preferring a cooler condition while only 27% of the subjects in the open classrooms preferred a cooler condition.

Furthermore, more than half (55%) of the subjects in the open classroom preferred the thermal state to remain the way they met it, and that was during the rainy season. In the enclosed classrooms, in the same season, only 37% of the occupants preferred the thermal condition the way they found it.

Preferred Temperature (T_n) of Children

Based on children's thermal preferences on the McIntyre thermal preference scale, preferred temperature of the students' 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 1ºC interval (with the range from 24.5ºC to 32.5ºC). The result of the regression produced a preferred temperature. This temperature is where the intersection of the percentage of children who wanted to be warmer and those who wanted to be cooler meets. As was done in several studies in classrooms such as the works of Shamila Haddad (2016); R. de Dear et al., (2015); Hwang, Lin, & Kuo (2006) and Wong & Khoo (2003), 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 5.50, the two fitted lines intersected at a preferred operative temperature of 27.4ºC. Also, the result indicated that near to half of the children in both types of classrooms, precisely 40%, preferred to be cooler than the existing thermal condition. There were fewer votes on the warmer side preference than on the neutral and cooler side in both types of classrooms.

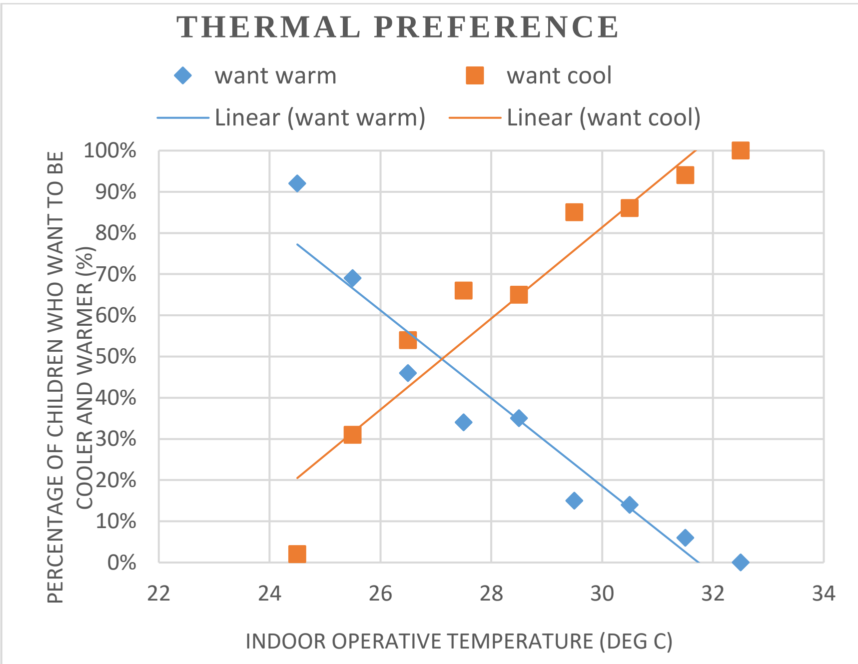

Figure 5.50: Linear regression models for preferred temperature

Comparing Thermal Sensation votes with Preferred Temperature

Figure 5.51 shows the comparison of the statistical distribution of the surveyed participants' thermal sensation votes with the distribution of the thermal preference votes. The comparison shows that while 82% of the entire subjects voted within the three central categories of the

ASHRAE thermal sensation scale, indicating satisfaction with the indoor thermal condition, 37% of this entire class preferred the thermal state to remain the way they met it. Further comparison shows that while a majority in the class voted within the three central categories of the ASHRAE scale, half of the entire class (50%) preferred a cooler environment while 13% of the class preferred a warmer indoor thermal condition. This suggests that 63% of the subjects preferred a different thermal state from what they met.

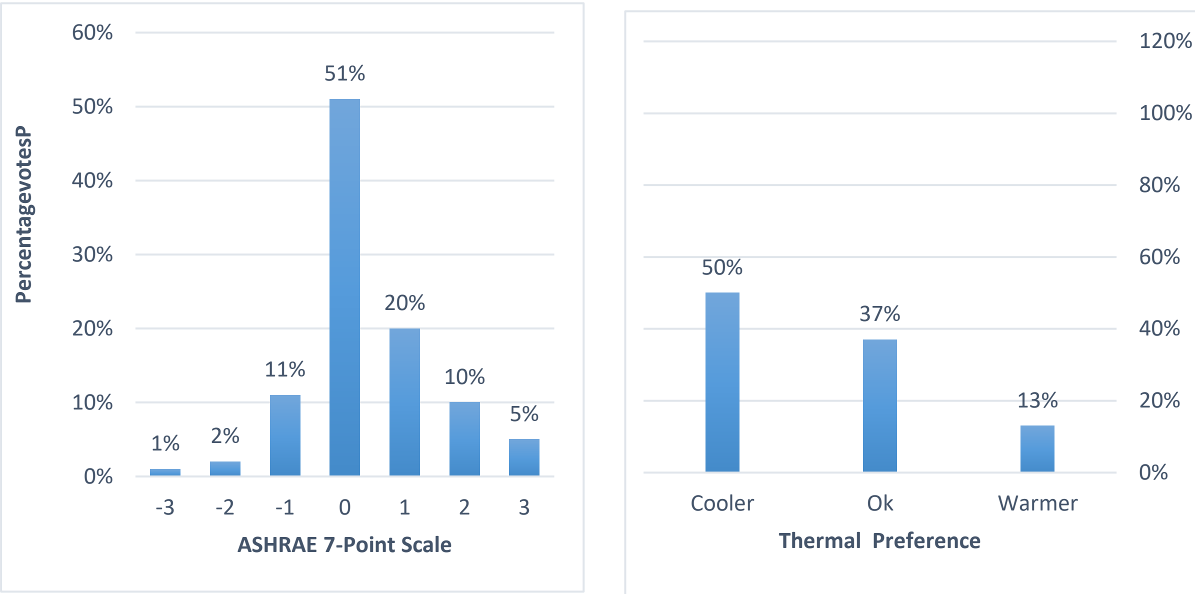

Figure 5.51: Thermal sensation (left) and thermal preference (right) votes in combined classrooms

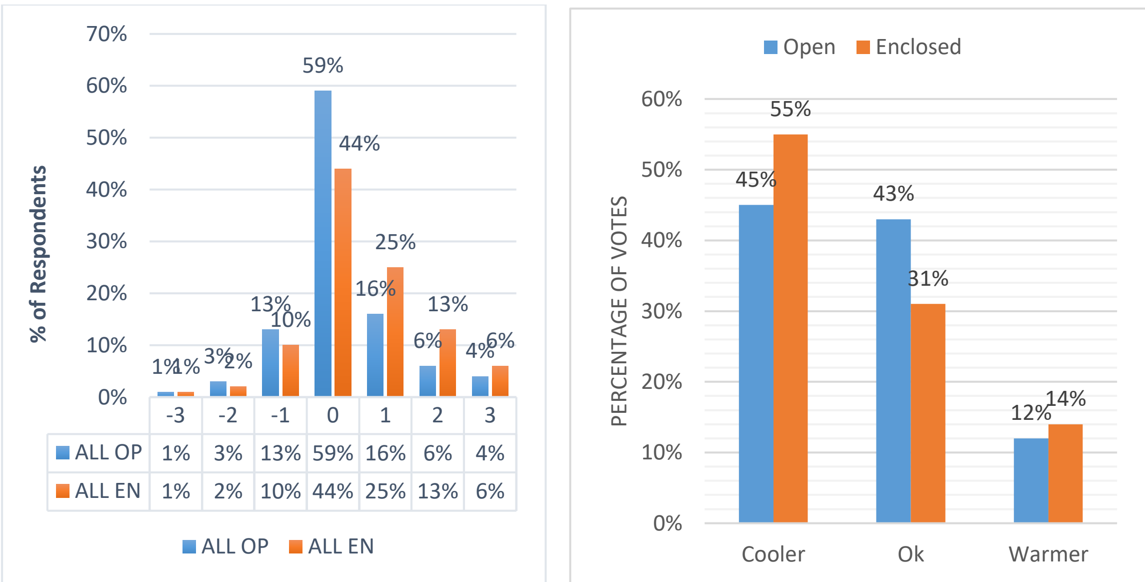

Figure 5.52: Thermal sensation (left) and thermal preference (right) votes according to building type.

5.3.5 Neutral Temperature of Children

Neutral temperature, a product of the relationship between thermal sensation votes and the indoor operative temperatures can be determined through linear regression analysis. Linear regression is popularly used to determine the trend of the mean response of a group of people over the range of temperatures they encounter (Nicol et al., 2012). This is on the assumption that the comfort votes and the temperatures are dependent and independent variables, respectively (Shamila Haddad, 2016). The relationship between the young children's thermal sensation and the indoor operative temperatures of the classrooms were examined through a linear regression analysis. This revealed the children's thermal behaviour in the classrooms, and how they respond to the variabilities in the classrooms.

To determine the neutral temperature (T_n) of the studied children, the classroom's mean indoor temperature together with the mean thermal sensation of the subjects, for each visit made to the classrooms, was calculated. The calculation of the neutral temperature was obtained from the regression equation derived by using Microsoft Office Excel version 16. The statistical test was analysed using SPSS version 17. Thereafter, linear regression analysis between the calculated mean thermal sensation vote (TSV_{mean}), as a dependent variable in the Y-axis, and T_{op} as an independent variable on the X-axis was applied to obtain a neutral temperature. Thus, the model assumed that the comfort vote was being predicted from the operative temperature. In this study, the neutral temperatures of the children characterized according to building time, season and time of the day are shown in Figures 5.53-5.59.

The approach employed in ASHRAE adaptive comfort standard was used to define the indoor operative comfort range, which defines the 80% operative comfort range as $-0.85 \leq TSV \leq +0.85$ (R. De Dear & Brager, 1998). This corresponds to approximately 80% thermal satisfaction, where the Predicted Percentage of Dissatisfied (PPD) is less than 20%. The neutral temperature corresponding to TSV (AMV) value equalling '0' was also calculated.

The 80% comfort zone is the primary consideration in this work. 90% comfort zone was used for comparison. The results of the findings, represented as in Equation 5.1, were summarized in Table 5.21 and presented according to season, time of the day, and according to classroom type in the subsequent sections.

$$TSV = aT_{op} + b \qquad (5.1)$$

Where

TSV *= is the mean thermal sensation*

a *=represents the gradient or coefficient*

$\boldsymbol{T_{op}}$*= represents the operative temperature*

b *=represents the value at the intersection*

Table 5. 21: Summary results from regression equations

	Regression equation	R-square	Tn (°C 80%)	Significance
All classrooms	TSV=0.29T_{OP} -8.33	0.51	28.8	$P < 0.01$
Open classroom	TSV=0.24T_{OP} -6.90	0.46	28.8	$P < 0.01$
Enclosed classroom	TSV=0.36T_{OP} -10.14	0.51	28.1	$P < 0.01$
Rainy season	TSV=0.27T_{OP} -7.62	0.56	28.2	$P < 0.01$
Dry season	TSV=0.35T_{OP} -9.75	0.46	27.8	$P < 0.01$
Morning hours	TSV=0.31T_{OP} -8.83	0.51	28.5	$P < 0.01$
Afternoon hours	TSV=0.21T_{OP} -5.91	0.32	28.1	$P < 0.01$

Furthermore, 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 (Shamila 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 for the combined classrooms all season. The percentage of the explanation of the relationship is not very high, however, with $p < 0.01$ obtained from the correlation analysis, the relationship is statistically significant. The neutral temperature, or optimum temperature, corresponds to thermal sensation votes (TSV) with value equal 0 on the seven-point ASHRAE scale when applied to analysis of TSV=0.29x-8.33 (Equation 5.2) for the combined classrooms all seasons, produces a neutral temperature of 28.8^{o}C. This temperature is the ideal comfort temperature of the studied children in the combined classrooms all seasons. The neutral temperature can also be obtained from the graph in Figure 5.53 where the intersection of regression line with neutral (okay or ‘0’) thermal sensation gives neutral temperature of the studied population.

$$TSV = 0.29T_{OP}\ 8.33 \qquad \textbf{(5.2)}$$

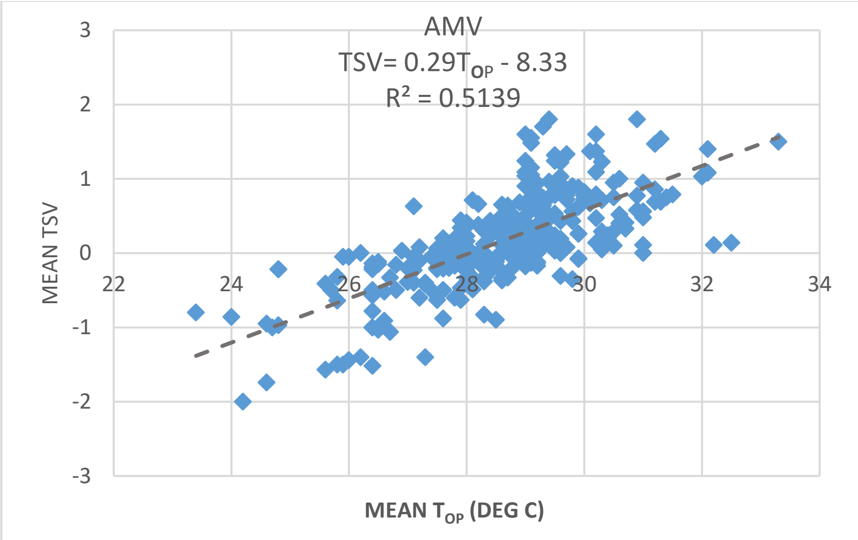

Figure 5.53: Bivariate scatter plot of mean TSV against weighted T_{OP} in combined classrooms all season.

According to Season: Furthermore, the regression of the mean responses of the young children upon the mean indoor operative temperature in the studied schools during the rainy season, irrespective of the classroom type, produced a regression equation of TSV =0.27T_{OP} -7.62 with r^2=0.56, (*p*-<0.01) as earlier shown in Table 5.21. A neutral temperature of 28.2°C was obtained by substituting the value of TSV in the equation with the voting 0 as the ultimate comfort vote. During the dry season, the regression produced an equation TSV=0.35T_{OP}-9.75 with r^2 =0.46, (*p*-<0.01). A neutral temperature of 27.8°C was obtained from the regression. The neutral temperature in the two seasons varied between each other by 0.4K. In a number of comfort studies in naturally ventilated buildings, the coefficient of determination (R^2) was quite low, such as in a study by (Rijal, Humphreys, & Nicol, 2015) where the value was 0.5 and by (Feriadi & Wong, 2004) in Indonesia where R^2 was less than 0.2. These were further expatiated in chapter 6.

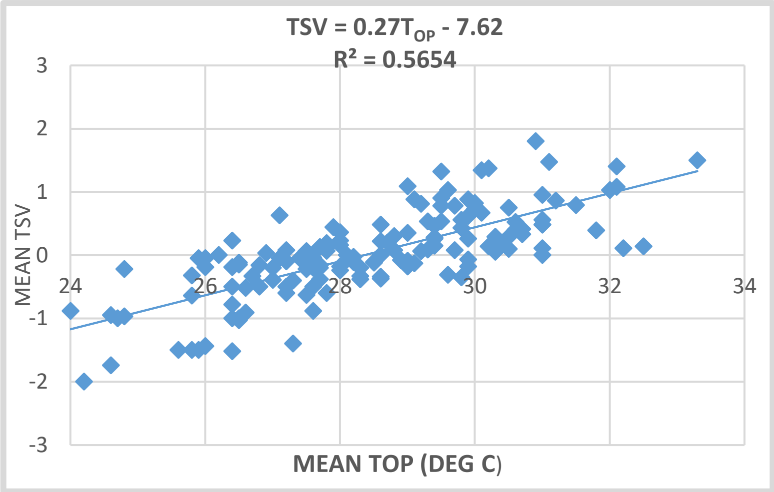

Figure 5.54: Bivariate scatter plot of mean TSV against weighted T_{OP} in combined rainy season

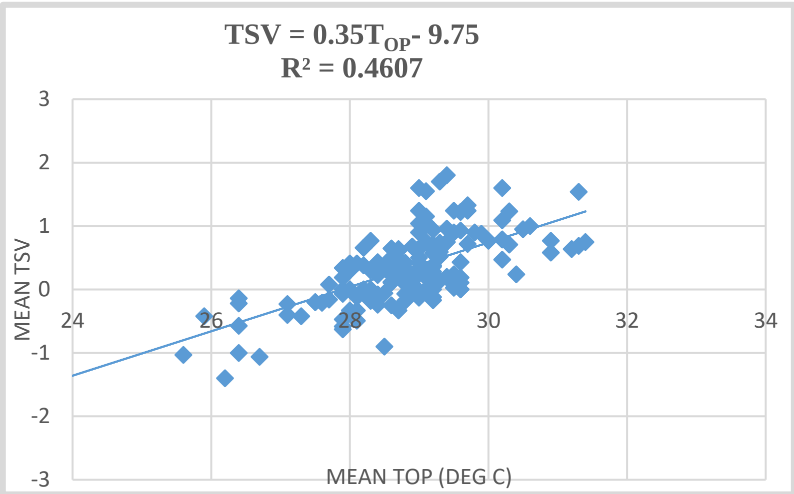

Figure 5.55: Bivariate scatter plot of mean TSV against weighted T_{OP} in combined dry season.

According to Time of Day: As shown in Figures 5.56 and 5.57, the regression of the mean responses of the young children upon the mean indoor operative temperature in the combined morning hours, irrespective of the classroom type, produced a regression equation TSV $=0.31T_{OP}-8.83$ with $r^2=0.51$, $(p-<0.001)$. A neutral temperature of 28.5°C was obtained by substituting the value of TSV in the equation with the voting 0 as the ultimate comfort vote. In the combined afternoon hours, the regression produced an equation TSV$=0.21T_{OP}-5.91$ with $r^2=0.32$, $(p-<0.001)$. At a mean TSV of 0, representing the ultimate temperature on 7-point ASHRAE scale, a neutral temperature of 28.1°C was obtained. The neutral temperature in the two seasons varied between each other by 0.4K.

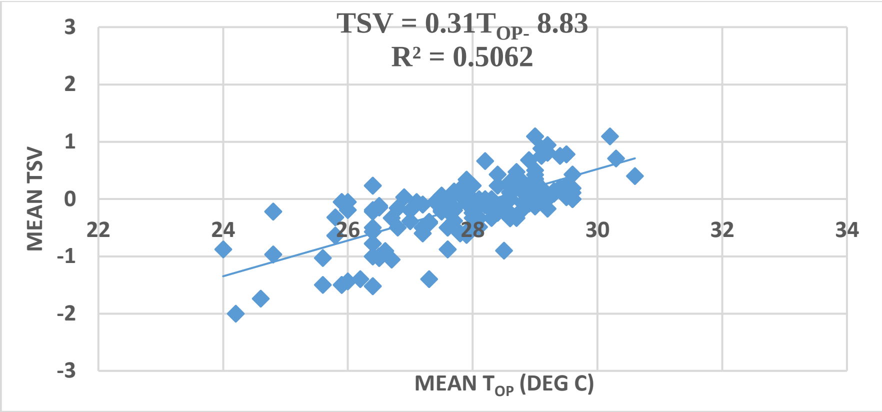

Figure 5.56: Bivariate scatter plot of mean TSV against weighted T_{OP} in combined morning hours.

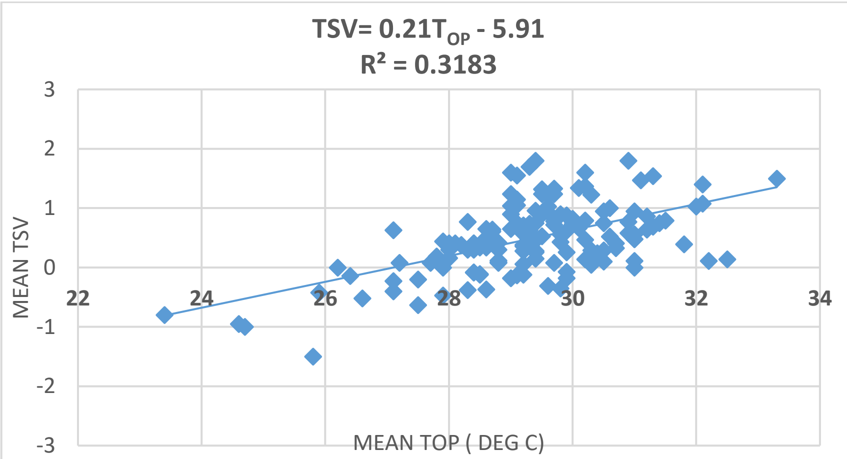

Figure 5.57: Bivariate scatter plot of mean TSV against weighted T_{OP} in combined afternoon hours.

According to Building Type: According to building type, the regression of the mean responses of the young children upon the weighted mean indoor operative temperature in the studied classrooms produced a regression equation TSV=0.24T_{OP}-6.9 in the combined open classrooms all season with r^2 =0.4675 *p-< (0.001).* This regression equation produced a neutral temperature of 28.8°C when the TSV (y-axis) value equalled 0. The regression produced a weak r^2 value, however this is commonly observed in studies that involve children as further discussed in chapter 6. The combined enclosed classrooms produced a higher *r* value (0.5139) compared to the combined open classrooms. The regression equation (TSV=0.36T_{OP} -10.14) produced in the combined enclosed classrooms, produced a neutral temperature with value 28.1°C when the TSV is submitted with the value 0 in the equation. The neutral temperature between the two types of classrooms varied by 0.7 K.

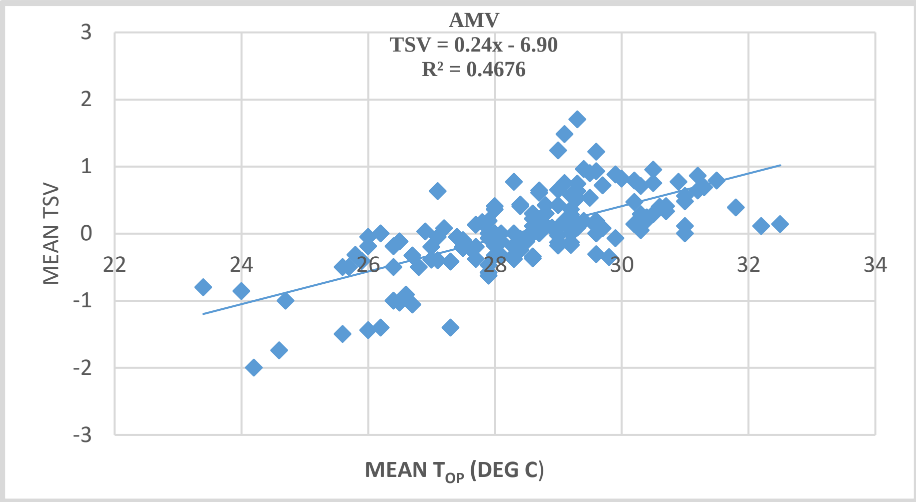

Figure 5.58: Bivariate scatter plot of mean TSV against weighted T_{OP} in combined open classroom all seasons.

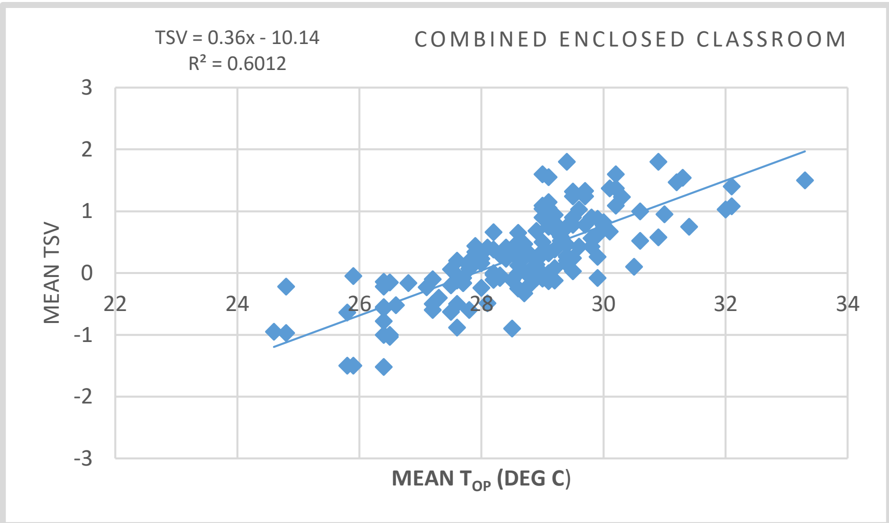

Figure 5.59: Bivariate scatter plot of mean TSV against weighted T_{OP} in combined enclosed classrooms all season.

5.3.6 Comfort range of children

The comfort range of the young children can be determined using thermal comfort indices such as the Predicted Mean Votes (PMV) established by (Fanger & Toftum, 2002) or the adaptive method established by (de Dear & Brager (2002). In this study, the Adaptive Comfort Model (ACM) that sets an 80% comfortable zone, -0.85≤TSV≤+0.85, was adopted to determine the thermal comfort range. The reasons for adopting the ACM was earlier discussed in section 2.7.6 of Chapter 2. In this study, the mean thermal sensation votes were regressed against the indoor operative temperatures (T_{OP}). 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. The range between (*0.5≤TSV≤+0.5)* for 90% acceptable indoor thermal condition was used for further test to check compliance to a more stringent requirement. Based on the regression equation, TSV=0.29T_{op}-8.33, a comfort range of 25.8-31.6°C (*-0.85≤TSV≤+0.85)* and 28.7-30.4°C (*0.5≤TSV≤+0.5)* were calculated for the combined classrooms all seasons as summarized in Table 5.22.

Table 5. 22: Results of operative temperature plotted against thermal sensation votes

	Equation	**Comfort Range (°C) -0.85≤AMV≤+0.8 (80%)**	**Comfort Range (°C) -0.5≤AMV≤+0.5 (90%)**
All classrooms	TSV=0.29T_{op}- 8.33	25.8-31.6	28.7-30.4
All open classrooms	TSV=0.24T_{op}-6.9	25.2-32.3	26.6-30.8
All enclosed classrooms	TSV=0.36T_{op}-10.14	25.8-30.5	26.7-29.5
All classroom rainy season	TSV=0.27T_{op}-7.62	25.1-31.4	26.3-30.1
All classrooms dry season	TSV=0.35T_{op}-9.75	25.4-30.2	26.4-29.3
All morning	TSV=031 T_{op}-8.83	25.7-31.2	26.0-30.1
All afternoon	TSV=0.21T_{op}-5.91	24.1-32.2	25.7-30.4

*According to Season***:** As shown in Table 5.22, the comfort range (acceptable indoor temperature) for the combined classrooms in the rainy season was from 25.1-31.4°C (-*0.85≤TSV≤+0.85)* for 80% acceptability criterion, while during the dry season the comfort range was from 25.4-30.2°C. Comparing with 90% acceptability criterion, the comfort ranges are 26.3-30.1°C and 26.4-29.3°C for the rainy season and the dry season, respectively. These results were obtained from the linear regression of the thermal sensation votes from the field work and the mean indoor operative temperatures also from the field work

According to Time of Day: Furthermore, as summarized in Table 5.22, in the combined morning hours in the classrooms the regression equation obtained (TSV=031T_{op}-8.83) produced the range between 25.7°C-31.2°C (*-0.85≤TSV≤+0.85)* which equalled 80% acceptability. A range between 26.0-30.1°C (*0.5≤TSV≤+0.5),* which equalled 90% acceptability was also obtained. The comfort range for the combined afternoon hours in the classrooms was 24.1-32.2°C, (*-0.85≤TSV≤+0.85)* for 80% acceptability and 25.7-30.4°C (*0.5≤TSV≤+0.5)* for 90% acceptability, obtained from regression equation TSV=0.21T_{op}-5.91.

According to Building Type: The comfort range (acceptable indoor temperature) for the studied children in the warm humid climate in the combined 'open space' classrooms was between

25.2°C-32.3°C ($-0.85 \leq TSV \leq +0.85$) which equalled 80% acceptability and 26.6-30.8°C ($0.5 \leq TSV \leq +0.5$), which equalled 90% acceptability. These were determined from the linear regression of the thermal sensation votes and the mean indoor operative temperature from the field work that produced the equation $TSV = -6.9 + 0.24T_{OP}$. The comfort range for the combined 'enclosed plan' classrooms was 25.8°C-30.5°C, ($-0.85 \leq TSV \leq +0.85$) for 80% acceptability and 26.7-29.5°C ($0.5 \leq TSV \leq +0.5$) for 90% acceptability, obtained from regression equation $TSV = -10.14 + 0.36T_{OP}$.

5.3.7 General Comfort Votes of children

The comfort level of the studied children towards the existing indoor thermal conditions in the naturally ventilated classrooms they use for class lessons was determined using the comfort question. Comfort temperature is another indicator used in assessing the thermal perception of building occupants. ASHRAE Standard 55 defined the comfort zone in terms of thermal environments that are 'acceptable' to at least 80% of the occupants. Their responses to this comfort question were characterized according to season, building type and according to time of the day as summarized in Table 5.23 and presented in the histogram in Table 5.60. As can be seen in the Table, the thermal comfort votes show that 70% of the subjects in combined classrooms all season indicated that they were comfortable with the prevailing indoor thermal condition, whereas 30% indicated they were uncomfortable.

Table 5. 23: Summary of comfort votes in each classroom

Classroom	Comfortable		Uncomfortable	
	Rainy Season	Dry Season	Rainy Season	Dry Season
A_{OP}	326 (88%)	564(79%)	44 (12%)	149(21%)
A_{EN}	263(64%)	365(52%)	148(36%)	343(48%)
B_{OP}	289 (88%)	508(62%)	41(12%)	309(38%)
B_{EN}	282 (70%)	585(64%)	122(30%)	295(36%)
C_{OP}	493 (83%)	428(84%)	102(17%)	80(16%)
C_{EN}	432 (60%)	365(71%)	284 (40%)	233(29%)
$A_{OP}+B_{OP}+C_{OP}$	1108(86%)	1500(74%)	187(14%)	538)26%)
$A_{EN}+B_{EN}+C_{EN}$	977(64%)	1315 (60%)	554(36%)	871(40%)
All classrooms	2085(74%)	2815(66%)	741(26%)	1409(34%)
$A_{OP}+B_{OP}+C_{OP}$	2608(78%)		725(22%)	
$A_{EN}+B_{EN}+C_{EN}$	2292(62%)		1425(38%)	
All classrooms	4900(70%)		2150(30%)	

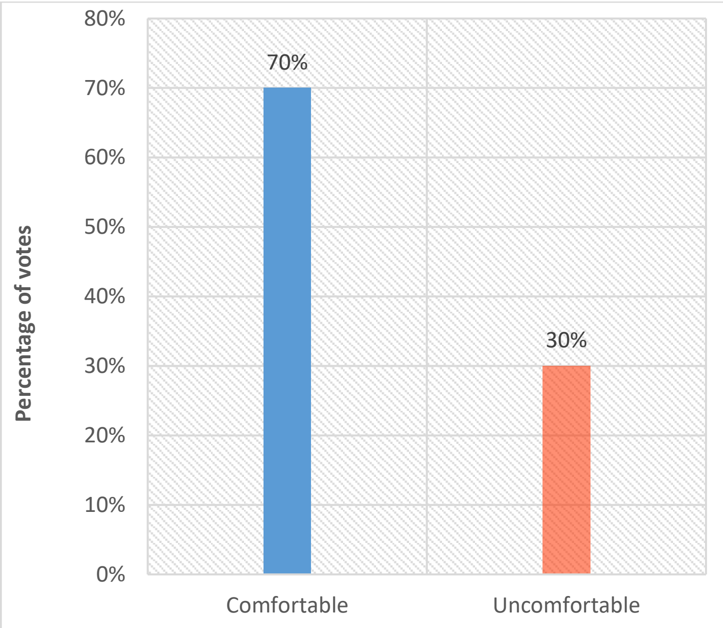

Figure 5.60: Distribution of comfort votes of the children in combined classrooms all season

According to Season: Table 5.23 shows that the subject's comfort votes on 'comfortable' was 74% in the rainy season, while in the dry season the vote was 66%. Further breakdown indicates that higher votes on comfortable was more during the rainy season compared to the dry season, approximately 85% of the time the survey was carried out in each of the classrooms. The highest variation of the votes cast on 'comfortable' was in classroom B_{OP} where the subjects voted 88% in rainy season and 62% in dry season indicating a significant difference of 26% between the two seasons. The lowest variation in comfort votes (1%) on 'comfortable; was in classroom C_{OP} where the occupants voted 83% and 84% in rainy season and dry season, respectively to indicate they were comfortable.

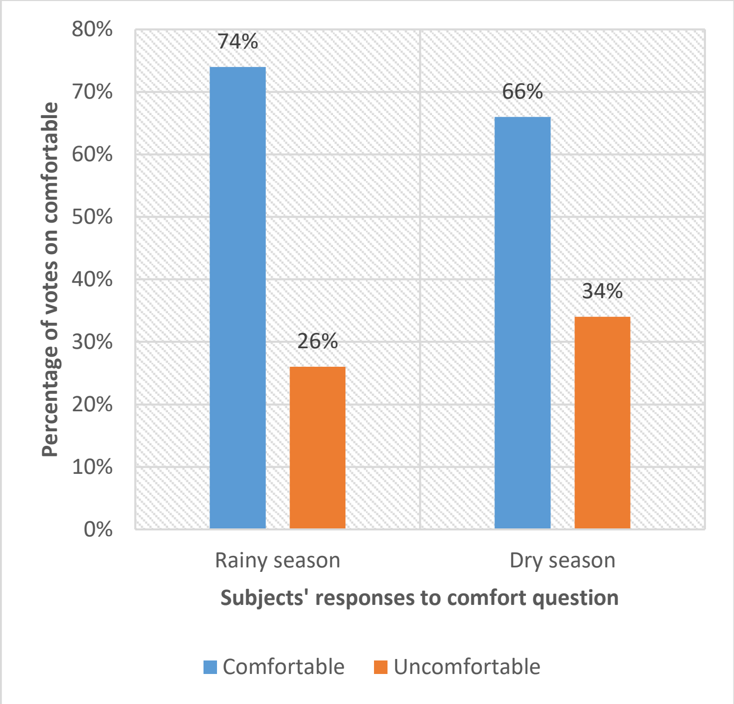

Figure 5.61: Distribution of the children's comfort votes according to season

According to Time of Day: Figure 5.62 categorizes the thermal comfort responses of the children according to time of the day; morning (before 11am), and afternoon (11am-2pm). For approximately 100% of the time the fieldwork was carried out, the studied children rated their indoor thermal conditions more comfortable in the morning hours compared to the afternoon hours. However, the expression of their thermal environment as 'comfortable' was higher in the open classrooms compared to the enclosed classrooms in the morning hours and afternoon hours. For instance, during the rainy season in school A, the occupants of classroom A_{OP} gave votes of 89% and 86% during the morning and afternoon surveys, respectively indicating comfortable. While the occupants of the corresponding classrooms (A_{EN}) in the same compound and the same block voted 69% and 63% in the same time period indicating their condition as comfortable. The same trend was followed during the dry season where the occupants of classroom A_{OP} voted 85% and 70% in the morning hours and afternoon hours, respectively indicating they were comfortable. The corresponding classroom, A_{EN}, in the same season voted 60% and 38%.

The highest variation of comfort vote recorded between the morning and afternoon surveys during the rainy season in the surveyed classrooms was 49%, and that was in classroom B_{OP}. During the same season, the lowest variation (3%) was observed in classroom A_{OP}. In dry season survey, classroom C_{EN} recorded the highest variation (52%), while classroom B_{EN} recorded the lowest variation (16%).

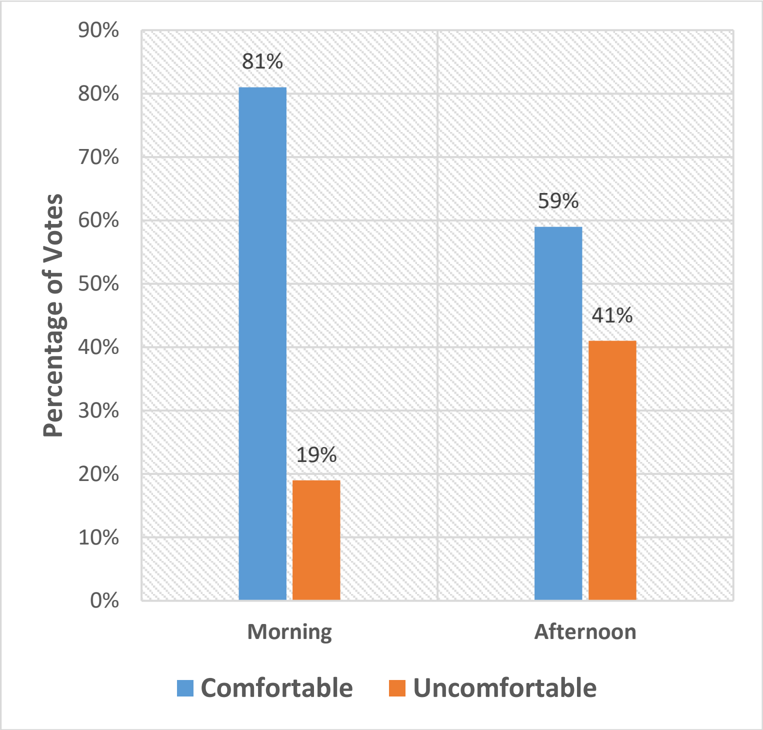

Figure 5.62: Distribution of subjects' comfort votes according to time of day

According to Building Type: Figure 5.63 categorizes the thermal comfort responses according to building type. Higher percentage of the subjects voted that they were comfortable in the open classrooms compared to the subjects in the enclosed classrooms. While 78% of the occupants in the combined open classrooms all season voted that they were comfortable with the indoor thermal conditions, the occupants in the combined enclosed classrooms voted 62%. This indicates a significant difference (26%) of more subjects in the combined open classroom who voted they were comfortable when compared to the subjects in the enclosed classrooms all seasons. Further breakdown of the comfort votes according to classroom type indicates that the comfort votes in the open classrooms were higher than the comfort votes in the enclosed classrooms by approximately 90% of the time the survey was conducted. Furthermore, the highest percentage of comfort votes that indicates comfortable were cast in classrooms A_{OP} and B_{OP} with 88% of votes cast each way. The children expressed the highest discomfort in classroom A_{EN} with a comfort vote of 48%, which shows that near to half of the class were uncomfortable..

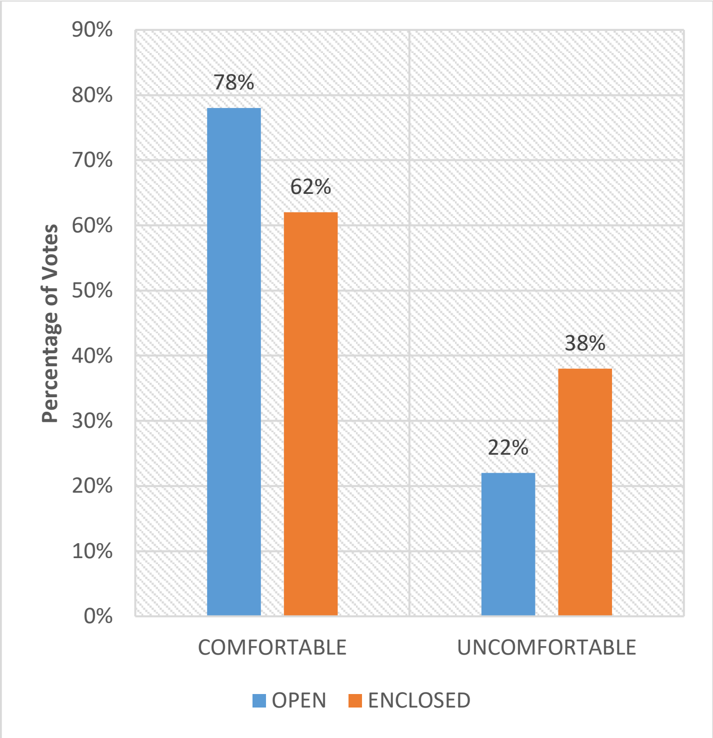

Figure 5.63: Distribution of subjects' comfort votes according to classroom type

5.3.8 Thermal Acceptability of Children

The thermal acceptability of the children to the current classroom temperature was assessed. The results of the assessment are presented in Table 5.24 and summarized in a histogram shown in Figure 5.64. The responses to the acceptability question as it relates to the prevailing indoor thermal condition question show that 56% of the children in the combined classrooms all seasons accepted the prevailing indoor thermal conditions as against 44% that did not accept it

Table 5.24: Summary of thermal acceptability

School	Season	Acceptable		Unacceptable	
		Morning	Afternoon	Morning	Afternoon
A_{OP}	Rainy	151(82%)	138(74%0	34(18%)	47(26%)
	Dry	240(67%)	96(27%)	117(33%)	261(73%)
	Both	391(72%)	234(43%)	151 (28%)	308(57%)
	Both periods	625(58%)		456 (42%)	
A_{EN}	Rainy	151(73%)	151(73%)	34(27%)	54(27%)
	Dry	239(67%)	113(34%)	115(33%)	241(66%)
	Both	390(70%)	264(47%)	169(30%)	295(53%)
	Both periods	654(58%)		464(42%)	
B_{OP}	Rainy	145(88%)	155(94%)	20(12%)	10(6%)
	Dry	241(59%)	174(43%)	164(41%)	231(57%)
	Both	386(68%)	326(57%)	184(32%)	244(43%)
	Both periods	712(62%)		425(38%)	
B_{EN}	Rainy	140(69%)	123(61%)	62(31%)	79(39%)
	Dry	299(70%)	174(40%)	141(30%)	266(60%)
	Both	439(68%)	297(46%)	203(32%)	345(54%)
	Both periods	736(57%)		548(43%)	
C_{OP}	Rainy	160(54%)	138(46%)	137(46%)	158(54%)
	Dry	135(53%)	121(47%)	119(47%)	133(53%)
	Both	295(53%)	259(47%)	256(47%)	291(53%)
	Both periods	554(55%)		447(45%)	
C_{EN}	Rainy	197(55%)	185(51%)	166(45%)	173(49%)
	Dry	158(53%)	112(37%)	141(47%)	187(63%)
	Both	355(53%)	297(45%)	307(47%)	360(55%)
	Both periods	652(49%)		667(51%)	
$A_{OP} + B_{OP} + C_{OP}$	All periods	1,072(64%)	819(49%)	591(36%)	840(51%)
$A_{OP} + B_{OP} + C_{OP}$	Both	1891(57%)		1431(43%)	
$A_{EN}+B_{EN}+C_{EN}$	All periods	1184(63%)	858(46%)	679(37%)	1015(53%)
$A_{EN}+B_{EN}+C_{EN}$	Both	2042(54%)		1694(46%)	
All	All season	2256(64%)	1677(47%)	1270(46%)	1855(53%)
$A_{OP} + B_{OP} + C_{OP}$	All season	1891(57%)		1431(43%)	
$A_{EN}+B_{EN}+C_{EN}$	All season	2042(54%)		1694(46%)	
All	All season	3933(56%)		3,125(44%)	

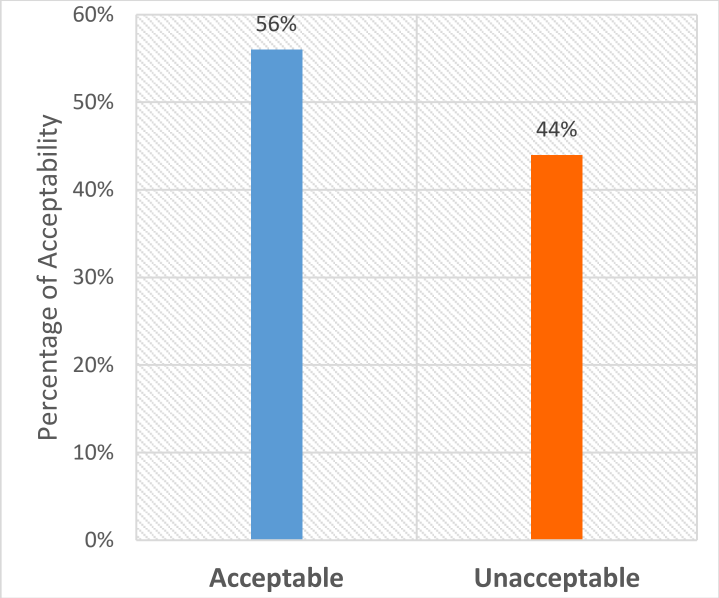

Figure 5.64: Distribution of children's acceptability votes

According to Season: More of the children accepted the prevailing indoor thermal conditions during the rainy season compared to the dry season. While the acceptability was 64%, during the rainy season, 62% in the surveyed children accepted the thermal conditions during the dry season survey. The occupants in the combined open classrooms expressed slightly higher acceptability during the rainy season (57%) compared to the dry season (54%).

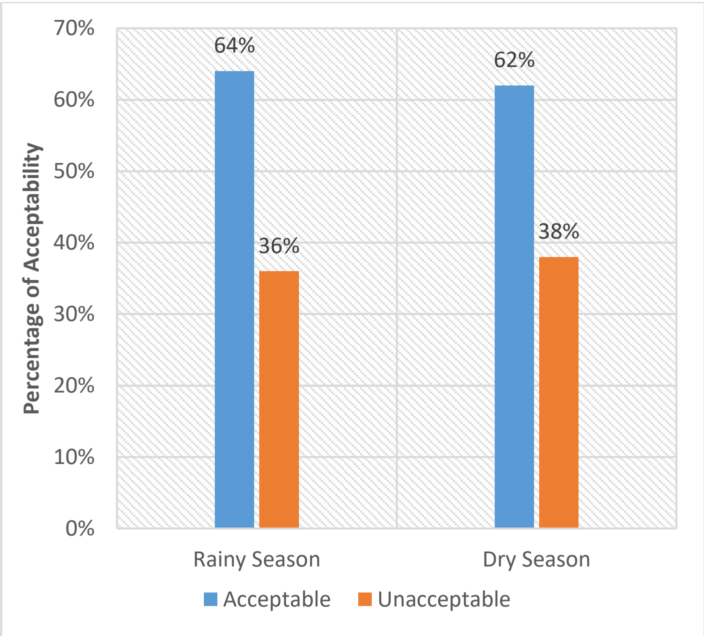

Figure 5.65: Distribution of the children's acceptability votes

According to Time of the Day: For the combined classrooms all seasons, the acceptability was 64%, in the morning hours, while in the afternoon hours it was 47% (Table 5.24 and 5.66). The result is further illustrated in the histogram in Figure 5.66. This suggests that more than half of the class do not accept the prevailing indoor thermal conditions in the afternoon period. It is certain from the results that the occupants accepted the indoor thermal conditions in the morning hours compared with the afternoon hours, and the difference in votes of the participants between the two periods (morning and afternoon) is significant in almost all the classrooms that were investigated. However, acceptability was higher in the afternoon hours in classroom B_{OP} during the rainy season. The reason for the lower acceptability in the morning hours compared to the afternoon hours is linked to the cold experienced in most of the morning hours the survey was conducted in the classroom. Further explanation to this is given in Chapter 6.

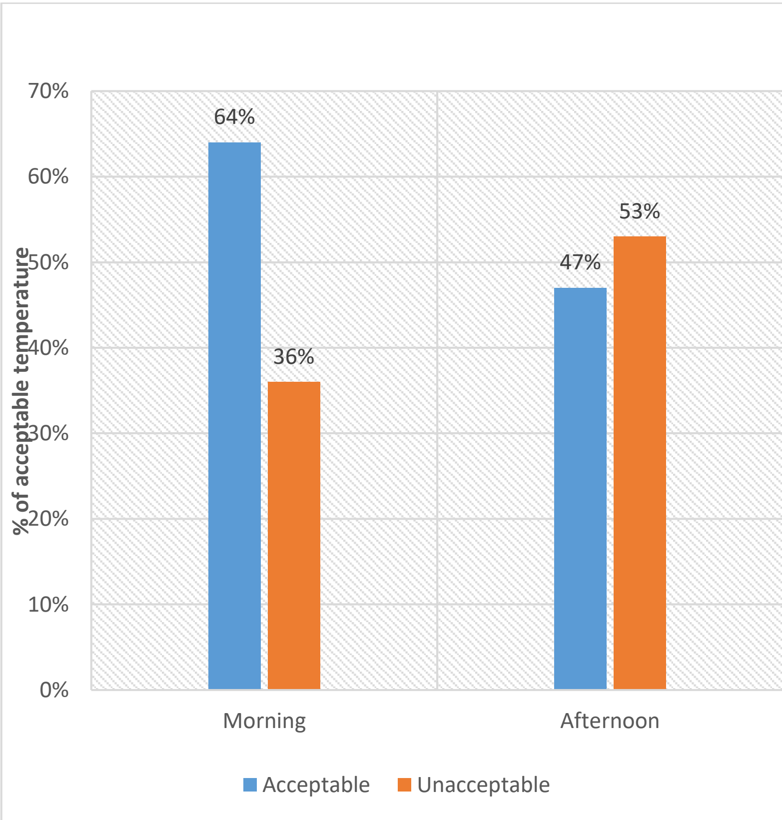

Figure 5.66: Thermal acceptability according to time of day

According to Building Type: As shown on Figure 5.67, more than half of the class accepted the indoor temperature in both types of classrooms. However, acceptability was slightly higher in the combined open classrooms compared to the combined enclosed classrooms. Further breakdown of acceptability according to building types (referring back to Table 5.24) show that the highest variation in the acceptability between the two types of classrooms was reported in school B. While classroom B_{OP} reported 88% acceptability during the rainy season in the morning hours, the corresponding classroom B_{EN}, the same period reported 69%, a significant difference of 19%. This was further discussed in chapter 6. `

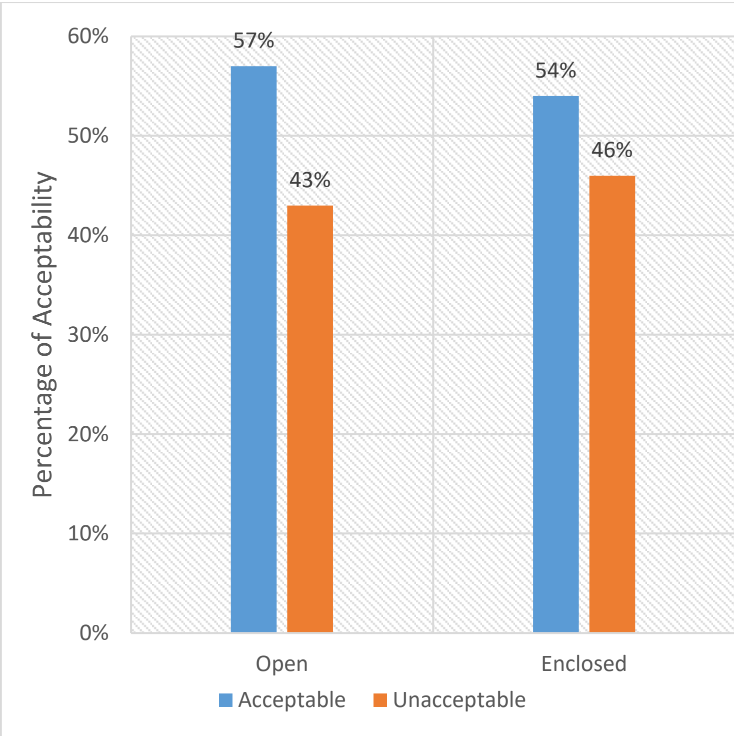

Figure 5.67: Thermal acceptability according to classroom type

5.3.9 Relative Humidity Acceptability of Children

The indoor humidity acceptability question gave two options to the children to accept or not to accept the current relative humidity (RH) in their classrooms. Figure 5.68 shows the percentage distribution of votes toward the RH level in the classrooms according to season and time of day. From the Figure, approximately 83% of the children in the combined classrooms, all season, accepted the current RH in their classrooms. 17% of the sampled children did not .accept the RH.

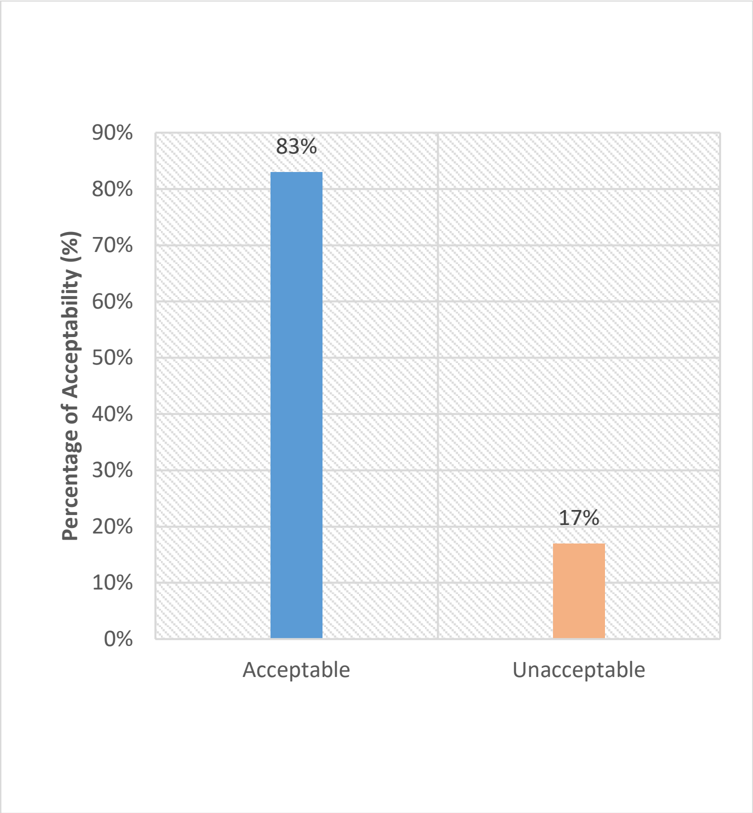

Figure 5.68: Humidity acceptability level

According to Season: Figure 5.69 shows the distribution of humidity acceptability according to season. 84% of the sampled population accepted the RH during the rainy season survey, close to the same number (81%) that accepted the RH during the dry season. Similar percentage of the children who did not accept the RH in the rainy season (16%) did not accept it in the dry season (19%). This suggests that there was no significant difference in RH acceptability between the two seasons.

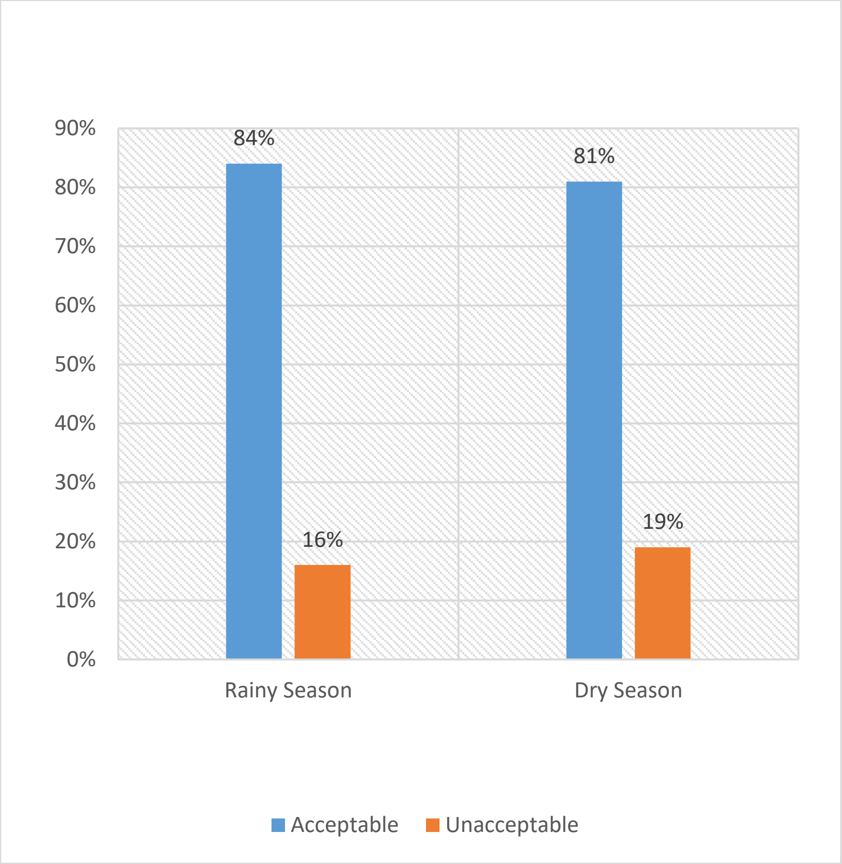

Figure 5.69: Humidity acceptability level

According to Building Type: Figure 5.70 shows the distribution of the acceptability to indoor humidity according to building type. The detail in the Figure shows that the acceptability to the current indoor RH was higher in the combined open classrooms in combined seasons compared to the combined enclosed classrooms. 85% of the class population accepted the relative humidity in the open classrooms while 80% acceptability was observed in the enclosed classroom. Unacceptability was 15% in the open classroom and 20% in the enclosed classroom. However, acceptability to RH between these two types of classrooms did not differ significantly.

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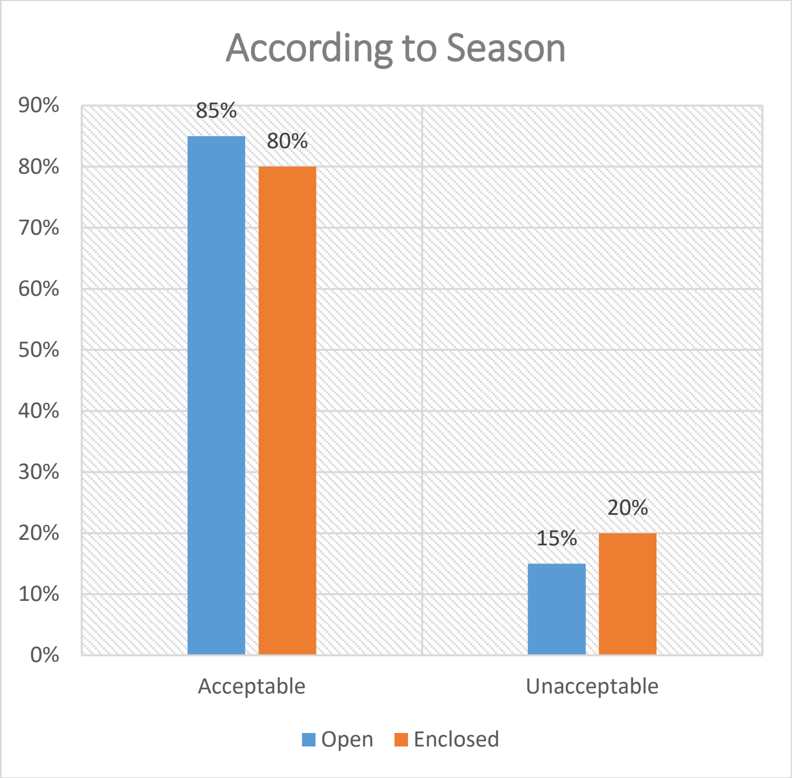


Figure 5.70: Humidity acceptability level

According to Time of Day: As shown in Table 5.25**,** acceptability to indoor RH was generally high in both the morning and afternoon hours in most of the days the surveys were conducted in the classrooms. The difference in acceptability between these two periods was not significant. Furthermore, acceptability to RH was very high in the afternoon in this classroom (B_{OP}) in rainy season where 97% of the sampled children accepted the indoor relative humidity, while only 3% did not accept it. The lowest acceptability (35%) was recorded in classroom A_{EN} in the afternoon hours during the dry season. A high percentage of the children (65%) did not accept the RH in this classroom (A_{EN}) during that period. Further check on the Table reveals that the acceptability to RH in both the morning and afternoon periods in classroom A_{OP} during the rainy season was equal (80% each way).

Table 5. 25: Children's acceptability to humidity

Classroom	Season	Period	Humidity acceptability	
			Acceptable	**Unacceptable**
A_{OP}	Rainy	Morning	(80%)	20%)
		Afternoon	(80%)	20%)
		Both	((80%)	20%)
	Dry	Morning	(87%)	13%)
		Afternoon	(81%)	68(29%)
		Both	(84%)	113(16%)
A_{EN}	Rainy	Morning	(81%)	38(19%)
		Afternoon	(72%)	58(28%)
		Both	(76%)	96(24%)
	Dry	Morning	(70%)	105(30%)
		Afternoon	(35%)	278(65%)
		Both	(53%)	333(47%)
B_{OP}	Rainy	Morning	(97%)	5(3%)
		Afternoon	(86%)	23(14%)
		Both	(91%)	28(9%)
	Dry	Morning	(80%)	80(20%)
		Afternoon	(65%)	144(35%)
		Both	(72%)	224(28%)
B_{EN}	Rainy	Morning	(72%)	56(28%)
		Afternoon	(52%)	96(48%)
		Both	(63%)	152(37%)
	Dry	Morning	(76%)	106(24%)
		Afternoon	(69%)	135(31%)
		Both	(72%)	241(28%)
C_{OP}	Rainy	Morning	(73%)	162(27%)
		Afternoon	(76%)	140(24%)
		Both	(74%)	302(26%)
	Dry	Morning	(80%)	101(20%)
		Afternoon	(75%)	123(25%)
		Both	(78%)	224(22%)
C_{EN}	Rainy	Morning	(69%)	222(31%)
		Afternoon	(49%)	361(51%)
		Both	(59%)	583(41%)
	Dry	Morning	(76%)	142(24%)
		Afternoon	(57%)	257(43%)
		Both	(66%)	399(34%)

5.3.10 Air Movement Acceptability and Preference of Children

The occupants' responses to indoor airflow acceptability and preference are summarized in Table 5.26. The acceptability question aimed to determine the children's acceptability or not to the current air movement in their respective classrooms. The preference for air movement question was a follow up to the acceptability question which aimed to assess if the children needed more air, or less air or were okay with the current air flow in their respective classrooms. Results show that with the indoor air movement of approximately 0.19m/s, 75% of the subjects in the combined classrooms all season accepted the air movement. 25% of the entire class did not accept the air movement. Preference for more air at this mean air velocity was 64% for the combined classrooms all season.

Table 5. 26: Children's acceptability and preference according to airflow and operative temperature

Classroom	Season	Air Movement				
		Acceptability		Preference		
		Acceptable	Not Acceptable	More air	Okay	Less air
A_{OP}	Rainy	257(69%)	113(31%)	133(36%)	195(53%)	42(11%)
	Dry	520(73%)	193(27%)	467(65%)	203(28%)	43(7%)
A_{EN}	Rainy	329(80%)	82(20%)	228(55%)	120(29%)	63(16%)
	Dry	333(47%)	375(53%)	594(84%)	99(14%)	15(2%)
B_{OP}	Rainy	312(94%)	18(6%)	232(70%)	64(19%)	34(11%)
	Dry	575(70%)	242(30%)	567(69%)	153(19%)	97(12%)
B_{EN}	Rainy	191(47%)	213(53%)	240(59%)	131(32%)	33(9%)
	Dry	572(65%)	308(35%)	482(55%)	308(35%)	90(10%)
C_{OP}	Rainy	485(81%)	110(19%)	271(45%)	226(38%)	98(17%)
	Dry	271(53%0	237(47%)	406(80%)	96(19%)	6(1%)
C_{EN}	Rainy	422(58%)	294(42%)	394(55%)	177(25%)	145(20%)
	Dry	388(65%0	210(35%)	490(82%)	104(17%)	4(1%)
All Open	All season	2420(72%)	913(28%)	2076(62%)	937(28%)	320(10%)
All Enclosed	All season	2235(60%)	1482(40%)	2428(65%)	939(25%)	350(10%)
All	Rainy	1996(71%)	830(29%)	1498(53%)	913(32%)	415(15%)
	Dry	2659(63%)	2395(34%)	3006(71%)	963(23%)	255(6%)
All	**All season**	**4655(75%)**	**1565(25%)**	**4504(64%)**	**1876(27%)**	**670(9%)**
Total		**7050**		**7050**		

According to Season: As shown on Table 5.26, acceptability to air movement in the combined classrooms was higher during the rainy season (71%) compared to the acceptability during the dry season (63%). Though more than half of the class (63%) accepted the air movement during the dry season, however the overwhelming majority in the class (near to three quarter) preferred more air during the dry season.

According to Building Type: According to classroom type, higher acceptability to air flow was reported in the combined open classrooms all season (72%) as against 60% acceptability reported in the combined enclosed classrooms all seasons. While the preference for more air in the combined open classrooms is 62%, the preference in the combined enclosed classroom was 65%. Furthermore, while the preference for no change (okay) in the open classroom is 28%, that of the enclosed classrooms was 25%. Percentage of preference for less air is equal (10%) in both types of classrooms

According to Time of Day: As shown in Table 5.27, acceptability to air movement was highest in the morning hours compared to the afternoon hours, irrespective of the classroom type. The exemption to this trend was observed in classroom B_{EN} where acceptability was higher in the afternoon hours than in the morning hours. The highest acceptability was reported in classroom B_{OP} in the morning hours with 92% of the entire class accepting the indoor air movement. Only 8% of the class did not accept the air movement. The highest acceptability rate in the enclosed classroom in the morning hours was expressed in classroom A_{EN} where 74% of the entire subjects accepted the air movement. The differences in the air movement acceptability can further be checked based on minimum and maximum air movement values in these two types of classrooms. While the maximum acceptability was 92% in the open classrooms, the maximum was 74% in the enclosed classrooms. Furthermore, the minimum acceptability in the open classroom was 75% the minimum was 65% in the enclosed classrooms.

Table 5. 27: Air flow acceptability according to time of day

	Period	Acceptable	Unacceptable
A_{OP}	Morning	81%	19%
	Afternoon	79%	21%
B_{OP}	Morning	92%	8%
	Afternoon	88%	12%
C_{OP}	Morning	75%	25%
	Afternoon	69%	31%
A_{EN}	Morning	74%	26%
	Afternoon	77%	23%
B_{EN}	Morning	63%	37%
	Afternoon	26%	74%
C_{EN}	Morning	65%	35%
	Afternoon	55%	45%

5.3.11 Field Work vs Laboratory Experiment

The Actual Mean Votes (AMV) considered psychological and behavioural factors in determining comfort temperature of the studied school children, while the Predicted Mean Votes (PMV) did not consider these two variables of interest in determining the children's comfort temperature. The mean AMV of the children and their calculated PMV were regressed against the classrooms indoor operative temperature. The essence of this regression is to compare if the results of these two methods of determining comfort temperature match. The results of the scatter plot and regression between (a) the operative temperature and AMV; and (b) the operative temperature and PMV are presented in Equations 5.3 and 5.4.

$$AMV = 0.29\ T_{OP} - 8.34\ (r^2 = 0.514) \quad \textbf{\textit{(5.3)}}$$

$$PMV = 0.31\ T_{OP} – 7.83\ (r^2 = 0.729) \quad \textbf{\textit{(5.4)}}$$

Based on Equation 5.3, the studied children felt neutral (0) at the indoor operative temperature of 28.8^{o}C. Based on Equation 5.4, the same subjects felt neutral at the indoor operative temperature of 25.3^{o}C. At the mean thermal sensation vote of +0.5, the AMV predicted the indoor operative temperature of 30.5^{o}C, while the PMV at the same thermal sensation value predicted temperature of 26.9^{o}C. Furthermore, at mean vote of -0.5, the AMV and PMV predicted indoor temperatures of 27.0^{o}C and 23.6^{o}C, respectively. These results are discussed extensively in Chapter 6.

5.3.12 Correlation matrix between selected variables

To establish if any relationship exists between the subjective variables and the environmental factors, Pearson's correlation was carried out. The main objective of this section is to express the thermal sensation vote as a function of the environmental factors to which the surveyed children were exposed, Correlation analysis between the indoor operative temperature, neutral temperature and relative humidity were selected as independent variables and thermal sensation votes as dependent variable. The results analysis is summarized in the table below. Results are presented with Pearson's correlation coefficient (r), the P-value significance (two-tailed), and the number of observations (N).

The thermal sensation of the studied children exhibited a strong relationship with the neutral temperature and with the indoor operative temperature in the two types of classrooms, irrespective of the season (Appendix G). The exception was in the enclosed classrooms during the rainy season where the relationship with the neutral temperature was very weak (r=.177, p- > 0.05). Apart from this weak relationship exhibited in this classroom in the rainy season, the statistical analysis suggested that the children's thermal sensation votes (AMV) were generally influenced by the outcome of the neutrality felt by the children and also influenced by the indoor operative temperatures. In order words, as the neutral temperature or the indoor operative temperature in the surveyed classrooms increased, the thermal sensation of the subjects followed suit; and *vice versa*. However, the relationship between the thermal sensation of the subjects and the indoor relative humidity was very weak in the statistical analysis carried out in all the studied classrooms. This suggested that the thermal sensation of the children was not influenced by the outcome of relative humidity in the surveyed classrooms. This result was also observed in many related works done in classrooms located in the tropical climates.

Furthermore, the highest correlation of the thermal sensation votes with the neutral temperature and the indoor operative temperature was observed in the combined open space classrooms during the rainy season. The thermal sensation had a high correlation with the neutral temperature (r^2 =.830, p-<0.01) and with the indoor operative temperature (r^2=.736, p-<0.01). The square of the correlation coefficient (r^2) can be used to estimate the proportion of the variation of the variable that is explained by the other (Nicol et al., 2012). The correlation of the thermal sensation with the neutral temperature implies that 68% of the variation of the thermal sensation, in the combined open classrooms in the rainy season, is related to the neutral temperature in the classroom. In the same classroom in the same season, the correlation of the thermal sensation with T_{OP} (r^2=.736), also implies that r^2=53% of the variation of the thermal sensation of the children is attributed to the variation of the indoor operative temperature.

5.3.13 Sensitivity of Children to Temperature Changes

The gradient coefficient (slope) of the regression line for the mean thermal sensation was used to determine the sensitivity of the children to the changes in the indoor operative temperatures. Sensitivity means the change in room temperature corresponding to the change in the average thermal sensation of the occupants and is usually expressed in scale units per degree of room temperature (Humphreys et al., 2015). The regression gradient demonstrates how much the thermal comfort increases per 1k rise in operative temperature (Humphreys et al., 2007). The regression slope is inversely proportional to the adaptability of the building occupants under analysis (de Dear et al., 2015). A shallow regression slope shows an effective adaptability of the subjects, while a steep gradient indicates that the children are not adaptable to change in the classroom thermal environment.

To find the change in temperature to shift in one thermal sensation vote, the inverse of the coefficient attached to the mean thermal sensation was calculated. Referring back to Table 5.21 of Chapter 5, for the combined classrooms all season, the children reported a regression gradient of 0.29 scale units/^oC. In other words, a mean regression gradient of 0.29 thermal sensation for every unit per ^oC was observed. Therefore, during the combined season the studied children experienced a 1 unit change (e.g. from 0 to +1) on the 7-point ASHRAE thermal sensation scale for every 3.3^oC change in operative temperature

According to Season: the slope value derived in the regression model during the rainy season was 0.27, while it was 0.35 during the dry season (Flash back to Table 5.21 of Chapter 5). Thus, the value was by 0.08 lower in the rainy season compared to the value in the dry season. The shallower slope reported in the rainy season is an indication that the school children were better adapted in this season compared with the dry season period. It shows that it took up to 3.7°C rise in operative temperature for 1 unit change in the thermal sensation of the children in the rainy season, while it took just 2.8°C rise in operative temperature for 1 unit change in the thermal sensation in the dry season, indicating a temperature change difference of 0.9°C per 1 unit change in their thermal sensation which is a significant temperature difference. The results are further discussed in Chapter 6

According to classroom type: Considering sensitivity according to classroom type may help to understand the influence of buildings on occupants respond to changes in temperature. The combined open classrooms produced a shallower slope (0.24) compared to the combined enclosed classrooms (0.36) all season (Table 5.21), showing a better adaptation in the combined open classrooms compared to the enclosed classrooms. Thus, while it took up to 4.2°C change in indoor operative temperature for the children to experience I unit change in their thermal state in the combined open classrooms, it took only 2.8°C in the combined enclosed classrooms. This shows a significant difference of 1.4°C in operative temperature. Even with the higher variations in the indoor operative temperature in the open classrooms, the children still showed more tolerance to temperature changes in the open classrooms compared to those in the enclosed classrooms. The result further indicates that the children in the enclosed classrooms were more sensitive to temperature changes compared to those in the open classrooms. The reason for this may be related to the differences in the building characteristics. The open classrooms recorded higher indoor airflow compared with the enclosed classrooms. An increased air velocity has been reported as helping to offset thermal discomfort expressed by building occupants, helping them to attain better thermal comfort.

5.3.14 Adaptive Behaviour

This study applied questionnaire methods to obtain the schoolchildren's adaptive responses to the discomfort caused to them by the indoor environmental conditions in their classrooms. Data was collected from the 'enclosed-plan' classrooms. These 'enclosed plan' classrooms have operable windows and doors for environmental controls. The studied children were asked questions to find out if they have access to environmental controls in their classrooms. During the survey, the researcher together with his assistant had a copy of a notebook where the usage of these controls was noted through observation. The subject's responses to this question are summarized in Table 5.28. A follow-up question asked the subjects whether they choose the control to be 'cooler' or to be 'warmer' (Table 4.12). These questions are important because building occupants are believed to adapt to indoor thermal conditions by adopting different adaptive options available to them.

Table 5.28 Access to environmental controls

Control type	Windows	Doors	Fans
Access (%)	74.3	25.7	NA

The results of the survey showed that only 48.0% of the entire schoolchildren indicated having access to the environmental controls available in the classrooms. About 74.3% of this group that indicated having access confirm that they preferred using windows while only 25.7% indicated preferring to use the doors. The use of the fan was not considered an adaptive option in this study since no fan was installed in the classrooms, though provisions were created for them to be mounted. The use of these environmental controls to be 'cooler' or to be 'warmer' in was characterized according to season and time of day as summarized in Table 5.28. According to the table, the preference to use these environmental controls to be cooler was higher during the afternoon hours compared with the morning hours, irrespective of the season. However, in the afternoon the preference to use them to be cooler was higher during the dry season (96.6%) compared to the rainy season (86.8%). The preference to use the controls to be warmer was higher in the morning hours compared to the afternoon hours, irrespective of the season. However, the preference to be warmer during the morning hours was higher during the rainy season (57.6%) compared to the morning hours of the day season (51.2%). The findings from this study are further discussed in chapter 6.

5.4 Thermal Perception of Teachers

5.4.1 Introduction

The thermal perception of the teachers was determined alongside that of the school children in this study. Both subjects were exposed to the same indoor thermal environment. Literature information is very scanty on the thermal perception of teachers and the relationship in the thermal perception between adults and children. A school environment is an ideal platform to conduct this investigation because a good number of children and teachers congregate in that environment. Comfort investigation on the teachers was not as robust as that of their students because it was not the main objective of this study. The feedbacks from review papers and from conferences attended by this researcher necessitated the need to include it as one of the objectives of this study. The obstacle this research work encountered on the onset was getting approval to survey the teachers. After a series of consultations, approval was given on the condition that the survey on teachers should be well mapped out and be brief in order not to disrupt their teaching schedules.

The same procedure used to obtain data from the children was also adopted in obtaining data from the teachers. Teachers, like their children, also wear government-approved uniforms to school. However, they do not adhere strictly to the official dress code like their children. The clo value of the teachers, male and female, was estimated to be 0.58 clo. To ensure their metabolic rate is within the ASHRAE standard 55 for adaptive thermal comfort, 1.0-1.3 met (ASHRAE, 2017), the questionnaire for the teachers were distributed to them when they were seated and not engaged in any other activity except making lesson notes or marking scripts.

5.4.2 Descriptive Measures

General Characteristics and Samples

As summarized in Table 5.29, 44 teachers participated in the survey. A sample size of 21, representing 47.7%, participated during the dry season, while 52.3% representing 23 teachers participated during the rainy season. There were by far a greater number of female teachers (88.6%) than their male counterparts (11.4%). The age of the teachers ranges from 19 to 59 with 37 years as the mean age. Majority of the teachers who participated (56.8%) were below 40 years in both seasons the survey was conducted. Generally, there was a wide gap in age between teachers and the children which provides a good basis for the comparison of the thermal comfort perceptions between these two groups of people. Furthermore, majority of the teachers (93.2%) had lived in the study area for more than one year.

Table 5.28: Summary of teachers background

		Total (n=44)		Dry season (n=21)		Rainy season (n=23)	
		Sample size	Percentage	Sample size	Percentage	Sample size	Percentage
Gender	Male	5	11.4%	2	9.6%	3	3.1%
	Female	39	88.6%	19	90.4%	20	86.9%
Age (years)	19-29	11	25.0%	4	19.1%	7	30.4%
	30-39	14	31.8%	7	33.3%	7	30.4%
	40-49	10	22.7%	6	28.6%	4	17.4%
	50-59	9	20.5%	4	19.0%	5	21.8%
Living in Imo State(years)	<1	3	6.8%	-	-	-	-
	1-5	12	27.3%	-	-	-	
	>5	29	65.9%	-	-		

5.4.3 Thermal Sensation of Teachers

Fanger's approach to thermal sensation evaluation of building occupants using the ASHRAE 7-point thermal sensation scale (-3=colder, -2=cooler, -1= a bit cold, 0=okay, +1= a bit warm, +2=warmer, +3= hotter) was also adopted to assess the degree of satisfaction of the teachers to the indoor thermal conditions in the classrooms they occupy with their students. The central three categories of the scale that range between -1 to +1 are taken as indication to thermal sensation at which the occupants will be satisfied with the thermal conditions, while the votes outside this central category (-3, -2, +3. +2) are taken assumed as indication of discomfort. Table 5.30 summarizes the mean thermal sensation votes of the teachers characterized according to the combined classrooms all seasons and according to time of day.

According to Season: With a mean thermal sensation vote of +0.58, for the combined classrooms all season, the teachers evaluated their indoor thermal condition to lie in-between 'okay' and 'a bit warm', however tending more to 'a bit warm'. The range of the thermal sensation was from -0.7 to +1.9, SD (.79). The results of the thermal sensation votes of the teachers are further illustrated in relative frequency distribution shown in Figure 5.73. The highest percentage of thermal sensation votes (35%) was on 'a bit warm' section of the ASHRAE scale, while 10% of the votes were on the 'cold' (-1) side of the ASHRAE 7-point thermal sensation scale. Only 28% of the teachers cast their votes on okay (0). The percentage of the teachers who voted on ASHRAE three central categories (-1,0,1), that indicates comfortable, was 76%. The percentage of votes on the two extreme ends of the ASHRAE scale which indicates discomfort (-3, -2, +3, +2) totalled 37%. However, the discomfort was more on the warmer side of the scale (20%), than on the cooler side of the scale (17%).

According to Time of Day: Table 5.30 further shows the distribution of the mean thermal sensation votes of the teachers in combined classrooms all season characterized according to time of day. Results indicate that in the morning hours, the studied teachers expressed their thermal conditions as slightly below 'okay', tending towards the cooler side of the ASHRAE scale. Also, the range of thermal sensation in the morning hours is from -.7 to 1.7 (SD=+0.66), suggesting that the teachers generally felt cold in the morning hours. In the afternoon hours, a mean thermal sensation of +1.0 was expressed by the subjects, suggesting that the subjects felt 'a bit warm' during that period of the survey, with a range between -0.1 to 1.9 (SD =+0.52).

A closer check on the data collected during the fieldwork reveals that the lowest thermal sensation vote (-1.6) was expressed on the 16th of October in the morning hours, at an observed mean indoor operative temperature of 24.8^{o}C.

Table 5. 29: Teacher's mean, standard deviation, min and max values of the main environmental parameters and mean thermal sensation votes.

	Mean thermal sensation votes			
	Aver	**Min**	**Max**	**Std**
Morning	-.16	-1.6	**+1.7**	**.66**
Afternoon	1.0	-0.1	+1.9	.52
All season	0.58	-1.6	+1.9	.79

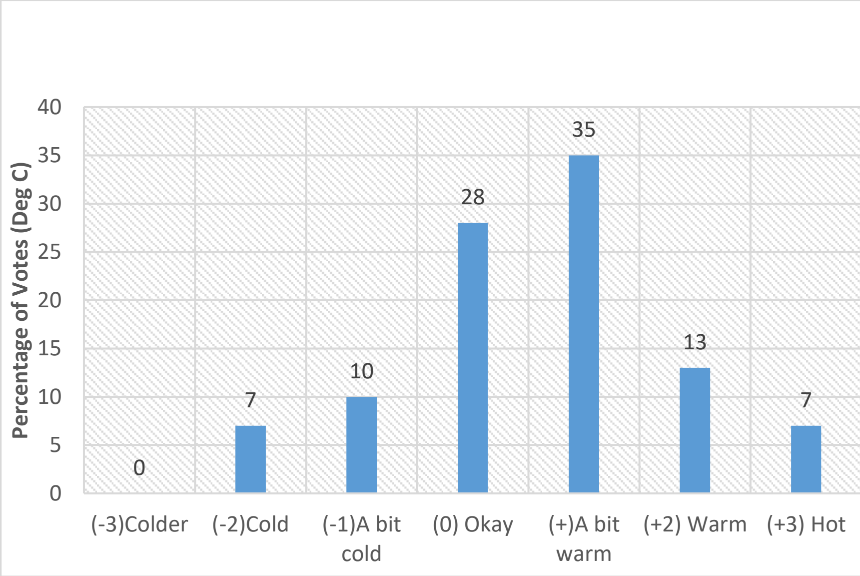


Figure 5.71: Histogram of thermal sensation of the teachers

5.4.4 Thermal preference of teachers

The McIntyre scale was adopted to evaluate the thermal preference of the teachers in the two types of classrooms as illustrated in Figure 5.73. Preferred temperature is the temperature that the subjects want to be feeling other than neutral temperature. The subjects were asked whether they would prefer 'warmer, 'cooler; or 'okay' (no change) to their indoor thermal conditions. From the Figure, almost half (49%) of the teachers preferred the thermal conditions in the classrooms to remain the way they found it during the survey period. 29% of the teachers preferred the classrooms to be cooler while 22% preferred it to be warmer.

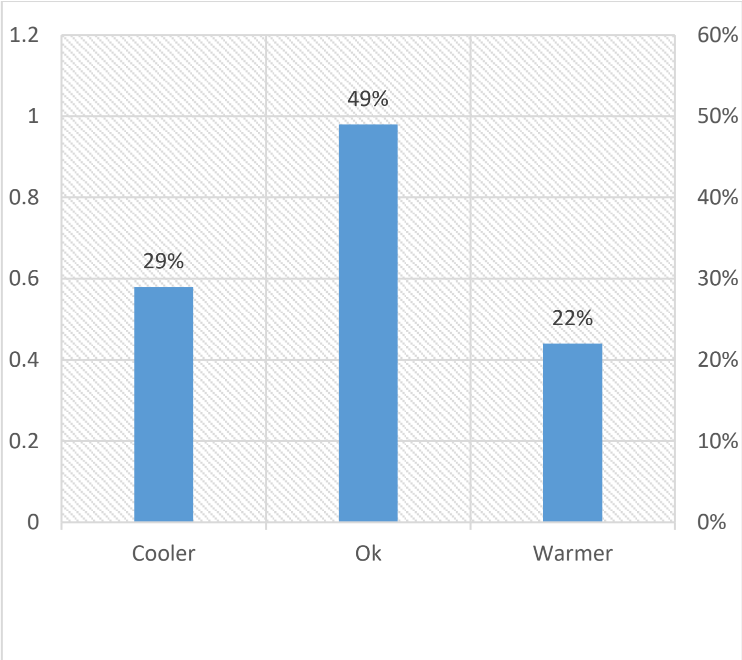


Figure 5.72: Histogram of thermal preference of the teachers

According to Time of Day: In the morning hours, more than half of the entire teachers (54%) preferred the indoor temperatures to remain the way they met it (Table 5.74). But in the afternoon period, the preference came down to 42%. This suggests that, 12% of the teachers who earlier preferred the indoor temperature the way they found it in the morning hours rather preferred a cooler or warmer temperature during the afternoon hours. In order words, a greater number of teachers were more comfortable in the morning hours than in the afternoon hours. The reason for this thermal behaviour is likely related to temperature variation. Temperature in the range 27-28^{o}C prevailed more in the classrooms in the morning hours, while higher temperature range (29-30^{o}C) prevailed more in the afternoon. The high temperature experienced by the teachers in the afternoon caused discomfort to some of them resulting to some of the teachers wanting another state other than okay (neutral). Furthermore, as would be expected, preference for a cooler in door environment was more in the afternoon hours (48%) than in the morning hours (14%). Also, preference for a warmer condition was more in the morning hours (22%) than in the afternoon hours (10%).

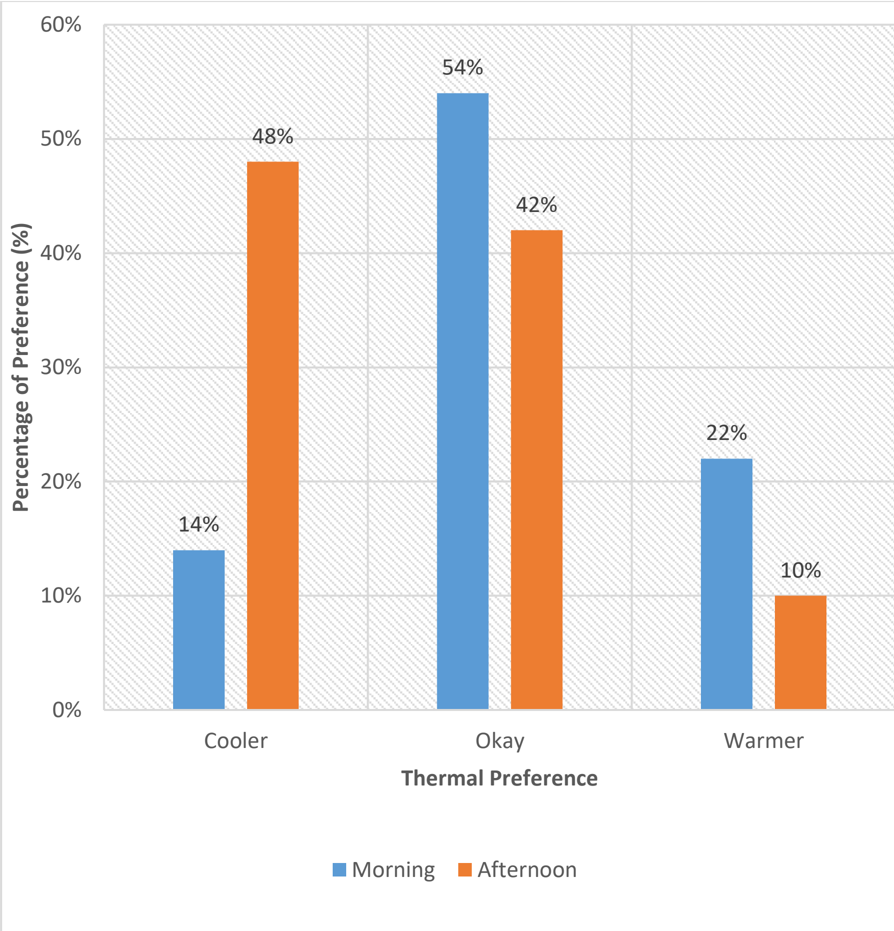


Figure 5.73: Distribution of teacher's thermal preference votes according to time of day

5.4.5 Neutral Temperature (T_n) of Teachers

In this study, the neutral temperature of the teachers was calculated statistically by applying linear regression analysis between their thermal sensation votes (TSV), as a dependent variable in the Y-axis, and T_{op} as an independent variable on the X-axis. Each point, in the graph presented in Figure 5.75, represented the mean value of thermal sensation and mean value of indoor operative temperature for each of the surveyed classrooms in the morning and afternoon period, cutting across the two seasons the fieldwork was carried out. A regression equation $TSV=0.87T_{op}-25.2$, ($r^2=0.70$) was obtained from the graph. A neutral temperature of 29.0°C was obtained, after substituting TSV with the neutrality (0) in the equation.

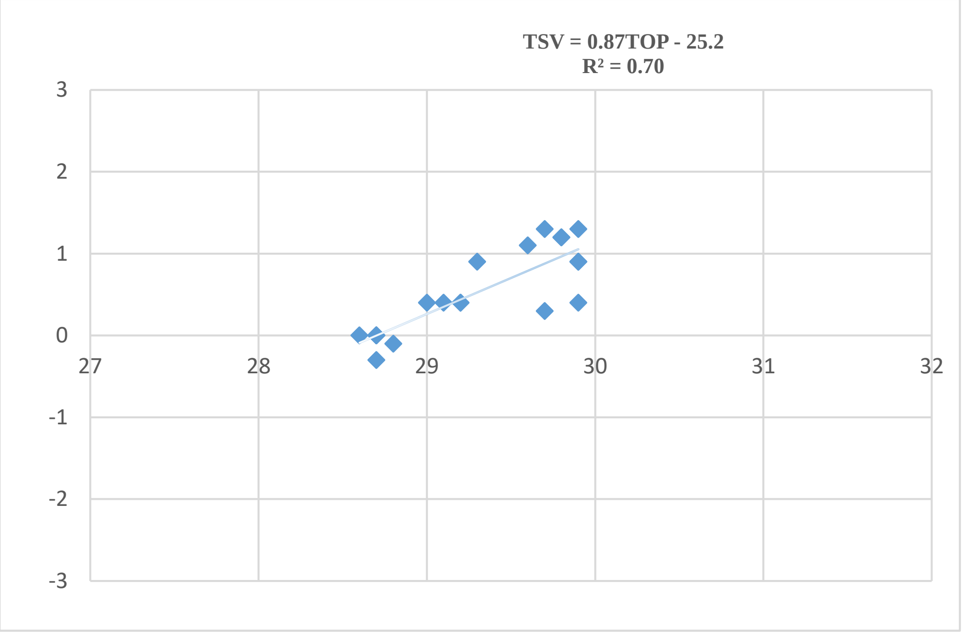


Figure 5.74: Mean thermal sensation votes of the teacher's vs classroom's operative temperature

5.4.6 **Comfort Range of Teachers**

The approach employed in ASHRAE adaptive comfort standard was used to define the indoor operative comfort range, which defines the 80% operative comfort range as -0.85≤TSV≤+0.85 . This corresponds to approximately 80% thermal satisfaction, where the Predicted Percentage of Dissatisfied (PPD) is less than 20%.

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. Based on the regression equation (TSV=0.87T_{op}-25.2) shown in Figure 5.76, a comfort range of 28.0-29.9^{o}C was produced. For comparison using a stricter acceptable temperature (90% acceptability in the range -*0.5≤TSV≤+0.5*) a comfort range of 28.4-29.5^{o}C was produced from the same regression equation. These results were for the combined classrooms all season.

5.4.7 Comfort vote of Teachers

The comfort level of the studied teachers toward the existing indoor thermal conditions in the naturally ventilated classrooms they occupy with their students are represented in the histogram in Figure 5.76. The thermal comfort votes indicated that 64% of the subjects in combined classrooms all season were comfortable with the indoor thermal condition, whereas 36% were uncomfortable.

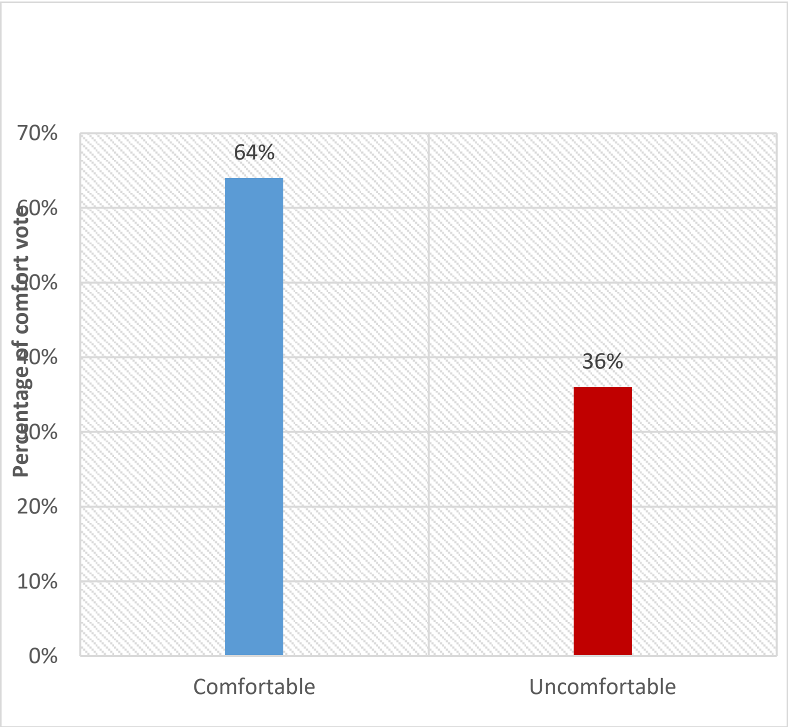


Figure 5.75: Thermal comfort votes of teachers

According to Time of Day: Generally, the teachers rated their indoor thermal conditions more comfortable in the morning hours compared to afternoon hours in both seasons 100% of the time the survey was conducted. Furthermore, 78% of the teachers voted ‘comfortable’ in the morning hours, while in the afternoon 14% of the number that voted ‘comfortable’ in the morning voted that they were ‘uncomfortable’ in the afternoon. The percentage of the teachers who voted ‘uncomfortable’ in the morning hours was 28% while in the afternoon the percentage rose to 3%, an increase of 8%.

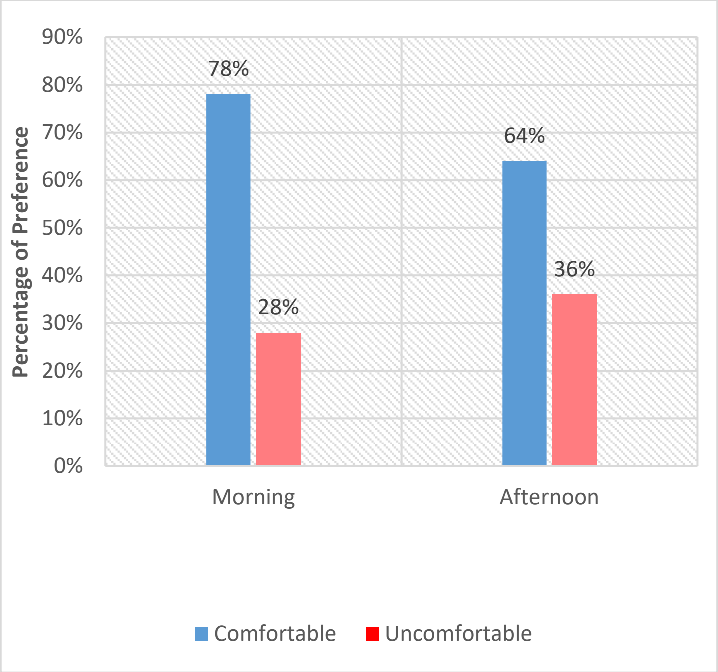


Figure 5.76: Distribution of teacher's comfort votes according to time of day

5.4.8 **Thermal Acceptability of Teachers**

The thermal acceptability question of the teachers in the surveyed classrooms was judged adopting the same questions used on children. As shown in Figure 5.78, only 35% of the teachers accepted the indoor thermal conditions while a good majority (65%) did not accept.

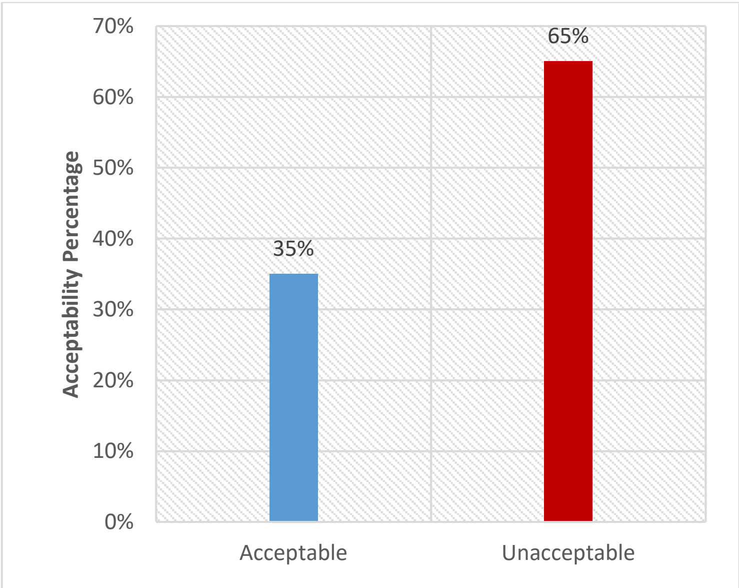


Figure 5.77: Thermal acceptability of the teachers combined classrooms all season

5.4.9 Relative Humidity Acceptability of Teachers

Teachers' responses to the humidity conditions in the classrooms based on humidity votes are represented in the histogram shown in Figure 5.79. It can be observed that 81% of the teachers felt that the humidity was comfortable, while 19% felt it was uncomfortable.

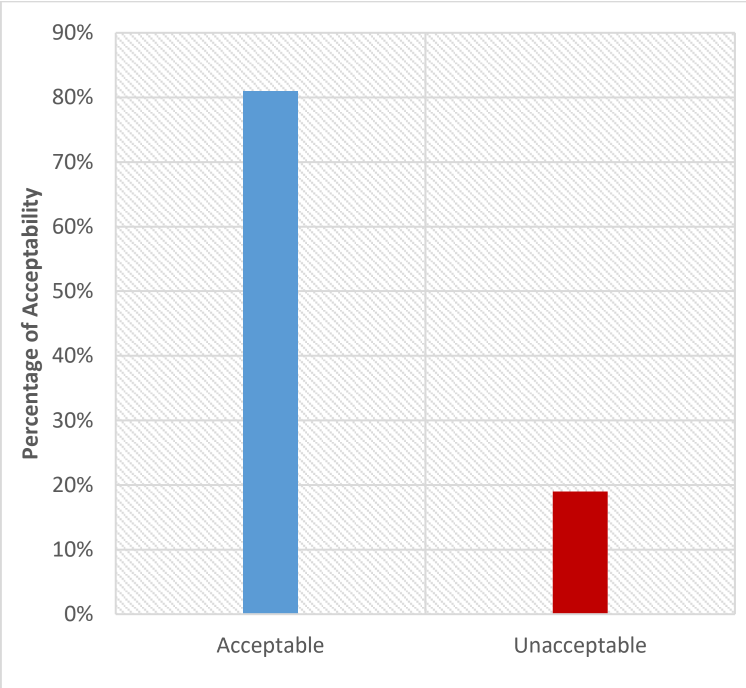


Figure 5.78: Distribution of teacher's RH acceptability combined classrooms all season

According to Time of Day: The acceptability level to relative humidity was higher in the morning hours compared to afternoon hours. While the acceptability was 80% in the morning hours, in the afternoon hours it was 64%. One would expect that as the RH increased the level acceptability would drop, as often in the case of temperature. But this trend was not observed in the relative humidity voting.

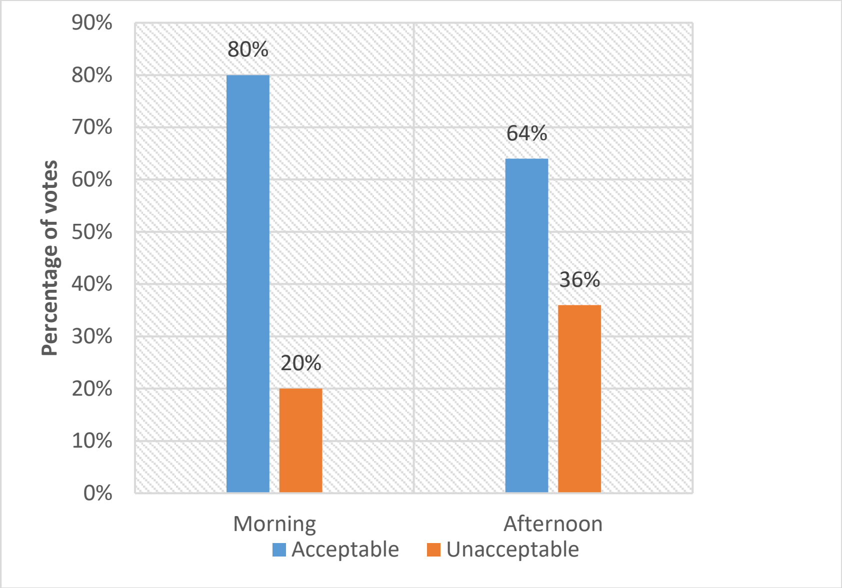
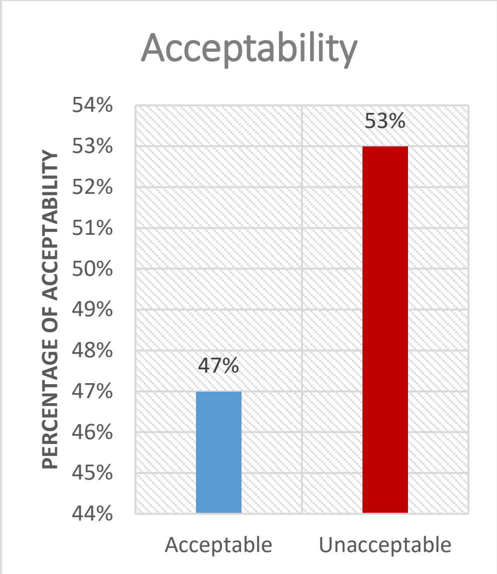


Figure 5.79: Distribution of teacher's relative humidity acceptability according to time of day

5.4.10 Air Movement Acceptability and Preference of Teachers

Teachers' responses to the airflow in the classrooms based on the indicator of air velocity assessment can be seen in Figure 5.81. The acceptability to the airflow is shown in the left side of the figure, while the preference for air is shown on the right side of the figure. It can be observed that more than half of the surveyed teachers (53%) did not accept the air flow in the classrooms. In order words, the majority of the teachers indicated that the airflow was not enough. The teachers' response to the airflow in the classrooms based on air velocity preference can be seen in Figure 5.81(right). The figure shows that the majority of the responses (56%) preferred an increased airspeed, and only 9% wanted a decrease in airspeed.



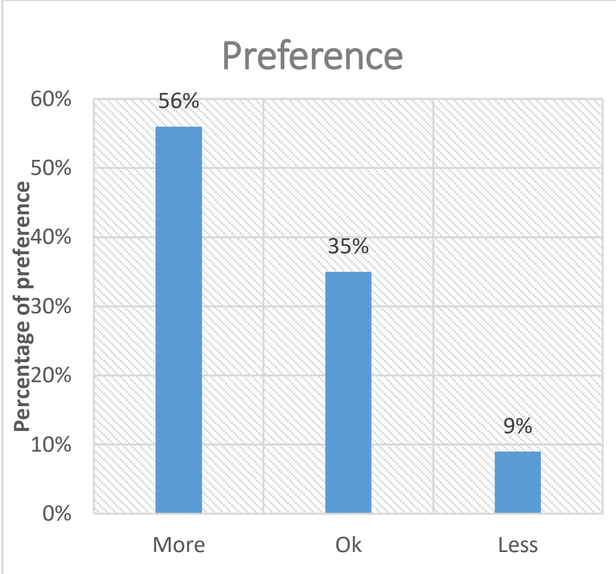


Figure 5.80: Teachers' responses to air acceptability (left) and the air preference (right)

According to Time of Day: Teachers' responses to the airflow according to time of day, as shown in Figure 5.82, indicates that the majority of the subjects preferred more airflow in the afternoon hours (72%) compared to the preference for more airflow in the morning hours (48%). The subject's preference for less air in the afternoon hours was only 7%, while in the morning hours it was 14%. More subjects accepted the airflow in the morning hours (38%) compared to afternoon hours (21%).

According to time of day, in the morning hours 72% of the surveyed teachers rather preferred the indoor thermal condition to remain as it was(okay), while 14% (each way) preferred more air and less air. In the afternoon period, the preference for more air increased from 14% in the morning to 55% in the afternoon, a significant difference of 40%. Only 6% would preferred less air in the afternoon hours.

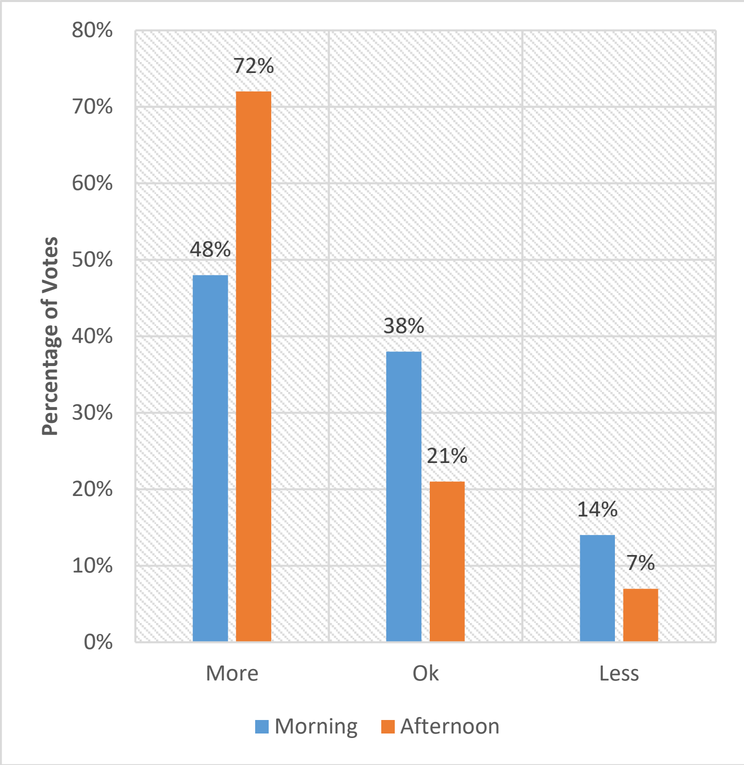


Figure 5.81: Distribution of teacher's air preference according to time of day

5.4.11 **Outlying in Comfort Votes**

The regression equation below shows the dependence of the mean comfort votes upon the mean classrooms temperatures using the combined open classroom all seasons as an example. As shown in Figure 5.83, the studied children expressed a mean thermal sensation close to -2 at the indoor mean temperature of around 24.0^{o}C. Also, circled at the upper side of the graph is an observed mean thermal sensation vote that tended towards +2.0 on the ASHRAE 7-point thermal sensation scale at the mean indoor temperature of approximately 30.0^{o}C. This mean temperature that hovered around 24.0^{o}C was far below the overall mean indoor temperature of the combined classrooms all season (29.1^{o}C) and the neutral temperature found in this study (28.8^{o}C), while the mean temperature that hovered around 30^{o}C is significantly above this overall mean indoor temperature and neutral temperature. In order words, these outlying points were not typical of the average temperature expressed by the surveyed children, and so they could not be expected to adapt to them, having found temperatures around 24^{o}C and 30^{o}C 'too cold' and 'too warm', respectively based on their comfort votes.

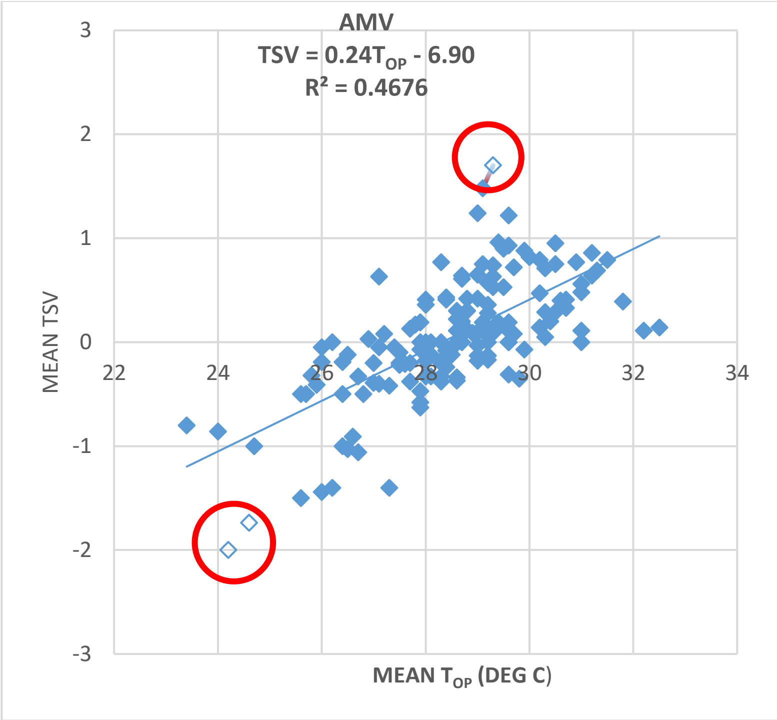


Figure 5.82: Mean Thermal Sensation votes of the Children vs Classroom's T_{OP}

5.5 What Thermal Comfort Guideline is Suitable to be Applied in the Study Area? (Objective v)

This section does not intend to usurp the duty of the various international and local bodies responsible for recommending various indoor thermal comfort standards. Rather, this work intends to highlight some relevant findings, from the field work, that may provide some useful information to the research world. The worldwide awareness of the need to address the high level of energy consumption in buildings draws attention to the need to consider adaptation in naturally ventilation buildings which can help to achieve sustainable buildings. Excessive heat in indoor spaces has been acknowledged by researchers as capable of causing ill health. In UK, for example, there is no statutory maximum internal temperature in the current UK building regulations, rather a methodology for determining the upper threshold temperature beyond which normal adaptive actions will be insufficient to restore personal comfort is set (Butcher, 2014). The information provided in this guideline is based on the result of the field work that focused on adaptation. Building codes that reflect thermal comfort are required to be embedded in design guides of schools. When these guidelines are not available, it becomes a big challenge to facility managers to define the various range of temperatures building occupants can find comfortable. In addition, with these guidelines, a large amount of energy can be saved by appropriate application of design requirements that consider thermal comfort range of acceptable temperatures. Furthermore, the information may be necessary in the current review of the Nigerian Building Code (NBC) which is yet to consider the comfort requirements of children and schools.

Nigeria has different climatic classifications, with this study area falling within the warm and humid climate. There is a need for researchers to conduct survey in schools located in the other climatic regions in order to compile a comprehensive data to be used as a unified guideline of thermal comfort requirements in primary schools in Nigeria. However, in trying to provide a unified comfort standard for school children, one has to be cautious. From the study of comfort requirements for adults in Nigeria, already conducted by researchers, one can observe from their various findings, the comfort requirements for adults differ according to climatic zone. In that case, a unified comfort requirement of adults in the country may not be likely. Another example of a country where thermal comfort requirements were found to differ from one city to another is Indonesia. For example, (Arsandrie, Kurvers, Bokel, & Van der Linden, 2012) found a neutral temperature of 32.5^{o}C in Surakarta, while other researchers found various neutral temperatures; Bandung (24.7^{o}C), Jakarta (27.2^{o}C), and in Yogyakarta (29.2^{o}C). All these cities are located in Indonesia.

Not having a specific thermal comfort requirement of a group of people in an indoor environment has been the position of the supporters of adaptive thermal comfort based on their various findings. Future research work to determine the comfort requirements of primary school children in the other climatic zones in Nigeria will indicate if the results follow the same trend with that of adults.

This study, therefore, recommends thermal comfort requirements for primary school children in the warm and humid climate in Nigeria. However, it is important to equally acknowledge that the study that focused on the warm and humid climate of Imo State, Nigeria may not be a 100% reflection of the thermal comfort requirements of the other remaining states in the climatic zone. Presented below are the list of recommendations which cuts across the seasons; rainy season and dry season. A unified standard is for the two seasons having observed no significant difference in thermal perception and the dressing habit of the studied children in these two seasons. The guidelines suggested in this paper are applicable to naturally ventilated classroom blocks and the indoor environment in the classrooms. These may be updated based on future research.

5.5.1 Classroom Buildings

The classroom block has to be naturally ventilated and will also be assessed based on adaptation defined by (Kwok & Rajkovich, 2010) as a 'design approach that relies on an implicit understanding of the ecological and physical context of the site, orientation, site planning, passive heating, cooling design strategies, openings in the envelope for optimal daylight and natural ventilation, shading, insulation and envelope strategies. The following are other basic requirements recommended to be considered when designing classroom buildings in the warm and humid climate in Nigeria:

- Adaptive actions such as drinking water, adjustment in clothing, closing and opening of doors and windows (where applicable) should be considered.
- The design of roof overhangs should not be less than 1.2 meters in order to prevent solar radiation from striking a large portion of the walls.
- Polyvinyl Chloride Ceiling (PVC) are to be installed to reduce thermal gain inside buildings.
- Complementary ventilation device for sun shading such as corridors and entrance foyer should be considered

Buildings that comply with the above requirements will then be considered for subsequent analysis regarding acceptable indoor thermal conditions.

5.5.2 Acceptable Indoor Conditions

Comfort Range: Schoolchildren in the warm and humid area of Nigeria are capable of being comfortable in naturally ventilated classrooms in the range of temperatures between 25.8 to 31.6^{o}C, irrespective of the time of day.

Maximum acceptable temperature: The maximum temperature the school children can accept is 31.6^{o}C. Beyond this temperature they may feel heat stress. Thus, this temperature is proposed as the overheating benchmark.

Minimum temperature: The minimum temperature the schoolchildren can accept is 25.8^{o}C. Below this temperature hypothermia may set in.

Optimum temperature: The optimum temperature of the schoolchildren is 28.8^{o}C

Preferred temperature: The preferred temperature of the children is 27.4°C. However, it is recommended that optimum temperature be used as the comfort standard rather than using the preferred temperature. This will help in energy saving.

Range of relative humidity: The acceptable range of relative humidity is between the range 45.2% to 91.6% at 80% occupant (schoolchildren) satisfaction.

Air velocity: The maximum limit of acceptable indoor air velocity could not be defined because the maximum mean indoor air velocity did not exceed 0.3m/s. However, this maximum value was accepted by the studied children and were willing to accept higher air velocity. Fans can be used to enhance indoor air flow.

There is no doubt that even when the temperature is within these acceptable range the children may be under some thermal stress while in school. They may need additional techniques to adapt to in order to maintain the comfort during the extreme weather conditions. As additional recommendation other sustainable measures, such as planting more trees in the schools, will help to cut off direct sun radiation and aid in air circulation.

5.6 **Chapter Summary**

The analysis of the fieldwork presented in this chapter has shown that the thermal performance in the two types of classrooms used in the survey performed differently. Of the two types of classrooms, the 'open-space' classrooms performed better than the 'enclosed-plan' classrooms.

ASHRAE Standard 55 recommends that an adaptive approach should not apply in surveys where the maximum and minimum outdoor temperatures are outside the range 10.0-33.5°C. However, results from this fieldwork indicate that the maximum and minimum outdoor temperatures were within this range.

Another key finding in this work is that the indoor operative temperature, in the classrooms irrespective of the season, occurred most frequently within the range 27-30°C.

This work is consistent with some previous works that came out with findings that occupants who live in a warm and humid climate can acclimatize to the local environment they are used to. Result and analysis of the fieldwork showed that the optimum temperature, the preferred temperature and the comfort range of the subjects were within the temperature range (27-30°C) mostly observed during the survey, irrespective of the season or classroom-type

The mean outdoor temperatures in each of the surveyed classrooms correlated strongly with the corresponding mean indoor operative temperatures. However, some classrooms displayed higher coloniality than others. The result indicated that as the mean outdoor temperature was increasing or decreasing the mean indoor operative temperature in each of the surveyed classrooms followed suite.

The thermal sensation votes (AMV) of the schoolchildren strongly correlated with the indoor operative temperature and with the neutral temperature in most of the indoor space, and poorly correlated with relative humidity.

Results in this chapter indicated that when the respective prevailing mean indoor temperatures, mean outdoor temperatures, and the mean air velocity of the classrooms were inputted into the CBE comfort tool, all the surveyed classrooms complied with the 80% acceptability comfort range prescribed by ASHRAE Standard 55. The exceptions were classrooms A_{OP} and A_{EN} (during the dry season). However, these two classrooms complied when the indoor air velocity was elevated to 0.3m/s (at 80% acceptability criterion). The finding indicates that the adaptive thermal comfort applies to primary school classrooms in the study area.

The observed air velocity during the survey was generally low, with 0.3m/s as the maximum mean value, However, this could not be confirmed with certainty since the instrument used for the measurement was not logged continuously as was done in temperature and humidity measurements. However, rigorous spot measurements taken at different positions in the surveyed classrooms provided some level of reliable evidence enough to be used for analysis. Low air velocity was also reported by previous thermal comfort researchers who conducted research works in the same climate.

Finally, the result from this work clearly showed that the thermal perception of the schoolchildren differed from that of their teachers who stayed in the same indoor environment with them.

6 Chapter 6: Discussion

6.1 Introduction

This Chapter discusses how the results obtained from the field survey relate to the research objectives of this work. These were discussed in five sections.

Section 6.1 introduced chapter 6

Section 6.2 discusses the results and analysis of the thermal performance in 'open-space' and 'enclosed-plan' classrooms and with focus on adaptive thermal comfort (objective i)

Section 6.3 discusses the results of the relationship between the measured thermal variables and the children's thermal comfort perception (objectives ii-iii)

Section 6.4 discusses the results and analysis of the teachers' perception of thermal environment and compares the findings with that of the children's thermal perception (objective iv)

Section 6.5 summarizes chapter 6

6.2 Relationship in the Thermal Performance Between the Two Types of Classrooms and Comparison with Adaptive Thermal Comfort (Objective i)

The first objective of this study was to examine the relationship in the thermal performance of naturally ventilated 'open-space' and 'enclosed plan' classrooms, and to compare their thermal performance to the adaptive thermal comfort. This objective was achieved through the analysis of the measured thermal variables in the classrooms, and the comparison of these variables with the adaptive thermal comfort. The results and analysis of the measured thermal variables and subjective data presented in Chapter 5 are discussed in the subsequent section.

6.2.1 Thermal Variables in the Two types of Classroom Building

Tables 5.2 to 5.5 of Chapter 5 showed some evidence of difference in the thermal performance between the 'open-space' and 'enclosed-plan' classrooms. For example, the range in the indoor air temperature in the combined 'open-space' classrooms was wider that the range in the combined 'enclosed-plan' classrooms. While the range in the combined 'open-space' classroom was 14.4K, that of the combined 'enclosed-plan' classroom was 10.7K, a difference of 3.7K in range between these two types of classroom buildings. The difference in the mean values in relative humidity between the two classroom types is 5.7%. Also, the range in the indoor air velocity also differed between the two categories of classrooms. The reason for the differences in the thermal performance in these two types of classrooms is likely linked to the differences in their architectural compositions. The façade of the two types of classrooms differed significantly. The Coefficient of Variation (CV) was further used to compare the difference between these two types of classrooms. There was more variability (CV) in thermal variables in the 'open-space' classrooms compared to the one found in the 'enclosed-plan' classrooms. For instance, Table 5.2 of Chapter 5 suggested that in the combined 'open-space' classrooms, the variability in indoor temperature was 5.2% while in the combined 'enclosed-plan' classrooms it was 4.8%. Also, the variabilities in the indoor relative humidity were 1.8% and 1.6% in the combined 'open-space' classrooms and combined 'enclosed-plan' classrooms, respectively.

Furthermore, considering the thermal performance of the classrooms on each individual basis, it can be observed in Table 5.3 of Chapter 5 that during the rainy season, the minimum temperature in classrooms A_{OP} was 21.2°C, while the minimum temperature in the corresponding classroom, A_{EN}, was 22.9°C. The difference between the maximum indoor temperature and the minimum temperature in classroom A_{OP} during the rainy season was 13.5k, while the difference in classroom A_{EN} was 11.8k. In dry season, the differences were 13.0k and 8.9K in classrooms A_{OP} and A_{EN}, respectively. In classroom B_{OP}, the difference was 8.3K in the rainy season survey, but the difference in the corresponding classroom B_{EN} was 6.5k. In the dry season survey, 7.7K and 4.7k were observed as the differences in classrooms B_{OP} and B_{EN}, respectively. However, in school C, the differences in the maximum indoor temperature and the minimum indoor temperature between these two types of classrooms were marginal for both seasons; 0.2K in rainy season and 0.2K in dry season. In school B, classroom B_{OP} recorded 34.2°C as the maximum indoor temperature while classroom B_{EN} the maximum temperature recorded was 31.5°C.

Some differences in the thermal performance between these two types of classrooms were also observed according to time of day. For example, the indoor spaces in the combined 'open-space' (A_{OP}) classrooms recorded lower indoor temperatures in the morning hours when compared to the indoors of the combined 'enclosed-plan' (A_{EN}) classrooms at the same time period, as shown in Figure 6.1. The reason for the differences in the thermal behaviour between these two types of classrooms at this period of the day (morning hours) is partly linked to the effect of night cooling on the immediate environment. The 'open-space' classrooms took advantage of their open façade to flush out pockets of heat retained the previous day, by cross-ventilating the spaces with cool air at night. The 'enclosed-plan' classrooms did not take good advantage of this, because the doors and windows were closed after their use, thereby retaining some of the heat accumulated the previous day. As a result, subjects coming into the classrooms in the morning hours felt cooler in the ‘open-space’ classrooms compared to those in the ‘enclosed-plan’ classrooms. However, the thermal sensation expressed by the children changed as mid-day approached. The children in the open-space classrooms at this period felt warmer. This is because the indoor temperatures in the ‘open-space’ classrooms reported higher values at that period (mid-day to afternoon) compared to that observed in the ‘enclosed-plan’ classrooms as shown in Figure 6.2.

Further analysis was conducted between the daily mean indoor operative temperatures of these two types of classrooms using sampled *t*-test to investigate if the samples from the two types of classrooms are statistically different from each other. Comparing the mean daily indoor temperatures of the two types of classrooms yielded a p-value > 0.05 at 95 % confidence interval (difference in mean was -0.3538). In addition, the differences in the thermal variables presented in the histograms in Figures 5.3 to 5.10 are further evidences of the difference in the thermal performance of the two types of classrooms. These findings showed that the thermal performance between these two types of classrooms differed considerably.

10-25-2017 07:58:00	27.635 °C	10-25-2017 07:58	27.872 °C	10/25/2017 07:58:00	28.626 °C
10-25-2017 08:03:00	27.650 °C	10-25-2017 08:03	27.961 °C	10/25/2017 08:03:00	28.548 °C
10-25-2017 08:08:00	27.692 °C	10-25-2017 08:08	28.019 °C	10/25/2017 08:08:00	28.415 °C
10-25-2017 08:13:00	27.790 °C	10-25-2017 08:13	28.146 °C	10/25/2017 08:13:00	28.295 °C
10-25-2017 08:18:00	27.882 °C	10-25-2017 08:18	28.213 °C	10/25/2017 08:18:00	28.272 °C
10-25-2017 08:23:00	28.006 °C	10-25-2017 08:23	28.224 °C	10/25/2017 08:23:00	28.251 °C
10-25-2017 08:28:00	28.095 °C	10-25-2017 08:28	28.183 °C	10/25/2017 08:28:00	28.237 °C
10-25-2017 08:33:00	28.164 °C	10-25-2017 08:33	28.212 °C	10/25/2017 08:33:00	28.248 °C
10-25-2017 08:38:00	28.195 °C	10-25-2017 08:38	28.218 °C	10/25/2017 08:38:00	28.284 °C
10-25-2017 08:43:00	28.236 °C	10-25-2017 08:43	28.192 °C	10/25/2017 08:43:00	28.278 °C
10-25-2017 08:48:00	28.301 °C	10-25-2017 08:48	28.284 °C	10/25/2017 08:48:00	28.327 °C
10-25-2017 08:53:00	28.363 °C	10-25-2017 08:53	28.565 °C	10/25/2017 08:53:00	28.446 °C
10-25-2017 08:58:00	28.490 °C	10-25-2017 08:58	28.862 °C	10/25/2017 08:58:00	28.530 °C
10-25-2017 09:03:00	28.661 °C	10-25-2017 09:03	29.150 °C	10/25/2017 09:03:00	28.599 °C
10-25-2017 09:08:00	28.804 °C	10-25-2017 09:08	29.447 °C	10/25/2017 09:08:00	28.683 °C

Figure 6.1: Morning: T_{OP} classroom B_{OP} (left side), outdoor temperature (middle), T_{OP} classroom B_{EN} (Right side)

10-25-2017 10:03:00	29.905 °C
10-25-2017 10:08:00	29.819 °C
10-25-2017 10:13:00	29.937 °C
10-25-2017 10:18:00	30.049 °C
10-25-2017 10:23:00	30.037 °C
10-25-2017 10:28:00	29.973 °C
10-25-2017 10:33:00	29.861 °C
10-25-2017 10:38:00	29.835 °C
10-25-2017 10:43:00	29.913 °C
10-25-2017 10:48:00	30.040 °C
10-25-2017 10:53:00	30.002 °C
10-25-2017 10:58:00	29.888 °C
10-25-2017 11:03:00	29.925 °C
10-25-2017 11:08:00	30.047 °C
10-25-2017 11:13:00	30.211 °C

10-25-2017 10:03	30.780 °C
10-25-2017 10:08	30.680 °C
10-25-2017 10:13	30.867 °C
10-25-2017 10:18	30.728 °C
10-25-2017 10:23	30.549 °C
10-25-2017 10:28	30.667 °C
10-25-2017 10:33	30.427 °C
10-25-2017 10:38	30.552 °C
10-25-2017 10:43	30.800 °C
10-25-2017 10:48	30.904 °C
10-25-2017 10:53	30.583 °C
10-25-2017 10:58	30.609 °C
10-25-2017 11:03	30.830 °C
10-25-2017 11:08	31.086 °C
10-25-2017 11:13	31.284 °C

10/25/2017 10:03:00	29.385 °C
10/25/2017 10:08:00	29.631 °C
10/25/2017 10:13:00	29.820 °C
10/25/2017 10:18:00	30.003 °C
10/25/2017 10:23:00	30.134 °C
10/25/2017 10:28:00	30.243 °C
10/25/2017 10:33:00	30.395 °C
10/25/2017 10:38:00	30.508 °C
10/25/2017 10:43:00	30.597 °C
10/25/2017 10:48:00	30.664 °C
10/25/2017 10:53:00	30.772 °C
10/25/2017 10:58:00	30.864 °C
10/25/2017 11:03:00	30.926 °C
10/25/2017 11:08:00	30.975 °C
10/25/2017 11:13:00	31.087 °C

Figure 6.2: Mid-day**:** T_{OP} classroom B_{OP} (left side), Outdoor temperature (middle), T_{OP} classroom B_{EN} (right side))

However, some similarities were observed in the thermal performance in these two types of classrooms as can be seen in Tables 5.6 to 5.8 of Chapter 5. For example, in school A during the rainy season, the ‘open-space’ and the ‘enclosed-plan’ classrooms reported maximum indoor temperature on the same day (Oct 12) and between the same period (3.25 pm-4.40 pm). The two types of classrooms, in the same season, also recorded minimum indoor temperatures on the same day and at the same time. In the dry season, in the same school, the two types of classrooms reported minimum indoor temperatures on the same day and at the same time. In school B, the observed indoor temperatures in both types of classrooms recorded minimum temperatures on the same date (Nov 1). Also in this school, the two types of classrooms recorded their maximum temperatures on the same day (Oct 25). These were during the rainy season. In the dry season in the same school, both types of classrooms reported maximum temperatures the same day (April 5). Furthermore, both types of classrooms reported lowest indoor temperature on the same day (Oct 16) in the morning hours. Furthermore, in school C both types of classrooms reported highest temperature on the same day May 23 and at the same time in rainy season and on the same date (Jan 28) at the same time in dry season.

6.2.2 Comparison with Adaptive Thermal Comfort

Part of objective one of this study was to compare the thermal performance in these classrooms with the Adaptive Thermal Comfort Model. To achieve this, two approaches were adopted. The first approach determined the compliance of these naturally ventilated classrooms with ASHRAE Standard 55. The mean indoor operative temperature, the prevailing mean outdoor temperature and the airspeed were used to determine the extent of their compliance with the adaptive thermal comfort model. The results were earlier presented in section 5.2.3 of Chapter 5. The second approach determined the extent of relationship between the mean indoor temperatures and the mean outdoor temperatures in these classrooms, using correlation analysis. The results were also presented in section 5.2.4 of Chapter 5. The subsequent sections discuss these results.

Compliance with ASHRAE Adaptive Comfort Model

Table 6.1 summarizes the result and analysis of the degree of compliance of the surveyed classrooms to 80% (primary consideration) and 90% acceptability of the adaptive comfort model of ASHRAE Standard 55. Results of the analysis indicate that irrespective of the season, the surveyed classrooms in school B showed compliance with ASHRAE standard 55 at the mean indoor air velocity prevailing at the time of the survey. That means, even at lower mean indoor air velocity in this school (when compared to the other two schools), the surveyed classrooms in school B still showed 100% compliance with the standard. The reason could be because of the periods the surveys were conducted in school B. The rainy season survey in school B was conducted in November, towards the end of the rainy season. During the survey, this period witnessed persistent rainfall leading to generally lower daily mean indoor temperature (when compared to the other two schools) as earlier represented in a histogram in Figure 5.7 of Chapter 5. The dry season survey also witnessed lower daily mean indoor temperatures as presented in the histogram in Figure 5.9 of Chapter 5. In school A, classrooms A_{OP} and A_{EN} complied to the standard during the rainy season as summarized in Table 6.1. These two classrooms, however, failed compliance during the dry season. That means 50% compliance was achieved in school A (considering both seasons) at the prevailing mean indoor air velocity. Further check in Table 6.1 gave a hint of what could be the possible reason for the inability of classrooms A_{OP} and A_{EN} to comply to the standard at the prevailing indoor air velocity. The indoor and outdoor temperatures experienced in these classrooms in the dry season were high. The dry season survey in school A was conducted in February, one of the warmest months of the year. In school C, both classrooms failed compliance during the rainy season. Under the prevailing mean indoor air velocity, classrooms C_{OP} and C_{EN} also failed compliance during the dry season. That shows 25% compliance was met by the classrooms in this school at the prevailing indoor air velocity. However, at an elevated indoor air velocity 0.3m/s, using the Centre for the Built Environment Thermal Comfort Tool recommended by ASHRAE standard 55, (ASHRAE, 2017), classrooms A_{OP} and A_{EN} (dry season), classroom C_{OP} (rainy season) and classrooms C_{EN} (rainy and dry seasons) all complied.

Table 6. 1. Summary of compliance with ASHRAE Standard 55

Classroom Type	Season	Prevailing mean temp (°C)		Air movement for compliance (m/s)	
		Indoor	Outdoor	80% Compliance as primary consideration (Prevailing air velocity)	80% Compliance Elevated air velocity (≥0.3)
A_{OP}	Rainy	28.6	29.2	0.27√	-
	Dry	29.4	29.6	0.18x	0.3√
A_{EN}	Rainy	28.7	29.2	0.21√	-
	Dry	29.5	29.6	0.20x	0.3√
B_{OP}	Rainy	28.2	28.6	0.19√	-
	Dry	28.9	29.1	0.11√	-
B_{EN}	Rainy	28.3	28.6	0.12√	-
	Dry	28.9	29.1	0.16√	-
C_{OP}	Rainy	28.7	29.4	0.17 x	0.3
	Dry	28.8	29.1	0.15√	-
C_{EN}	Rainy	29.2	29.4	0.30 x	0.3
	Dry	29.0	29.1	0.25 x	0.3

√ *Indicating compliance and* x *indicating non-compliance*

In summary, the results indicates that the ASHRAE Standard 55 adaptive comfort model is very applicable to the studied classrooms. Since these classrooms are representatives of primary school classrooms in the study area, it is most likely that the model will be applicable to naturally ventilated classrooms in the warm and humid climate zones of Nigeria. With adequate provision of shading devices (as was found in the studied classrooms) and with proper designs that can take good advantage of air flow (though observed to be low), there is every likelihood that occupants of spaces in the primary schools located in the warm and humid zones in Nigeria will be comfortable without the use of air-conditioning systems. Apart from air conditioning systems depositing carbon in the atmosphere, they are also expensive to run and to maintain. The findings from this work show the importance of air velocity to enhance thermal comfort, agreeing with the results of the findings from previous works such as (Boerstra et al., 2015). ASHRAE Standard 55 recommends air speed of up to 0.8m/s to achieve improved thermal sensation in naturally ventilated buildings (Hwang et al., 2009). However, providing this level of airflow in the study area can only be achieved with the use of fans. This might not be a good option because of the cost and the non-availability of electricity to power the fans when needed. For air velocity higher than 0.3m/s, based on field data collected, it will be rare to have an air speed more than that value on a prolonged period in the study areas. However, this cannot be confirmed with certainty since it was not possible to record the airspeed on a continuous basis at the same time as the operative temperature and the indoor relative humidity. However, fieldworks conducted by (Efeoma, 2017) and Okafor (2016) in the same climatic zone with this study confirmed the generally low air velocity in the study area.

Relationship between Indoor operative temperature and Outdoor Temperature

As presented in Chapter 5, a strong relationship was found between these two variables (indoor and outdoor temperatures) for the combined classrooms all season, with a Pearson correlation of 0.82 which is statistically significant at 0.03 (p-value < 0.05). The correlation coefficient also means that some 67% of the variation in indoor operative temperature could be explained in terms of the outdoor temperature alone in the combined classrooms all season. The relationship found in each of the studied classrooms is also summarized in Table 6.2.

Furthermore, results presented in Table 6.2 indicates that all the surveyed classrooms have correlation significance less than 0.05, with positive Pearson correlation, except classrooms C_{OP} and C_{EN} which exhibited correlation significances with a values higher than 0.05 (during the dry season). Apart from this classroom, the relationship found in the other classrooms suggests that an increase in the outdoor temperature also resulted to an increase in the indoor temperature in the surveyed classrooms. Furthermore, the classrooms in School B reported the highest correlation in the two seasons compared to the classrooms in the other two schools (schools A and C). As further shown in Table 5.9 of Chapter 5, classrooms B_{OP} and B_{EN} exhibited the strongest indoor-to-outdoor with Pearson correlation values .947 and .918, respectively. The strong relationship in these classrooms were observed in the rainy season. This strong correlation in school B may be related to the steady indoor operative temperatures in the months of November (in rainy season) and in April (in dry season). The classrooms in schools A (A_{EN}) and C (C_{EN}) reported the lowest correlation and that was during the dry season. This may be related to the periods both surveys were conducted. While the dry season survey in school A was conducted in the month of February, that of school C was conducted in the month of January. In the study area, the months of January and February are characterized by high variations in indoor operative temperatures and are usually hot periods of the year. The low correlation between the indoor temperature and the outdoor temperature is an indication that the indoor temperatures in both classrooms were not in close agreement with fluctuations in temperature. The results of the first method used to determine the thermal performance of the surveyed classrooms were consistent with the outcome of this second approach.

According to Season: In the surveyed classrooms, there were higher correlations between the indoor operative temperatures and the outdoor temperatures during the rainy season compared with dry season, irrespective of the classroom type. This suggested that the indoor operative temperature related closer to the outdoor temperature in the rainy season compared with the dry season. Similar finding was observed by (Nguyen, Schwartz, & Dockery, 2014) who observed stronger correlation at warmer outdoor temperature in a thermal comfort study.

According to Building Type: The indoor temperatures in the 'open-space' classrooms showed higher collinearity with the outdoor temperatures when compared to the 'enclosed-plan' classrooms. The reason could be linked to the differences in the building characteristics of the classrooms. The 'open-space' classrooms were more connected to the outdoor because of the open facade concept. Apparently, this closeness influenced the strong relationship between the indoor temperature and the outdoor temperature. In free running buildings, the relationship between the indoor and outdoor temperature is largely decided by the form and materials of the building (F. Nicol et al., 2012; J Fergus Nicol & Roaf, 2017).

Table 6. 2. Summary of correlation between the indoor and outdoor temperature

Classrooms	Season	2-tailed significant	Remarks
A_{OP}	Rainy	**0.000 (<0.05)**	✓
	Dry	**0.001 (<0.05)**	✓
A_{EN}	Rainy	**0.000 (<0.05)**	✓
	Dry	**0.042 (<0.05)**	✓
B_{OP}	Rainy	**0.000 (<0.05)**	✓
	Dry	**0.008 (<0.05)**	✓
B_{EN}	Rainy	**0.000 (<0.05)**	✓
	Dry	**0.000 (<0.05)**	✓
C_{OP}	Rainy	**0.000 (<0.05)**	✓
	Dry	0.060 **(>0.05)**	X
C_{EN}	Rainy	**0.000 (<0.05)**	✓
	Dry	0.205 **(>0.05)**	X
All	All	0.03 **(<0.05)**	✓

z ✓

✓ *Indicates statistical significant correlation,* × *shows no significance*

6.3 Relationship Between the Measured Thermal Variables and the Thermal Perception of the Children, and Comparison with Previous Works (Objectives ii – iii).

***The second* objective** was to examine and compare the relationship between measured thermal variables and subjective comfort responses of the children. This objective was achieved by using the comfort votes to judge how comfortable the subjects felt at the prevailing indoor operative temperatures, taking into consideration the 80% ASHRAE Standard minimum requirement for judging an indoor environment comfortable. Comfort votes can be used to judge how comfortable or uncomfortable building occupants feel about the indoor thermal conditions (Kwok et al., 1998). This is discussed under section 6.3.1 of this Chapter.

The third objective was to determine the thermal perception of the children and to compare the results from this work with the prescriptions of ASHRAE Standard 55 and with previous works. This very objective was discussed under section 6.3.2 of this Chapter.

6.3.1 Measured Thermal Variables vs Children's Comfort Votes

From the results presented in Table 5.23 and illustrated in the histogram in Figure 5.60 of Chapter 5, approximately 70% of the studied children in combined classrooms all season voted 'comfortable' at a mean indoor operative temperature of 29.1^{o}C. ASHRAE standard 55 considers an indoor thermal environment satisfactory when 80% or more of the occupants vote 'comfortable' on the comfort scale. Based on this premise, the mean indoor temperature in the combined classroom all season is found to be comfortable only to 70% of the studied children. Furthermore, the histogram shown in Figure 6.3 displays the range of temperatures the studied children rated their comfort condition. The Figure clearly shows that the highest vote on 'comfortable' were observed at the temperature ranges between 26-28^{o}C and 28-30^{o}C, where 73% and 67% of the subjects, respectively voted 'comfortable'. This suggests that at these temperatures the majority of subjects found them comfortable. Furthermore, at the range of temperature from 26-30^{o}C the majority of the subjects voted comfortable, the neutral temperature, the preferred temperature and the subjects comfort range lie within this range. This further suggests that the subjects were consistent in their pattern of voting while expressing how they felt to the indoor thermal conditions. The findings support the adaptive hypotheses which posits that people tend to be adapted at the temperatures they are more accustomed to.

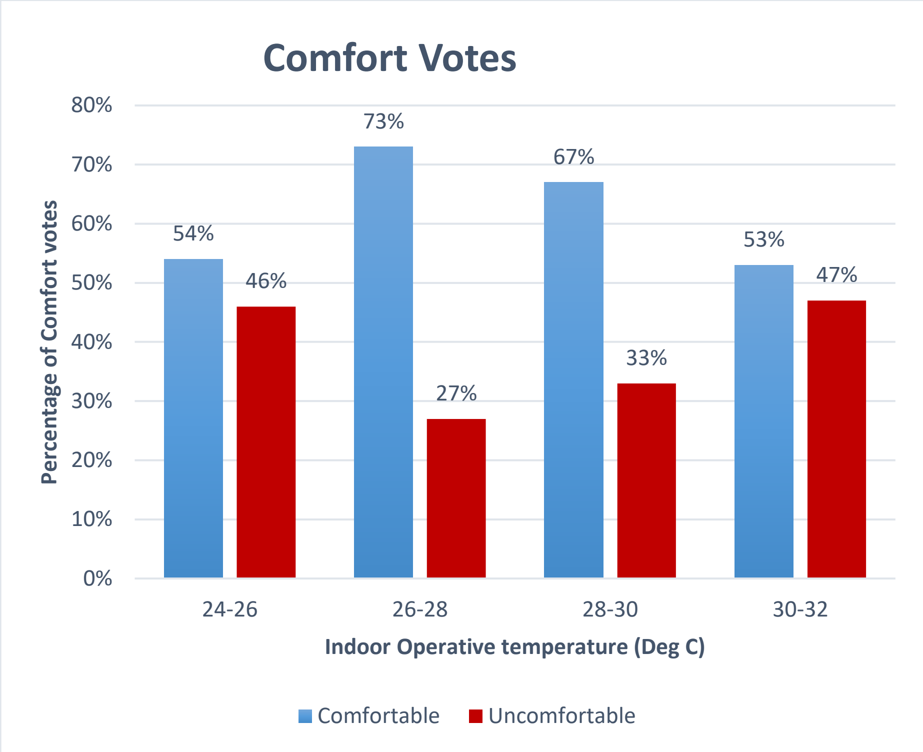


Figure 6.3: Comfort votes vs range of indoor operative temperature

According to Season: The results of the thermal comfort vote shown in Figure 5.61 of Chapter 5, suggested that a majority of the children were comfortable with the indoor thermal conditions. However, the subjects were more comfortable during the rainy season than during the dry season. However, based on the 80% comfort limit, the children can be adjudged as being 'uncomfortable' during the two seasons. The result justifies the importance of investigating subjects' thermal perception according to season. This will help to differentiate building occupants' thermal needs based on season, and will help to plan energy use in buildings. Furthermore, a check at the mean indoor temperatures reported in these surveyed classrooms according to the season gave an insight on the reason for the differences in the subjects' comfort vote according to season. The mean indoor operative temperature in the rainy season was lower than that found in the dry season, though the difference did not vary significantly. The subjects' votes on 'comfortable' may have been probably enhanced by the higher indoor air velocity expressed by the occupants during the rainy season and the cold brought by the continuous rainfall. The cold reduced the heat spell.

Another observation in the comfort vote according to the season is that the neutral temperature, the preferred temperature and the comfort range of the subjects in the two seasons were approximately 95% within the temperature range of 26-30°C that occurred most frequently during the survey. Temperatures within this range were mostly observed in the surveyed classrooms as evidenced in the retrieved data from the dataloggers summarized in the histograms in Figures 5.31, 5.36 and 5.41 of Chapter 5. The results further suggested that the studied children seemed to have adapted to the temperatures within this range which they were most accustomed to, irrespective of the season, classroom-type and time of day.

Table 6. 3. Summary of thermal comfort votes on different categories

All classrooms	**Both**	**70 %**	**30%**
All classrooms	Rainy	82%	18%
All classrooms	Dry	66%	34%
Morning hours	Both	77%	23%
Afternoon hours	Both	59%	41%
Open classrooms	Both	78%	22%
Enclosed classrooms	Both	62%	38%

According to time of day: The results shows a clear shift in the comfort votes from ‘comfortable’ in the morning hours to ‘uncomfortable’ in the afternoon hours. Precisely, 23% of the subjects who voted ‘comfortable’ in the morning hours voted ‘uncomfortable’ in the afternoon hours. A check at the mean indoor temperatures observed in both periods of the day irrespective of the classroom type, as shown in Figures 5.32, 5.33, 5.38, 5.39, 5.42 and 5.43 of Chapter 5, explained the reason for the shift in the comfort votes. The afternoon periods in the surveyed classrooms in all the schools were generally warmer than the morning periods. The same trend in the increase in temperature in occupied zones was equally observed by Saleem, Abel-Rahman, Ali, & Ookawara (2016) in a fieldwork conducted in naturally ventilated primary school cleanrooms in Egypt. The researcher observed a steady increase in operative temperature that ranged from 25.5°C (in the morning hours) to 34.5°C (in the afternoon hours). Furthermore, Karyono (2000) reported higher neutral temperature in the afternoon survey; at 9 am the temperature was 25.5°C while at 1pm the temperature was 27.5°C. Higher neutral temperature in the afternoon was earlier found by Mackowiak, Wasserman, & Levine (1992) in a survey conducted in a naturally ventilated building. The reason given by the researchers for the higher temperature at that time of the day is the Circadian rhythm of human core temperature that peaks during the afternoon. Part of the reason for this higher neutral temperature (in the afternoon) could be this variation in body setpoint temperature. This thermal behaviour obviously had an influence in the direction of comfort votes of the subjects at these two periods of the day. However, when the indoor temperature had an increase in the afternoon hours, some of the subjects still found the indoor environment comfortable. This is a plus to the adaptive thermal comfort approach which champions adaptation rather than heating indoors as a better alternative to providing thermal comfort. Adaptation has a great potential to reduce energy use in naturally ventilated classroom buildings. For example, there is an assumption that an increase in temperature by 1^{o}C in the United Kingdom, during winter, to heat indoor spaces causes an increase in energy consumption by about 10% (Humphreys & Hancock, 2007).

Further examples reinforce the reason for the higher votes on ‘comfortable’ in the morning hours as observed in the retrieved data from the data loggers that were matched with the subjects’ comfort votes. For example, the result of the comfort vote on Oct 25, 91% of the subjects indicated being ‘uncomfortable’ when the indoor temperature in the data logger reported 30.1^{o}C, and that was in the afternoon hours. This also meant that about 9 of every 10 (approx. 90%) of the subjects voted ‘uncomfortable’. Also, on the 6th of May, 62% of the children voted ‘uncomfortable’, corresponding to a high mean indoor OT observed in the afternoon (29.9^{o}C). The reason the subjects gave for the high percentage of votes on ‘uncomfortable’ in the afternoon hours was ‘too much temperature’. On the other hand, higher votes on ‘comfortable’ were cast in the morning hours. A typical example was in the morning hours of May 28, where at an observed indoor temperature of 27.9^{o}C, nearly 100% of the subjects voted ‘comfortable’. These are few examples, of many similar instances, the direction of subjective behaviours of the children changed in line with variations in indoor temperature characterized according to time of day.

However, it was not in all the morning hours that the majority of the subjects indicated that they were comfortable with the indoor thermal conditions. There were instances the subjects expressed in their voting high percentage of votes on ‘uncomfortable’ in the morning hours. For example, on the 25th of May in the morning hours at the mean indoor operative temperature of 24.6^{o}C, approximately 100% of the entire class voted ‘uncomfortable’ at a mean thermal sensation with value -0.84. This finding was cross checked with air flow acceptability at that period of the day, which reported constituency in the pattern of voting of the subjects; revealing that 100% of the subjects preferred less air because of ‘cold’. Also, in the morning hours on Nov 1, at the mean indoor temperature of 26.4^{o}C, 49% of the subjects voted uncomfortable, with a mean thermal sensation reporting -0.78. However, the cases where the subjects voted high on ‘uncomfortable’ in the morning hours were few. The finding in the thermal expression on the comfort vote of the children in the morning hours gives an important information not observed in the analysis of the comfort vote according to season. The analysis of the field work data in this research reveals that the surveyed children could some days in the morning hours express being ‘uncomfortable’ because of ‘cold’, and in that instance, they may prefer a warmer indoor condition. This is against the belief (often seem to be generalized) in thermal comfort research that building occupants in the tropics would always prefer a colder indoor thermal condition. The need for more thermal comfort research according to time of day, rather than focusing only on seasonal surveys may provide further information. A study by van Marken Lichtenbelt, Hanssen, Pallubinsky, Kingma, & Schellen (2017) show that for persons exposed to an indoor temperature at the low end or even just below comfort range, non-shivering thermogenesis is activated, which leads to increased metabolism. Because of health issues, it is important to understand that children in the study area in some days in the morning hours may prefer a warmer environment.

According to Building Type: Results suggested that more subjects indicated ‘comfortable’ in the combined ‘open-space’ classrooms compared with the ‘enclosed plan’ classrooms, indicating a significant difference of 16% in the comfort votes. These comfort votes were cast at the temperature in the range from 26-30^{o}C, which prevailed between 75-85% of the time in these surveyed classrooms, irrespective of the season as earlier reported in Figures 5.31, 5.36 and 5.41 of Chapter 5. Furthermore, the optimum temperature, preferred temperature and the comfort range obtained in these two types of classrooms were within this range of indoor temperature (26-30^{o}C) that prevailed most in these classrooms.

6.3.2 Thermal Sensation of children

***The third* objective** of this study was to determine the thermal perception of the children in the classrooms they use for class lessons and to compare the findings with the prescriptions of ASHRAE Standard and with previous works. This very objective was achieved through the analysis of thermal sensation and thermal preference votes of the subjects discussed in the subsequent sections

The school children expressed a mean thermal sensation with a value of +0.16, for the combined classrooms all season at the mean indoor temperature of 29.1^{o}C. The mean thermal sensation vote lay between ‘okay’ (neutral) and ‘a bit warm’, however closer to neutrality, as summarized in Table 5.16 of Chapter 5. This indicated that the subjects thermal feeling was towards ‘a bit warm’ and this was at a mean indoor temperature of 29.1°C. ASHRAE standard 55 considers any thermal sensation vote within the range -0.85 to +0.85 as ‘comfortable’ based on the 80% comfort limit (ASHRAE Standard-2017). This suggested that the studied children adjudged their indoor thermal condition ‘comfortable’. Furthermore, the subjects voted 82% (Table 5.17 of Chapter 5) on the three central categories (-1, 0, +1) of the ASHRAE scale, indicating acceptance of the indoor thermal conditions by the subjects. This again suggested that the subjects found their indoor thermal environment comfortable. A tighter and more stringent comfort limit (90% comfort limit; range from -0.5 to +0.5) when considered indicated that the subjects’ thermal sensation votes for the combined classrooms all season was also within this strict comfort limit.

A check on the scatter plots in Figures 5.53-5.59 of Chapter 5 show a wide spread of the voting of the children. According to Humphreys et al., (2007), most of the scatter represents genuine differences of comfort temperature between different groups at the same outdoor temperature, and further posited that the scatter in the TSV’s reflects the diversity of activity that was usually among a class of young children.

According to Season: The mean thermal sensation votes of the children, summarized in Table 5.18 of Chapter 5, were -0.01 and +0.3 in the rainy season and in the dry season, respectively. This suggested that the subjects expressed their mean thermal sensation on the colder side of the ASHRAE thermal sensation scale during the rainy season, while during the dry season the mean thermal sensation was on the warmer side of the scale. In order words, during the rainy season the mean thermal sensation was very close to ‘okay’ (neutral), while during the dry season, the subject’s mean thermal sensation was between ‘okay’ and ‘a bit warm’. Both mean thermal sensation votes were within the 80% and 90% acceptability comfort zone. Furthermore, the range of the thermal sensation votes during the rainy season was from -2.0 to +1.8, while the range in the dry season was from -1.4 to +1.8.

According to Time of Day: The results of the subject’s mean thermal sensation vote in the combined morning hours summarized in Table 5.18 of Chapter 5 clearly showed the differences in the way the studied children felt in the two periods of the day. In the morning hours, the subjects felt cold, however, in the afternoon hours they felt warm. The reason is linked to the different mean indoor temperatures recorded in these two periods. Higher mean indoor temperatures were recorded in the afternoon hours, compared with the morning hours as presented in Figures 5.32, 5.33, 5.38, 5.39, 5.42 and 5.43 of Chapter 5. The temperature increase, from morning hours to afternoon hours, obviously influenced the thermal sensation votes of the subjects. Higher values of thermal sensation votes were similarly observed in the afternoon hours compared to the morning hours as reported in thermal comfort studies in schools by (Saleem et al., 2016).

According to Classroom Type: The mean thermal sensation votes of the subjects in both types of classroom buildings were on the warmer side of the ASHRAE 7-point thermal sensation scale as summarized in Table 5.16 of Chapter 5 (+0.09 for the combined open space classrooms and +0.29 for the combined enclosed plan classrooms). The mean thermal sensation votes obtained in the combined open space classrooms were very close to neutrality (0), while the mean thermal sensation obtained for the combined enclosed plan classroom was not far from neutrality. Furthermore, the neutral temperature obtained in the open and enclosed classrooms were 28.8^{o}C and 28.1^{o}C (Table 5.21), respectively. The neutral temperature obtained in the open-classroom (28.8^{o}C) (Table 5.21) and the mean indoor temperatures are the same (28.8^{o}C). Furthermore, the neutral temperature obtained in the enclosed-classrooms (28.1^{o}C) is also close to the mean indoor temperature (29.3^{o}C) found in the classroom (Table 5.12). The results strongly suggested the linear relationship between neutral temperature (comfort temperature) and indoor temperature, on one hand, and the relationship between adaptation and indoor comfort temperature as expounded by the adaptive comfort model.

Thermal Sensation vs Indoor T_{OP}

As summarized in Table 5.21 of Chapter 5, 51% of the variation (r^2=.51) in thermal sensation of the children is influenced by the changes in the classroom operative temperatures. This low coefficient value may be attributed to what Djamila, Chu, & Kumaresan (2013) and Shamila Haddad (2016) reasoned as the variation in thermal sensations and different comfort votes of individual participants exposed to similar indoor temperatures.

Further analysis was conducted to determine the extent of the relationship of these two variables (Thermal sensation and Indoor operative temperature) according to classroom type. Results indicated a satisfactory correlation in all the combined classrooms. However, the correlation showed higher satisfaction in the combined enclosed classrooms all season ($r^2=0.60$) compared with the combined open classrooms ($r^2=0.47$). This is not surprising because the indoor operative temperature in the open-space classrooms reported higher variation in temperature and thermal sensation votes. Though the R square in the combined open-space classrooms is low, however according to Mishra & Ramgopal, (2015) for surveys dealing with human behaviour an r^2 value of 0.40 indicates a strong correlation. In order words, the thermal sensation differed considerably between the individual children for the same indoor operative temperature.

Another way of examining the relationship between the indoor operative temperature and the thermal sensation of the children is by matching the thermal sensation votes with the corresponding indoor temperature as shown in Table 6.4. The Table shows that as the mean indoor T_{OP} went below approximately 28.8°C (neutral temperature), the mean thermal sensation votes of the studied children tended to the cold side of the ASHRAE thermal sensation scale. As the mean indoor T_{OP} went above the neutral temperature, the subjects mean thermal sensation votes tended to the warm side of the scale. The result is consistent with the optimal temperature (28.8°C) obtained in this study.

Also, all the classrooms showed some level of similarity in the trend of mean votes with respect to Operative Temperature (OT). The tendency for mean votes to shift from cold sensation to the warmer sensation as the indoor operative temperatures increased, and vice versa, were observed in all the surveyed classrooms. For example, A_{OP} recorded a mean thermal sensation vote of - 0.23 at the mean indoor operative temperature with a value of 27.7°C. It also recorded a mean thermal sensation vote of +0.14 at an OT of 30°C. Similarly, B_{OP} recorded -0.05 mean vote when the indoor OT was 28.1°C and recorded +0.16 mean vote when OT peaked to 30°C. In classroom A_{EN}, there was a rapid shift to a cold thermal sensation with value -1.5 as a result of the low indoor OT (26.2°C). However, there were differences in the perception of comfort by the occupants of both categories of classrooms even when they recorded a similar OT. For example, when A_{OP} recorded OT of 29.2°C, the mean vote was +0.07, but when A_{EN} recorded OT of 29.1°C, the mean vote was +0.17..

Table 6. 4.Thermal sensation votes and T_{OP} in the classrooms

School		Temp (°C)	Mean vote	% vote (neutral)	% Vote (-1. 0. +1)
A	A_{OP}	27.7	-0.23	48	86
		28.7	-0.05	61	96
		29.2	+0.07	89	84
		30.0	+0.14	94	59
	A_{EN}	26.2	-1.5	16	58
		27.5	-0.18	29	63
		28.5	-0.01	54	96
		29.1	+ 0.17	56	94
B	B_{OP}	28.1	-0.05	60	82
		28.7	-0.10	68	92
		30.0	+0.16	70	56
	B_{EN}	28.5	-0.02	42	90
		30.7	+0.90	65	69
C	C_{OP}	27.6	-0.15	45	78
		28.7	-0.01	75	89
		29.8	+0.18	78	81
	C_{EN}	27.6	-0.12	74	83
		28.6	- 0.01	75	84
		29.5	+0.17	79	75

6.3.3 Thermal Preference of Children

The previous section discussed how the children felt to the indoor thermal conditions in their classrooms. This section discusses how they preferred the indoor thermal conditions to be (thermal preference). This discussion on thermal preference is based on the results and analysis of the thermal preference of the subjects that adopted McIntyre thermal preference scale as summarized in Tables 5.19 and 5.20 of Chapter 5.

A check on the thermal sensation votes of the children and their thermal preference shows consistency in the voting of the subjects. The studied children having expressed their classroom to be 'warmer-than-neutral' were consistent by preferring a cooler environment. Furthermore, the preferred temperature was 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. The result is in agreement with the findings in some studies such as in the works of, Wong & Khoo (2003), Kwok & Chun (2003), Hwang et al., 2006), Al-Rashidi (2011) and Efeoma, (2017). These works reported that thermal sensations do not usually equate the optimal preferred thermal state of occupants.

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According to Season: During the rainy season near to half of the class (45%) preferred the thermal state to remain the way they met it. This is not surprising because the mean thermal sensation in this season (-0.01) was very close to the neutral temperature (0). This trend was confirmed in the general comfort votes (Table 5.23) where approximately 74% of the subjects voted 'comfortable' during the rainy season.

Furthermore, in the dry season survey 31% of the entire class preferred the indoor thermal conditions to remain the way they met it. This implied that 69% of the entire class wanted the indoor thermal conditions to change. Because of this desire for a change, only 9% preferred a warmer environment while a significant percentage of the children (60%) preferred a cooler environment. A check on the summary of thermal sensation votes in Table 5.16 showed that the children felt a warm environment by voting +0.31 as their mean thermal sensation. As a result, majority of them wanted a cooler indoor thermal environment.

According to Time of Day: The percentage of occupants, in the combined classrooms all season, who preferred to be cooler were 42% and 59% in the morning hours and afternoon hours (Table 5.20), respectively. This suggested that more than half of the class preferred a cooler environment in the afternoon hours. The mean thermal sensation votes of the children in the afternoon hours, irrespective of the season and classroom type, was as high as +0.49. That explained why majority preferred a cooler environment. Another observation was that even at this high mean thermal sensation, some subjects preferred a warmer environment. This can also be explained by the fact that not all human beings feel the same way. This is evidenced in the dispersion of the thermal sensation votes of the children observed in the regression analysis in in Figures 5.53-5.59 of Chapter 5. What is a bit difficult to explain is the reason for a significant percentage of the class (45%) preferring a cooler environment in the morning hours at a very low mean thermal sensation vote of -.18, (a high indication of feeling cold. The reason can be linked to what has already been explained, that people do not always feel the same way to an indoor thermal condition.

Field studies on thermal comfort found that people of warm climates may prefer what they call a ‘slightly cool’ environment (Humphreys & Hancock, 2007). The findings from this work also confirm this tendency. However, the results and analysis from this fieldwork, presented in Table 5.20 in Chapter 5, provided more detailed information that suggested that the notion should not be generalised in all conditions. From the Table, the preference for a warmer indoor thermal condition depended on the time of the day the survey was conducted. For instance, the preference for a warmer indoors, rather than cooler indoors, was a popular choice of the children in classrooms A_{OP}, A_{EN}, B_{OP} and C_{OP} and that was in the morning hours of the rainy season. The reason was linked to the persistent rainfall witnessed in most of the early morning hours these surveys were conducted. The participants felt cold in these days.

According to Building Type: 45% and 48% of the class in open-space classrooms and enclosed-plan classrooms, respectively preferred a cooler environment than what they found. Both occupants of the two types of classrooms expressed their indoor thermal environment warm, +0.10 for the open-space classrooms, and +0.29 for the enclosed-plan classrooms. More of the occupants in the enclosed classrooms felt warmer and more of them needed a cooler indoor environment (48%), compared to 45% that needed a cooler environment in the open classrooms.

Relationship Between Thermal Sensation and Thermal Preference

It is expected that those who vote ‘neutral’ on the thermal preference scale will also vote ‘no change’ (okay), since both indicate ultimate comfort. Results summarized in Figure 5.51 of Chapter 5 gave a different assessment result. While 51% of the occupants voted ‘neutral’ on the 7-point ASHRAE thermal sensation scale, 37% preferred neutral (okay) using the McIntyre scale. Furthermore, 17% of those who voted ‘neutral’ thermal sensation preferred a ‘cooler’ temperature. This suggested that votes on the thermal sensation and thermal preference scales may not be consistent. Teli et al.,(2012) and some other thermal comfort research works also came to a similar finding.

6.3.4 Neutral Temperature of Children

Predicting Neutral Temperature

The results and analysis of neutral temperature of the children reported in Chapter 5 and summarized in Table 5.21, are categorized according to season, time of day and according to classroom type in the subsequent sections

According to season: The neutral temperature or comfort temperature produced in this work for combined classrooms all season (28.8°C) is close to the mean indoor temperature for the combined classrooms all season (29.1°C). This suggested that the subjects were good at adapting with the temperature prevailing in their surroundings. Furthermore, the neutral temperature was by 1.9K higher than that suggested by ASHRAE Standard 55, and by 1.4k higher than the preferred temperature obtained in this work (27.4°C). The neutral temperature from the regression analysis for the rainy season survey was 28.2°C, while for the dry season a neutral temperature of 27.8°C was obtained. This indicates a difference in the neutral temperature of 0.4K between the two seasons.

According to Time of Day: Also, observed were some differences in neutral temperature according to time of day. 28.5°C and 28.1°C were the neutral temperatures for the morning hours and afternoon hours, respectively, indicating a difference of 0.4K.

According to Classroom Type: The open classrooms and enclosed classrooms produced neutral temperatures of 28.8°C and 28.1°C, respectively. The predicted mean votes of the studied children approximated warmer thermal sensation by 0.27 (based on the fieldwork) in the open classrooms. The research work by Dhaka, Mathur, Wagner, Agarwal, & Garg (2013) also observed varied neutrality in each classroom survey was conducted. Another observation is that the comfort temperatures were lower than the mean indoor operative temperatures irrespective of the season, time of day and classroom type. This agrees with the observation by Nicol et al., (2012) who posited that in hotter environments the comfort temperature is generally lower than the mean operative temperature.

6.3.5 Correlation Between Neutral Temperature and Indoor Top

The neutral temperatures obtained in this study are close to the respective mean indoor temperatures obtained from them. The results strongly suggested that the linear relationship between neutral temperature (comfort temperature) and indoor temperature, on one hand, and the relationship between adaptation and indoor comfort temperature as expounded by adaptive comfort model

Further analysis were conducted using Paired sampled T-test to determine the relationship between the neutral temperature (T_n) and indoor operative temperature (T_{OP}) in each of the classrooms, characterized according to season, classroom type and time of day. The result of the test, summarized in Table 6.5, show that the two variables correlated strongly. The finding agrees with the adaptive hypotheses which posits that the optimum temperature for comfort would strongly correlates with the mean indoor temperature building occupants experience, provided that they have stayed long in the indoor environment (Humphreys et al., 2015). Furthermore, this phenomenon is consistent with the findings from some other studies conducted by Hwang et al., (2006), Wong & Khoo (2003), Feriadi & Wong (2004). These studies were conducted in naturally ventilated buildings. Thus, an increase in indoor operative temperature will always increase the neutral temperature of the building occupants provided other variables do not come into dominance.

Table 6. 5. Statistical summary of significant correlation between T_n and T_{OP}

All classrooms	2-tailed significant	Remark
All classrooms	*0.000 (< 0.05)*	✓
Open classroom	*0.000 (< 0.05)*	✓
Enclosed classroom	*0.000 (< 0.05)*	✓
Rainy season	*0.000 (< 0.05)*	✓
Dry season	*0.000 (< 0.05)*	✓
Morning hours	*0.000 (< 0.05)*	✓
Afternoon hours	*0.000 (< 0.05)*	✓

6.3.6 Offset Between Thermal Sensation and Preference from Neutral

The differences in the 'neutral' temperature from ASHRAE thermal sensation scale, and the preferred temperature from the preference scale is referred to as the '*semantic offset'* (M. Humphreys et al., 2015)). The ASHRAE thermal sensation scale regards 0 as the neutral temperature (de Dear & Brager, 1998; de Dear et al., 1997). This neutral temperature also referred to as optimum temperature, is the temperature in which building occupants do not feel cold or warm. This study produced a mean thermal sensation of +0.16 based on 7 point ASHRAE thermal sensation scale. This mean thermal sensation is within the 80% and 90% comfort zone with an offset of +0.16 from the neutral point (0). The temperature produced by substituting this offset in equation TSV=0.16Top-6.90 is 24.3^{o}C. The offset between the value obtained with 0 and the value obtained with +0.16 is big (4.5^{o}C), while the offset of the neural temperature from the preferred temperature is 3.1^{o}C (27.4-24.3^{o}C).

6.3.7 Comfort Range of Children

According to season: The comfort bandwidth obtained during the rainy season survey is by 1.5K higher than the bandwidth obtained during the dry season survey. This suggested that the studied children were more adaptable to temperature variations in the indoor temperatures in the rainy season compared to the dry season. Furthermore, the wider comfort bandwidth in the rainy season may be because of the higher airflow the school children experienced during that season (rainy season). Another explanation could be the rainfall experienced during the rainy season which helped to cool the environment. The lower limit of the children's comfort temperature in both seasons did not vary significantly (varied by 0.3K). However, at the upper limit the difference varied significantly (1.2K). One can infer that the school children were not as much worried at the variations in the indoor temperature at lower temperature values as they were at higher temperatures. In order words, the children were more perturbed at the higher temperatures than at lower temperatures

According to Building Type: The comfort range in the combined open classroom produced a comfort bandwidth of 7.1K, while the combined enclosed classrooms produced a bandwidth of 4.7K. The comfort bandwidth obtained in the combined open classrooms was almost double to that obtained in the combined enclosed classrooms. This indicated that the children in the combined open classrooms were comfortable under a wider indoor temperature compared to those in the enclosed classrooms. Further comparison between these two types of classrooms showed that the upper limit of the comfort range in the open classrooms was wider than that in the enclosed classroom by as much as 1.8K, while the lower limit of the open classroom was wider than that of the enclosed classroom by 0.6K. This also suggested that the children in the open classrooms were more tolerant to the variations in the indoor thermal variables. A possible explanation to this could be the generally higher indoor airflow recorded in the open classrooms which likely helped in removing the excess heat accumulated by the children in their classrooms.

According to Time of Day: In the combined morning hours, a comfort bandwidth of 5.5K was obtained from the regression analysis of the mean thermal sensation votes of the children against indoor operative temperature. The comfort bandwidth is narrower than the bandwidth obtained from the regression in the afternoon hours (8.1K). This showed a comfort bandwidth difference of 2.6K between the morning and afternoon surveys. What is a bit difficult to explain is the higher comfort bandwidth in the afternoon hours compared to the morning hours when the studied children experienced warmer indoor thermal conditions in the afternoon hours. The complaints by the studied children about the cold thermal sensation they experienced in some days in the morning hours may have been part of the reason for poor adaptation to the indoor thermal conditions in the morning hours compared to afternoon hours.

6.3.8 Air Flow Acceptability and Preference

Despite the high percentage of the studied children who accepted the air flow in the combined classrooms (75%) a significant number (64% of the entire class) preferred more air. This suggested that some of the children who accepted the air flow preferred more air. Furthermore, subjects preferring 'more air' movements were significantly more than those demanding less air movement in all the surveyed classrooms, irrespective of the season. The preference for more air was as high as 84%. This agreed with the findings from other previous research works which posit that building occupants in the tropics prefer more air. However, due to the small range of airspeed observed in this fieldwork, there was not enough evidence about the cooling effect of wind on the thermal perception of the studied children. Low airspeed within the study zone was also observed by previous thermal comfort researchers such as Efeoma (2017), Okafor (2016) and Tammy Amasuomo & Oweikeye Amasuomo (2016) in their various studies.

According to Season: The acceptability to air movement was higher in the rainy season (71%) compared to the dry season (63%), while the preference for more air was less in the rainy season (53%) compared to the dry season (71%). The result showed consistency in the voting of the children. The preference for less air movement during the rainy season was attributed to cold. The persistent rainfall experienced during the survey in most days in the rainy season brought with it outdoor cold air that circulated in the classrooms. As a result, the children experienced a cold thermal sensation which they found unpleasant.

According to time of day: As shown in Table 5.27 of Chapter 5, acceptability to air movement was higher in the morning hours compared to the afternoon hours for all the surveyed classrooms. The exemption was in classroom A_{EN} where acceptability was slightly higher in the afternoon hours compared to the morning hours. The reason for less acceptability to air movement in the morning hours could be explained by the frequent rainfall that occurred mostly in the morning hours during the rainy season, which caused draft. Draft according to (ASHRAE, 2017) is unwanted local cooling of the body caused by air movement.

According to Building Type: Acceptability to air movement was higher in the combined open classrooms (72%) compared to the combined enclosed classrooms (60%). The result was consistent with the preference vote of the same subjects on airflow were less percentage of them preferred more air in the combined open classrooms (62%) compared to the higher preference for more air in the combined enclosed classrooms (65%).

6.3.9 Acceptability to Temperature Changes

As summarized in Table 6.6, the highest acceptability to temperature was observed at the indoor temperature that prevailed more at approximately 28.5^{o}C, where 82% and 71% of the subjects in the combined open-space classrooms and combined enclosed-plan classrooms, respectively to indicate accepting the temperature. This acceptable temperature is close to the neutral temperature produced in this study (28.8^{o}C). This is further evidence that the studied children were consistent with the answers they proffered to thermal comfort questions. The table further showed that acceptability to temperature reduced as temperatures went above or below 28.5^{o}C, irrespective of the classroom type. The result is in agreement with that of K. E. Al-Rashidi (2011) who found out that subjects who express neutral sensations and preferred states beyond neutrality often express high percentage of unacceptability. Furthermore, at the temperature of 29^{o}C about 85% of the children were comfortable.

Comparison of acceptability to temperature changes according to classroom-type showed that the occupants in the open-space classrooms reported higher acceptability to higher indoor temperatures compared to the subjects in the enclosed classrooms. This may be explained by the higher air velocity recorded in the open space classrooms. The comparison of the spot checks of the air velocity in the classrooms showed higher airflow in the open classrooms compared to the enclosed classrooms. However, this high air flow inside the open classrooms became unpleasant to the occupants at lower indoor temperatures. For instance, as the indoor temperatures dropped below 27.5°C, the acceptability level dropped more in the open classrooms compared to the enclosed classrooms. This is explained by the coldness felt by the children, exacerbated by higher air velocity in the open classrooms.

In spite of the high and low temperatures found in these classrooms, more than half of the class still found them acceptable irrespective of the classroom type. However, it was only at temperatures of 31.5°C-32.5°C, that less than half of the subjects found the temperatures acceptable in the enclosed classrooms. The high acceptability to these temperatures could be linked to psychological adaptation to temperature the subjects were accustomed in the classrooms.

Table 6. 6: Summary of thermal comfort acceptability in classrooms according to T_{OP}

Temperature (°C)	OPEN		ENCLOSED	
	Acceptable	Unacceptable	Acceptable	Unacceptable
24.5	49(62%)	28(38%)	43(69%)	19(31%)
25.5	113(55%)	91(45%)	201(61%)	123(39%)
26.5	137(61%)	87(39%)	265(65%)	140(35%)
27.5	598(74%)	209(26%)	421(70%)	179(30%)
28.5	645(82%)	142(18%)	464(71%)	189(28%)
29.5	315(75%)	104(25%)	487(67%)	232(33%)
30.5	216(77%)	62(23%)	317(62%)	191(38%)
31.5	210(70%)	88(30%)	66(38%)	108(62%)

Table 6. 7. Acceptability to air flow according to T_{OP}

Classroom	Season	Period	T_{OP}	Air flow acceptability	
			°C	**Acceptable**	**Not acceptable**
A_{OP}	Rainy	Morning	26.7	147(81%)	33(19%)
		Afternoon	29.5	119(79%) ×	31(21%)
	Dry	Morning	28.6	221(84%)	42(16%)
		Afternoon	30.1	178(65%)	93(35%)
A_{EN}	Rainy	Morning	28.9	195(74%) ×	70(26%)
		Afternoon	29.1	204(77%) ×	62(23%)
	Dry	Morning	28.6	212	140
		Afternoon	30.1	125	99
B_{OP}	Rainy	Morning	27.3	154(92%) ✓	12(8%)
		Afternoon	30.3	138(92%)	12(8%)
	Dry	Morning	27.8	94(85%)	16(15%)
		Afternoon	27.9	57(57%)	43(43%)
B_{EN}	Rainy	Morning	27.8	120(63%) ×	69(37%)
		Afternoon	29.8	60(29%)	172(71%)
	Dry	Morning	28.2	102	48
		Afternoon	28.8	85	68
C_{OP}	Rainy	Morning	27.6	389(81%)	91(9%)
		Afternoon	29.5	321(69%)	145(31%)
	Dry	Morning	27.2	224	55
		Afternoon	29.9	150	102
C_{EN}	Rainy	Morning	27.5	390(66%)	195(34%)
		Afternoon	29.4	296(54%)	249(46%)
	Dry	Morning	26.9	102	45
		Afternoon	29.3	99	89

6.3.10 Acceptability to Humidity

The comfort level of relative humidity for the studied children were found to be within the range 45.2% to 91.6 % (at 80% occupant satisfaction) for the combined classrooms all season, at mean RH with a value of 71.8%. However, the number of counts relative humidity hovered around the maximum value was insignificant. At the mean value (71.8%), more than 80% of the school children found them acceptable. This suggests that the studied children accepted humidity beyond the value recommended by ASHRAE standard 55. The standard recommends 60% as the maximum indoor RH in naturally ventilated building.

Furthermore, acceptability to RH did not vary significantly according to season (Figure 5.70) and according to classroom type (Figure 5.71). However, the acceptability was slightly higher during the rainy season compared to the dry season. It was also slightly higher in the combined open space classrooms compared to the combined enclosed plan classrooms. Generally, the number of counts indoor RH above 80% appeared in the classrooms was low, especially in the open classrooms. RH above 80% has very high acceptability in the open classrooms. In the morning hours, acceptability of RH above 80% was 99% and 88% in the open classrooms and enclosed classrooms, respectively. While 87% and 65% acceptability was recorded during the afternoon hours in the combined open classrooms and combined enclosed classrooms, respectively. That infers that occupants of buildings in the warm and humid climates can be comfortable at humidity higher than 80%.

6.3.11 Indoor RH Versus Indoor Top

Literature information from this research indicated divided opinions from some thermal comfort researchers about the relationship between relative humidity and thermal comfort. While some researchers argued that RH does not play a significant part in determining the comfort of building occupants, some others believed RH, especially at above 90%, influences occupants' perception of the thermal environment. In this study, the extent of the relationship between the indoor temperature and the indoor RH in determining occupants' comfort are discussed, based on the results presented in Chapter 5. The comfort level of RH is within the mean RH with a value of 71.8% (Table 5.12 of Chapter 5).

The retrieved data from the data loggers presented an inverse relationship between the indoor relative humidity and the indoor temperature, irrespective of the classroom type or season. For example, in the morning hours when the indoor operative temperatures were low the relative humidity was high. As morning hours progressed to afternoon hours the temperatures were increasing while the RH was reducing. This was observed to be the general trend in all the surveyed classrooms all seasons. This inverse relationship was further proven in the minimum and maximum relative humidity observed in some of the classrooms. For instance, in school A, classroom A_{OP} to be precise, the indoor RH recorded the highest temperature the same day (Oct 16) and time (8.30 am) the indoor operative temperature recorded the minimum temperature. Inside the same classroom when the RH reported the lowest percentage on Oct 12, the indoor temperature recorded the highest temperature the same day. These occurred during the rainy season. In the dry season, both types of classrooms also reported minimum indoor operative temperature the same day (Feb 21) and at the same time (9.48 am). In school

B, both classrooms recorded the lowest indoor OT the same day (Nov 1) and within the same time period, the RH in these classrooms recorded the highest value. Both classrooms also recorded the highest indoor temperature (Oct 25) the same day the RH recorded the lowest value.

The relationship between the indoor operative temperatures and the indoor RH is further discussed by comparing these two variables according to classroom type. As shown in Figures 5.32, 5.33, 5.38 and 5.39 of Chapter 5, the indoor operative temperatures in the 'open-space' classrooms were, for most of the time, lower than the indoor operative temperatures in the 'enclosed-plan' classrooms. The indoor RH did not follow the trend. These were further evidences of the differences in the thermal performance of the two types of classrooms. A check on some of the data recorded in the various classrooms highlighted this relationship. For instance, in schools, A and B when the indoor operative temperature averaged 26.0^{o}C in the morning hours in school A the corresponding indoor RH was high (approximated 85%). The trend reversed in the afternoon period when the indoor operative temperature reached high values (averaged 29.0^{o}C), while the corresponding indoor relative humidity dropping to lower values averaging 72.0%. This trend was repeated in school B. Furthermore, in some of the months the surveys were conducted, the two types of classrooms shared some other similarities. In school A classroom A_{OP} and A_{EN} recorded maximum indoor relative humidity the same day (February 7) and at the same time period the surveys were conducted. In school B both types of classrooms also recorded maximum, and interestingly, minimum relative humidity the same day (Nov 1) and at the same time period.

Furthermore, no significant difference in RH acceptability, based on the differences in the indoor operative temperatures, was observed. For example, in the morning hours during the rainy season survey in classroom A_{OP} a mean operative temperature of 26.7^{o}C with mean RH of 77.1% was recorded. At these recorded thermal variables, 80% of the school children accepted the RH. In the afternoon hours in the same classroom, on the same day at a mean indoor operative temperature of 29.5^{o}C and mean RH of 72%, the same percentage of occupants (80%) accepted the RH even when the mean operative temperature between the two periods (morning and afternoon) varied significantly by 2.8K. Furthermore, the temperature variation between the two seasons the survey was conducted (0.3^{o}C; 29.2^{o}C dry season and 28.9^{o}C rainy season) did not affect the RH acceptability which stood at 71% (rainy season) and 70% (dry season). Generally, no significant decrease in comfort temperature, at high humidity, was found in this work, except when it exceeded 90% and the temperature hovering around

30°C. Though acceptability to indoor RH up to 92% was high in some cases, however in most cases at temperature more than 30°C, low acceptability was generally observed The findings seem to agree with that of Zhai et al., (2015) who posited that at temperatures of 26°C, 28°C and 30°C the acceptability to humidity was not statistically significant. F. Nicol (2004) suggested that the effect of high humidity on comfort in hot climates is less consistent. Furthermore, ISO EN 7730 (1994) and (CEN, 2007) posit that the effect of humidity on the thermal comfort is rarely important.

Table 6. 8. Summary of air flow and RH acceptability

				Air Flow Acceptability		Relative humidity		
Classroom	Period	T_{op} °C	Mean V_a m/s	Acceptable	Not Acceptable	Mean RH %	Accepted	Not Accepted
A_{OP}	Morning	26.7	-	133(80%) ✓	33(20%)	77.1%	152(80%) ✓	37(20%)
	Afternoon	29.5	-	119(79%) ✗	31(21%)	72.0%	138(82%) ✓	30(18%)
	Both	28.5	0.18	252(80%) ✓	64(20%)	74.8%	290(81%) ✓	67(19%)
B_{OP}	Morning	27.3	-	144(99%) ✓	2(1%)	78.7%	1469(100%) ✓	0(0%)
	Afternoon	30.3	-	138(96%) ✓	6(4%)	64.8%	134(92%) ✓	11(8%)
	Both	29.3	0.11	282(96%) ✓	8(4%)	72.1%	280(96%) ✓	11(4%)
A_{OB} + B_{OP}		28.8	0.19	534(88%) ✓	72(12%)	73.4%	570(89%) ✓	78(11%)
A_{EN}	Morning	28.9	-	195(74%) ✗	70(26%)	83.6%	234(88%) ✓	33(12%)
	Afternoon	29.1	-	204(77%) ✗	62(23%)	78.3%	215(81%) ✓	50(19%)
	Both	29.0	0.11	399(75%) ✗	132(25%)	81.4%	450(84%) ✓	83(16%)
B_{EN}	Morning	27.8	-	120(63%) ✗	69(37%)	83.3%	144(76%) ✗	45(24%)
	Afternoon	29.8	-	67(26%) ✗	188(74%)	74.2%	120(50%) ✗	118(50%)
	Both	29.2	0.12	187(42%) ✗	257(58%)	79.2%	264(62%) ✗	163(38%)
A_{EN} + B_{EN}		29.1	0.11	586(60%) ✗	389(40%)	80.3%	714(74%) ✗	245(26%)
ALL **(Both)**		28.9	-	1120(71%) ✗	461(29%)	77.1%	1285(80%) ✓	323(20%)

6.3.12 Comparing sensitivities of AMV and PMV

The gradient coefficient (slope) of the regression line for the mean thermal sensation was used to determine the sensitivity of the children to the changes in the indoor operative temperatures. The gradient is a measure of occupant sensitivity to indoor temperature changes and gives the degree to which a population can adapt to changes in the thermal environment. The regression slope demonstrates how much the thermal comfort increases per 1K rise in operative temperature (Humphreys et al., 2007). This is inversely proportional to the adaptability of the building occupants under analysis (de Dear et al., 2015). A shallow regression slope (less steep gradient) shows an effective adaptability of the subjects, usually, over a large range of temperatures (called the comfort band). While a steep gradient indicates that the children are not adaptable in change in the classroom thermal environment.

The regression gradients for the sampled children in this study for the combined classrooms al seasons were 0.29/^{o}C and 0.31/^{o}C for Actual Mean Votes (AMV) and Predicted Mean Votes (PMV), respectively. This suggests that for a shift of 1 point (in the thermal sensation) to the warmer side of the 7 point scale, there is an increase in temperature of 3.4K in the combined classrooms all seasons considering the AMV. For the shift of 1 point, there is an increase in temperature of 3.2K considering the PMV. Furthermore, the slope of the AMV is lower than that of the PMV. These differences suggest that, across the two seasons, the studied children were less sensitive to temperature changes than was predicted by the PMV model. The likely reason is the adaptive opportunities utilized by the young children making them to be less sensitive to temper changes.

Previous research in the field of thermal comfort shows that increased adaptive opportunity reduces discomfort and dissatisfaction and the thermal sensation tends to be less sensitive to temperature differences (Bordass & Leaman, 1997; Gail Brager & de Dear, 2000). It can be inferred that children in Imo State are well acclimatized and accustomed to warm-humid weather and would tolerate temperatures higher than the ones recommended by International Standards if they are allowed to make adequate use of the adaptive opportunities available.

6.3.13 Comparing with Previous Works in Classrooms

Thermal Sensation

In this work, more than half of the surveyed school children (51%) (Figure 5.51) voted within the three central categories (-1, 0, +1) of the ASHRAE 7-point thermal sensation scale. In the majority of previous surveys conducted in the tropical setting with children as subjects such as; Pepler (1972), Auliciems (1969), Auliciems (1973), Kwok et al., (1998), Wong & Khoo (2003), Corgnati, Filippi, & Viazzo (2007), Hwang et al., (2009), De Giuli et al., (2012), Liang et al., (2012) at least 50% of them voted the immediate thermal environment within this three central categories of the thermal sensation scale, indicating a high level of adaptability. Important observations from the various results is that the geographical, climatic and demographic differences that may have been involved in these works did not influence the similarities in the results.

Neutral Temperature and Comfort Range

Results from this work showed some differences in the neutral temperatures when characterized according to the season, time of the day and according to classroom type. Results indicated a difference of 0.4K in neutral temperature according to the season, 0.4K and 0.7K differences in the neutral temperatures according to time of day and classroom type, respectively. The findings support OLGYAY (1963), pp.14-23 position that although the comfort zone does not have real boundaries, the zone of thermal comfort and acclimatization is subject to geographical and seasonality and does not exceed 2K.

A good number of thermal comfort studies on primary schools have been conducted but not many of these studies were carried out in tropical climates, particularly in the tropical region of Africa. Table 6.9 summarizes the findings from other related works from other parts of the world. The findings are compared with the results of this study.

Table 6. 9. Some results of studies on thermal comfort of primary school children worldwide

Some Previous Studies	Location	Climate	Season	Vent*	Age	Respondents	Comfort range (°C)	Neutral temperature (°C)
Chen, Hwang & Shih (2014)	Taiwan	Subtropical	Spring	MM	-	-	Upper limit:29.3-29.7	-
Pereira, Raimondo, Corgnati, and da Silva (2014	Portugal	Mediterranean	Mid-season	NV	16-19	45	22.1-25.2	-
Haddad et al 2014	Iran		Spring	NV	10-12	1605		22.8
Trebilcock and Figueroea (2014)	Chile	Mediterranean	Winter/Spring	NV	9-10	2100		21.1summer
De Dear et al 2015	Australia	Subtropical	Summer	NV, AC	10-18	2850	18-27.5	22.4
Nematchoua et al (2013)	Cameroon		Tropical	NV			23.4-25.8	
d'Ambrosio Alfano et al. (2013)	Italy	Mediterranean	Winter and summer	NV	11-18	App. 4000	-	20
Teli et al 2012	UK		Spring	NV	7-11	230		20.8
Liang & Hwang 2012	Taiwan	Subtropical	Whole year	NV	12-17	1614		Autumn 22.4 Spring 29.2
Al- Rashidi et al (2009)	Kuwait	Hot dry	Mid season	AC	12-17	336	19-23.5	21.5
Hwang et al 2009	Taiwan	Sub tropical	Mid season and Winter	NV	11-17	1614	22.7-29.1	17.6-30.0
Karyono et al (2004)	Indonesia		Tropical	NV, AC				24.9
Wong & Khoo 2003	Singapore		Summer	NV	13-17	493		28.8
de Paula Xavier & Lamberts (2002)	Brazil	Tropical	Summer	NV	15-18	108	27.3-29.3	28.8
Kwok 1998	USA		Winter and Summer	NV, AC	13-19	NV 2181 AC 1363	22-29.5	NV 26.88 AC 27.48
Auliciems 1975	Australia	Subtropical	Winter	NV	8-17 12-17	--		Primary 24.2 Secondary 24.5
Humphreys (1976)	UK	Temperate	Summer	NV	7-11	262	24-26	-
Auliciems 1973	UK	Temperate	Summer	NV	11-16	624		19.1
Pepler 1972	USA	Temperate	Mid-season Winter	NV, AC	7-17	NV 100 AC 66		NV 21.5-25 AC 22-23
Auliciems 1969	UK	Temperate	Winter	NV	11-16	624		16.5

The neutral temperature reported in this study (28.8ºC) is close to the values obtained in some other studies done in other tropical field works in naturally ventilated classrooms in the warm and humid environment; 28.8^{o}C in Singapore by Wong & Khoo (2003), 28.4^{o}C in Malaysia by Hussein & Rahman (2009), 28.2^{o}C by Karyono & Delyuzir (2016) in a public primary school in a warm and humid Indonesia, 28.8^{o}C in Brazil by de Paula Xavier & Lamberts (2002), 28.03^{o}C in a school in Mexico, a hot and humid environment with comfort range of 25.4-30.6^{o}C (Cetz & Azpeitia, 2018). The reason for the similarity in the results may be related to the similarity of the climatic conditions in these countries and that of this study. However, the neutral temperature obtained in this study is higher than the neutral temperatures obtained in the same tropical environment in Ghana (26.8^{o}C and 27.4^{o}C) by (Appah-Dankyi & Koranteng, 2012). It is also higher than the neutral temperatures obtained in a study from a neighbouring country, Cameroon in both seasons; 25.0°C in Douala and 24.7°C in Yaounde, (Nematchoua et al., 2014). Differences in the prevailing temperatures may be the reason for the differences in neutralities in temperature. For example, the mean outdoor temperature reported in the study in Ghana was 26.8°C, while the mean outdoor temperature in this study is 29.6°C. This suggested that the neutralities are closer to the operative temperatures of each of the respective study areas. This confirms the relationship between the outdoor temperature and neutrality experienced by building occupants. Generally, the neutral; temperature in this study agrees with the neutral temperature range of between 24.5-28.9^{o}C reported by (Zomorodian et al., 2016) as that obtainable in group A classified by Koppen-Ginger as tropical/mega thermal climates. This study is located in this tropical region.

Furthermore, lower neutral temperatures were obtained in colder climates. For instance, R. de Dear & Fountain (1994) observed value of 24.5^{o}C for both seasons (wet and dry), while in Brisbane de Dear & Auliciems (1985) obtained neutral temperature of 23.8^{o}C. These values of neutralities were similar. But in this study, the thermal neutrality and together with those from warmer climates are higher. The climate of these countries differs from the tropical climate. According to F. Nicol et al., (2012), people in warmer climates may prefer a thermal state that is ‘slightly cool’, while people in cold climates may prefer a ‘slightly warmer’ thermal preference. This may be linked to adaptation, according to Schweiker, Huebner, Kingma, Kramer, & Pallubinsky (2018) adaptation to warm conditions leads to a higher neutral temperature for thermal comfort.

The comfort range obtained in this study for combined classrooms all season (25.8-31.6^{o}C) is comparable to the ones obtained in studies conducted in schools. For example, (Hussein & Rahman, 2009) in a study conducted in naturally ventilated classrooms in Malaysia, a tropical country, obtained a comfort temperature between the range 26.0 to 30.7^{o}C. The range is also comparable to other studies in classrooms in the tropics; 25.4-30.6°C by Cetz and Azpeitia (2018) in a primary school in Mexico; 27.1-29.3°C by Wong & Khoo (2003) in a study conducted in a school setting in Singapore

Furthermore, in this study, the mean outdoor temperature and the comfort temperature for combined classrooms all season (Chapter 5) were within the ranges between 23.0-37.4°C (Table 5.12) and 25.8-31.6°C, (Table 5.22) respectively. As summarized in Table 6.9, most previous results on thermal comfort in the tropics such as ; Nematchoua et al., (2014) and de Paule *et al.,* (2002) produced similar outdoor and comfort temperature ranges with the one observed in this study. However, results from studies in the cold and Mediterranean climates produced lower outdoor temperatures and lower comfort temperatures in the ranges between 16-26 °C as shown on the Table. It is clear from the results that people living in the tropics are comfortable at higher temperatures compared to those living in cold climates. This is in agreement with Humphreys *et al.,* (1992) who posited that comfort temperature tends to correlate with the mean outdoor temperature, and people who live in a tropical climate tend to be comfortable at a higher comfort temperature than those who live in temperature or cold climates.

Comparing R-Square Value with Previous Works stop

The R square produced in this work (0.51) is comparable to the ones produced in other related works. investigated thermal comfort The relationship between the room temperature and the thermal sensation of the average occupant, and the estimate of the sensitivity is the regression coefficient. The coefficient of determination (R-square) is another way of checking how sensitive building occupants are to variations in indoor temperatures. However, for surveys involving human behaviours an R-square value as low as 0.40 is often considered a strong correlation (Mishra & Ramgopal, 2015). Lower R-square indicates better adaptation to indoor thermal conditions. The lower value reported by the children suggests that the studied children are tolerant to the changes in the indoor thermal conditions. Some thermal comfort works on children reported similar low R-square values. For example, Teli et al in UK primary schools reported R-square value of 0.545 and posited that the correlation is satisfactory (Teli et al., 2012). Trebilock & Figueroa (2014) conducted thermal comfort studies of pupils in Chile during the summer period and produced an R-square with value of 0.297. Also, (Karyono & Delyuzir, 2016) got an R-square of 0.37 in a state primary school and 0.52 in private primary school all in Tangerang Indonesia. These are indications that the children's thermal responses has larger variations than that of adults. Furthermore, in several comfort studies in Naturally Ventilated (NV) buildings, the coefficient of determination (R-square) is usually low, such as in a study by Rijal et al., (2015) in Japan, where the R-square was less than 0.5, and by (Feriadi & Wong, 2004) in Indonesia, where R-square was less than 0.2. The results of the thermal perception of the teachers (adults)who share the same classroom with their students are further used to compare the thermal perception between these two groups of people. The findings of the thermal perception of the teachers are provided in the subsequent section, while Chapter six compares the perception between these two groups of people.

6.3.14 Comparison With Previous Works Conducted in Nigeria

Since there were no previous thermal comfort studies that involved children in Nigeria, this comparison can do with other research works that involve adults. All the previous thermal comfort studies carried out in Nigeria used adults in their investigation and did not involve children. The findings in this work showed that the neutral temperature for the combined classrooms all season obtained from this work (28.8°C) is closely related to some other studies on thermal comfort in Nigeria. The neutrality is closely related to T_n = 28.4°C obtained by ,Akande & Adebamowo (2010) T_n = 28.2°C from Adaji et al., (2017) and also, related to T_n = 28.8°C obtained by Efeoma (2017). The first observation is that, though the locations of these studies differ, however, the work of Akande and Adebamowo and that of Adaji were located in the same climatic zone (warm and humid climate) where they experience similar climates. Though the work of Efeoma was conducted in hot humid conditions, this work and his work are located in the same previous region (the Eastern Region). The adaptive comfort model posits that the neutral temperature in naturally ventilated buildings closely tracks the outdoor temperature. The second observation is that the neutrality of the children did not vary from that of the adults. The reason may be because the children at home stay in the same house with their parents (adults) and likely become used to the temperatures their parents found neutral. In schools, they found similar neutral temperature in line with 'expectation tendency' expounded by the adaptive comfort model.

Another similarity shared by this work and that of Akande & Adebamowo (2010) is that both studies reported higher neutral temperatures in the rainy season and lower neutral temperature in the dry season. A close examination in Table 6.10, one will observe that the neutral temperature of some of the studies varied significantly with the one produced in this study. For example, neutral temperature from the fieldwork of Ogbonna & Harris (2008) was lower than this study by 2.6°C. The reason for the significant difference is obvious. The work was conducted in Jos Nigeria, a location where the temperature is, for the whole year, cooler than the temperature in the study area. While the city of Jos reports an average monthly temperature between 21-30°C, the temperature in Imo State ranges mostly between 28-30°C. Adunola & Ajibola (2012) conducted a study in Ibadan and produced a much higher neutral temperature of 32.3°C compared with the one produced in this study. The high difference in the neutral temperatures may be because the survey was conducted in only one month (April).

Table 6. 10: Results of some thermal comfort studies conducted in Nigeria.

Location	Researcher	Year	Weather	Building	Survey group	Seasons	Key research findings
Imo State	This study	2020	Warm Humid	School	Children	Rainy& Dry	1.Regression equation: TSV =0.29 T_{op} -8.33 2.Neutral temperature T_n = 28.8°C 3. Acceptable comfort range: 25.8-31.6°C
Enugu	Efeoma M.	2016	Hot Humid	Office	Adults	Rainy and Dry	1 Regression equation: TSV =0.250 T_{op} -7.197 2. Neutral temperature T_n = 28.80°C 3. Acceptable comfort range: 25.4-32.2°C
Okigwe	Okafor et al	2016	Warm Humid	Residential	Adults	Dry Season	1. Traditional building recorded mean Indoor temp 28.8°C both seasons. 2. Contemporary building recorded mean indoor temp of 29.4°C for both seasons
Abuja	Adaji et al	2015	Hot Humid	Residential	Adults	Dry Season	1. Regression equation house 1: TSV =0.46 T_{op} -9.62 2. Regression equation house 2: TSV =0.31 T_{op} -4.74 3. Neutral temperature house 1 T_n = 29.6°C 4. Neutral temperature house 2 T_n = 28.2°C
Ibadan	Adunola A.	2014	Hot Dry	Residential	Adults	April	1. Regression equation: TSV =0.483 T_{op} -15.59 2. Neutral temperature T_n = 32.4°C
Ogun	Adebamowo & Akande	2012	Warm Humid	Hostel	Adults	-	1. Regression equation: TSV = 0.24 T_{op} -6.982 2. Neutral temperature T_n = 29.09°C
Bauchi	Akande & Adebamowo	2010	Hot Dry	Residential	Adults		1. Regression equation: TSV =0.357 T_{op} -10.2 (Dry season) 2. Regression equation: TSV =0.618 T_{op} -15.4 (Rainy season) 3. Neutral temperature rainy season T_n =28.44°C 4. Neutral temperature dry season T_n = 25.04°C
Jos	Ogbonna & Harris	2008	Temperate Dry	Residential & Classroom	Adults	July & August (Rainy season)	1. Regression equation; TSV =0.3589 T_{op} -9.4285 2. Neutral temperature T_n = 26.27°C 3.Acceptable comfort range=25.5-29.5°C Top 4. PMV neutral temperature T_n = 25.06°C
Lagos	Adebamowo	2007	Warm Humid	Residential	Adults		1. Neutral temperature T_n = 29.09°C
Ibadan	Akingbade	2004	Warm Humid	Residential	Adults	Dry Season	1. Comfort range 28°C-32°C
	Ojesu et al	1955	1.Temp Dry 2.Hot Humid 3.Warm 4.Humid	Office	Adults		1. Acceptable comfort zone=21-26°C 2. Acceptable comfort zone=18-24°C 3. Acceptable comfort zone=21-26°C 4. Acceptable comfort zone=21-26°C
P/Rivers	Amber		Warm Humid	-	Adults		1. Neutral temperature T_n = 23.13°C

6.3.15 Comparison with Adaptive Comfort Model

Comparing Acceptable Temperature with Adaptive Comfort Model

The present study on acceptable range of temperatures of the children categorized according to season, time of day and classroom type indicated that the studied children accepted warmer conditions than the one predicted by ASHRAE adaptive comfort model. The comfort temperature specified by the standard (for summer) for sedentary activity is between 26-28^{o}C (ASHRAE, 2004; Appah-Dankyi & Koranteng, 2012). The upper limit of the acceptable range of temperature in the combined classrooms all seasons was by 3.6^{o}C warmer than the upper limit of the Standard. According to season, the upper limit of the comfort range was by 3.4^{o}C and by 2.2^{o}C in rainy season and dry season, respectively higher than the upper limit of the standard. Furthermore, according to time of day the upper limit in the morning hours was by 3.2°C higher than the upper limit in the standard and in the afternoon hours the upper limit in the afternoon hours was by 4.2°C higher. According to classroom type, the upper limit in the combined open classrooms was by 4.3°C higher than that of the standard and was by 2.5°C higher than the standard in the enclosed classrooms. These results suggested that irrespective of the season, time of day and classroom type, the studied children in Nigeria, a tropical country, 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. The result is consistent with some previous studies that came out with similar findings of the comfort temperatures outside the ASHRAE recommended range (Saleem et al., 2016; Wong & Khoo, 2003).

Comparing RH votes on ASHRAE Prescription

Although the RH exceeded the upper limit of the range prescribed by ASHRAE Standard by approximately 23% of the time (upper limit of the standard is 70%), however approximately 71% respondents were satisfied with the indoor humidity. This suggests that occupants were not too sensitive to humidity variation and perceived their condition to be comfortable independent of the humidity level, especially when the RH is less than 90%. This result also confirms Jørn Toftum, Jørgensen, & Fanger (1998) conclusion that the effect of variation of humidity on thermal comfort may be very small in a certain range, but it becomes apparent at high temperature.

Table 6.11 compares the percentage acceptability of RH above 80% in both categories of classrooms. Generally, the number of recorded counts indoor RH above 80% appeared in the classrooms was low, especially in the open classrooms. RH above 80% has very high acceptability in the open classrooms all the time during the morning and afternoon surveys. The highest acceptability of 99% was recorded in the morning hours, while 87% was recorded in the afternoon survey. Even with a high variation of mean indoor operative temperature between the morning and afternoon surveys in classroom A_{OP} (2.8°C) and in classroom Bop (3.0°C), the acceptability to RH were still high in both periods. In the enclosed classroom, acceptability was high in the morning hours but low in the afternoon hours in spite of the marginal variation in the mean operative temperatures between the morning and afternoon surveys in both classrooms A_{EN} (0.2°C) and B_{EN}(2.0°C). Apart from suggesting that relative humidity has a marginal effect on thermal comfort it also means that occupants of buildings in the warm and humid climates can be comfortable at humidity higher than 80%.

Table 6. 11. Comparison of acceptability of RH above 80% in both categories of classrooms

Classroom Type	Morning (7.30am-11am)		Afternoon(11am-2.30pm)	
	Accepted	Not Accepted	Accepted	Not Accepted
Combined Open	69(99%)✓	1(1%)	61(87%)✓	9(13%)
Combined Enclosed	133(86%)✓	22(14%)	94(65%)✗	50(35%)

Furthermore, 89% of the occupants of the combined open classrooms accepted the mean relative humidity of 73.4% recorded in the classrooms, while 74% of occupants of the enclosed classrooms accepted the mean relative humidity of 80.3% recorded in the enclosed classrooms. No significant differences in humidity acceptability based on the differences in the indoor operative temperatures were observed. For example, when classroom A_{OP} in the morning hours recorded a mean operative temperature of 26.7°C with a mean relative humidity of 77.1%, 80% of the occupants accepted the relative humidity. In the afternoon, when the indoor operative temperature recorded a mean value of 29.5°C with mean RH of 72.0%, 82% of the occupants (almost the same percentage in the morning) accepted the RH even when the operative temperatures in both categories of classrooms varied significantly by as much as 2.8°C. The finding is in line with that of (Zhai et al., 2015) whose result indicates that at temperatures of 26, 28, 30°C, though the acceptability to humidity was consistently lower at 80% than at 60% the differences were not statistically significant. This goes to show that RH with respect to temperature may not have a significant effect on the thermal comfort perception of the occupants.

Comparing AMV and PMV on ASHRAE scale

The results of the field results were compared with the predictions of the PMV model. When the temperature predictions of both were evaluated based on thermal sensation votes on the negative and positive sides of the ASHRAE 7-point scale, both the AMV and PMV gave different results. The regression graph in Figure 5.71 of Chapter 5 showed that for the same level of indoor operative temperature, the Predicted Mean Vote (PMV) was greater than the Actual Mean Vote (AMV). This suggests that occupants' behavioural adaptation can provide better opportunity to achieve thermal comfort at a relatively higher indoor operative temperature at the warmer environment found in the tropics. The same finding was also observed in most other thermal comfort studies such as Yao et al, (2009), Plabit et al, (2014), Humphreys (1975), Mowakked et al, (2008). These studies were conducted in the warmer environment.

Furthermore, the results of the regression analysis of AMV and PMV upon the indoor operative temperature shown in Equations 5.3 and 5.4 of Chapter revealed that at neutrality (0) the PMV underestimated the observed neutral temperature by 3.5K. The bandwidths were 5.8^{o}C for the AMV and 5.5^{o}C for the PMV. The upper limit of the PMV was by 3.6^{o}C lower (narrower) than that from the actual TSV (AMV). The findings in this work clearly showed that the temperature predicted by both the AMV and PMV varied, and in most cases the variations were significant. The result is consistent with some previous works for PMV model which shows that the PMV predicts narrower comfort range compared to TSV (Indraganti et al., 2013). This further indicated that the PMV is not a suitable model for use in the study area. The reasons for the discrepancies in the results of AMV and PMV have been extensively discussed in literature by thermal comfort researchers. Humphreys and Nicol (2002) stated that the cause of the difference between the AMV and PMV are the variables inputted in the PMV calculation because Fanger's PMV model was developed based on variables such as; air temperature, relative humidity, air velocity, metabolic rate and clothing insulation. He argued that the introduction of any errors in their measurement of these variables may eventually lead to major error in the entire PMV calculation. Brager et al., (1993) earlier posited that the accuracy of the measurement of the input data, which includes the four environmental parameters and the two personal factors may not be assured during field works. Albatayneh et al., (2017) further argued that the PMV/PPD studied do not provide occupants clothing details, leading to specific clothing level assumption. Brager et al., (1993) estimated the error of the clothing value to reach 20%. To overcome these discrepancies between the PMV and AMV in warm climates, Fanger and Toftun recommended the introduction of the expectancy factor, ie, on PMV model. However, the introduction of the expectancy factor does not actually eliminate the discrepancies completely. Hence, the PMV model is said to be unsuitable for use in naturally ventilated buildings due to the unstable physical environments and metabolic rates (Chun et al., 2004).

Furthermore, the regression of PMV on indoor OT yielded a much lower neutral temperature of 25.4^{o}C, while neutral temperature of AMV is 28.8^{o}C. Similar discrepancy was observed in other studies

To further understand the relationships between the AMV and PMV, their thermal comfort acceptability range is considered based on Equations 5.3 and 5.4 of Chapter 5. Any mean vote between the range -0.85 to +0.85 and -0.5 to +0.5 for 80% and 90% thermal acceptability, respectively is deemed acceptable (Fanger, 1970; ASHRAE, 2004; Iso, 2005). From these two Equations (5.3 and 5.4), AMV predicts 80% and 90% thermal comfort range to be between 25.8-31.6 ^{o}C and 28.7-30.4^{o}C, respectively. The observed 80% and 90% thermal comfort range for the PMV were found to be between 22.5-28.0^{o}C and 23.6-26.9^{o}C, respectively. The results show that the observed (AMV) produced wider thermal comfort ranges than the predicted (PMV), considering both the 80% and 90% acceptability criteria.
Adopting the PMV ±0.85, the acceptable indoor temperature for the combined classrooms all seasons produced in this study, 25.8-31.6^{o}C, is within the range of 24.0-31.0^{o}C observed by Mishra & Ramgopal (2015) from the various thermal comfort studies in classrooms in the tropics. This indicates a comfortable bandwidth of 5.8K for the studied children in the combined classrooms all seasons. Using the actual mean PMV restriction of $-0.5 \leq TSV \leq +0.5$ at 90%, acceptability criterion (10% PPD) limits the comfort to a narrower comfort range between 26.4^{o}C-29.7^{o}C, indicating a comfort bandwidth of 3.3K. This is almost half of the bandwidth gotten from the TSV range between -0.85 to +0.85.

6.3.16 The use of environmental controls for adaptation

Some research works on thermal comfort seems to suggest that schoolchildren often do not have access to environmental controls because of the presence of their teachers. As reported in section 5.3.16 of chapter 5, the percentage of the children who indicated having access to available adaptive opportunities in the classroom was 48.2% an indication that a majority of the students do not have access to the controls. The use of environmental controls in the classrooms were carefully observed by the researcher and his assistant and the frequency of their usage was recoded in a notebook. The compiled data from the notes showed that a majority of the students who indicated having access to the windows and doors in the classrooms were sitting very close to these controls. This suggested that those children who were not close to the controls could have been able to have access to them if they sat near the controls. This shows that proximity to environmental controls has a positive relationship with their usage, which is an important consideration in adaptation. Access to these controls could help in mitigating their thermal discomfort.

The follow-up question that asked the children the reason for using the controls showed that the preference to feel cooler was a popular choice using the controls. The preference to use these controls to be cooler was higher during the afternoon period irrespective of the season. The preference was however higher during the afternoon of the dry season compared with the afternoon of the rainy season. An earlier report in this study revealed that the subjects were exposed to a higher indoor temperature in the afternoon hours than in the morning hours, irrespective of the season. This caused thermal discomfort to the subjects and to overcome the thermal discomfort they resorted to the use of environmental controls.

Furthermore, the result of the behavioural actions observed during the survey period shows that the number of times the subjects opened the windows in the morning hours during the rainy season was higher compared to the morning hours during the dry season. The reason for closing the windows was not because of the rain coming through the window, rather it was because of cold. The occupants in the classrooms encounter cold because of the cold breeze from the outdoor. The outdoor temperatures at this period of the season are usually low. Another observation that is an adaptive action is that they put on additional clothing such as sweatshirts to adapt to the changes in the indoor thermal environment. This indicated that thermal comfort is influenced by adaptation

Operable windows and doors enhance natural ventilation in warm and hot climates, helping building occupants to modify the indoor thermal conditions. Of all the adaptive controls, windows have the biggest effect on indoor climate and a person near the windows will have the greatest control over it. During the morning hours, some windows were observed to be closed, some were wide open while a few were completely opened. As the day progressed from morning to afternoon, the indoor air temperature was increasing and the children were observed to be opening the windows,. All the windows were observed to be completely opened as the indoor temperature exceeded 29.0^{o}C. This suggests that the opening of windows correlates with an increase in temperature. Opening the windows allows more air to enter the classrooms helping the occupants to overcome the effects of the rising temperature. This indicates that the indoor air velocity in the classrooms needs to be enhanced using fans. The use of low wattage fan, as low as 20 watts, can increase air movement and can be able to save 17-48% energy use (Schiavon & Melikov, 2008).

6.4 Comparing Thermal Perception of the Children with that of their Teachers (Objective iv)

This section compares the thermal perception of the young children and that of their teachers who stay in the same indoor environment with them. The differences observed in the analysis of their thermal sensation votes, neutral temperatures, comfort range and sensitivity to temperature changes are summarized in Table 6.12 and discussed in the subsequent sections.

Table 6. 12. Summary of thermal comfort perception of children and teachers

Group	Neutral Temp (°C)	TSV mean	Comfort Bandwidth		Comfort limits				Sensitivity	Correlation Coefficient (R^2)
			±0.85 (80%)	±0.5 (90%)	Upper ±0.85 (80%)	Lower ±0.85 (80%)	Upper ±0.5 (90%)	Lower ±0.5 (90%)		
Children	28.8	+.16	5.8	1.7	31.6	25.8	30.4	28.7	0.29	0.51
Teachers	28.9	+.55	1.9	1.1	29.9	28.0	29.5	28.4	0.87	0.70

6.4.1 Comparing Thermal Sensation and Preference

Thermal sensation

Poor correlation was found between the thermal sensation of the schoolchildren and teachers. While the mean thermal sensation of the teachers is +0.58 that of the children is +0.16. This suggested that the teachers perceived their indoor environment warmer than the children felt by 0.42 scale units. Also, the mean thermal sensation of the children was within the 90% comfort zone (-0.5 to +.05) while that of the teachers were outside this comfort zone. However, both classrooms showed commonality by having the mean thermal sensation votes falling within the 80% comfort zone (-0.85 to +0.85).

Another way of comparing the thermal sensation votes of these two age groups is a check on the results of the voting on the 7-point ASHRAE rating scale. As already discussed and further summarized in Figure 6.4, 82% of the children voted on the three central categories of ASHRAE scale (-1,0,+1), while 71% of the teachers cast their votes on the same central category. Because voting on the 3-central categories of the ASHRAE scale is taken as 'comfortable', the result suggested that the teachers perceived the indoor environment less comfortable when compared to the young children. The histogram further highlights other differences in the voting of the children and their teachers. While half of the class of the school children voted 'okay', only about a quarter of the teachers voted 'okay'. Furthermore, while 20% of the teachers voted on the warmer side of the scale (+3, +2), 15% of the children voted on the same side of the scale.

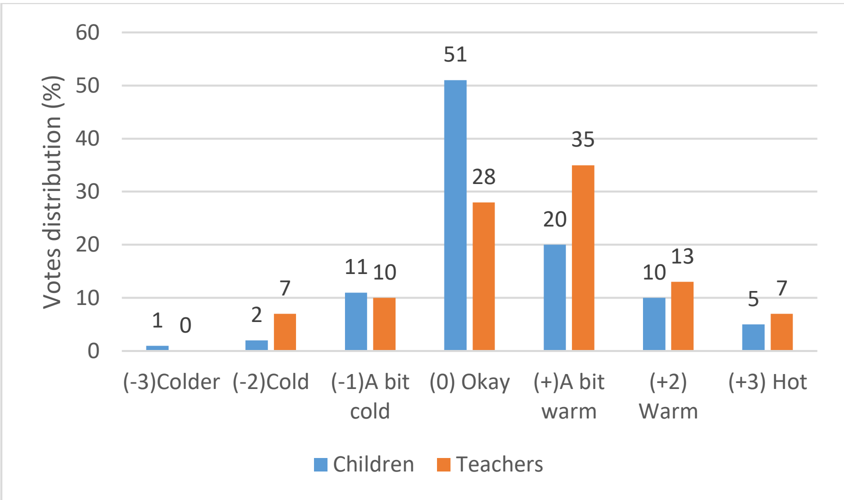

Figure 6.4: Comparing thermal sensation votes of teachers and schoolchildren

.Considering the thermal sensation votes of the schoolchildren and their teachers based on diurnal variation gave similar distribution patterns as observed in their thermal sensation all season as earlier discussed. The mean thermal sensation votes in the morning hours were -0.16 (SD 0.66) and -0.01 (SD 0.49) for the teachers and the students, respectively. At these mean thermal sensation votes, the teachers perceived the indoor environment colder than what the children felt. In the afternoon periods, the mean thermal sensation votes, of the teachers was

+1.0 (SD 0.52) and that of the children was +0.49 (SD 0.57). The teachers felt warmer that their students by a significant mean thermal sensation vote of +0.51. The result, apart from highlighting the differences, also suggests that the thermal sensation of the teachers in the afternoon hours was outside the 80% and 90% comfort zones.

Further observations on the differences in the thermal sensation votes between these two groups of people are additional proof of the differences in how they perceived the indoor thermal environment they use at the same time. For example, on October 13, the mean thermal sensation votes were -0.04 and -0.06 for the children and the teachers, respectively in the morning hours. Again, in the morning hours of October 16, one of the coldest days of the survey, the teachers expressed thermal sensation with a mean value of -1.6, while the mean value of the children was -0.86. In one of the hottest days of the survey (Oct 19), the mean thermal sensations were 1.8 and 0.82 for the teachers and the schoolchildren, respectively.

Thermal Preference

Poor correlation was also observed in the thermal preference of the students and the teachers, especially on the wanting to be warmer side of the 3-point McIntyre preference scale. While 13% of the students would prefer to be warmer, 28% of the teachers would prefer warmer conditions, indicating a significant difference in preferring to be warmer by 15%. 37% of the school children would prefer to remain in the thermal state they found themselves, while 32% of the teachers would rather prefer to remain in the thermal state they found it. Using the thermal sensation scale, alongside the thermal preference scale, reveals further differences between these two age groups. Relating the votes in Figures 6.4 and 6.5, 14% of the children who voted neutral on the thermal sensation scale would rather prefer to be cooler or warmer. While 4% of the teachers who voted neutral on the thermal sensation scale would rather prefer to be ‘okay’ on the preference scale. The reason for this higher shift in these two scales by the children may be linked to their higher metabolism when compared to that of their teachers. The higher activity of the children, when compared to that of their teachers, results in the high fluctuations (unsteady) in their body temperature.

However, both groups of people shared commonality by casting more votes on preference to be ‘cooler’ than on preference for ‘no change’ and on preference to be ‘warmer’; 40% for the teachers and 50% for the school children in combined classrooms all season.

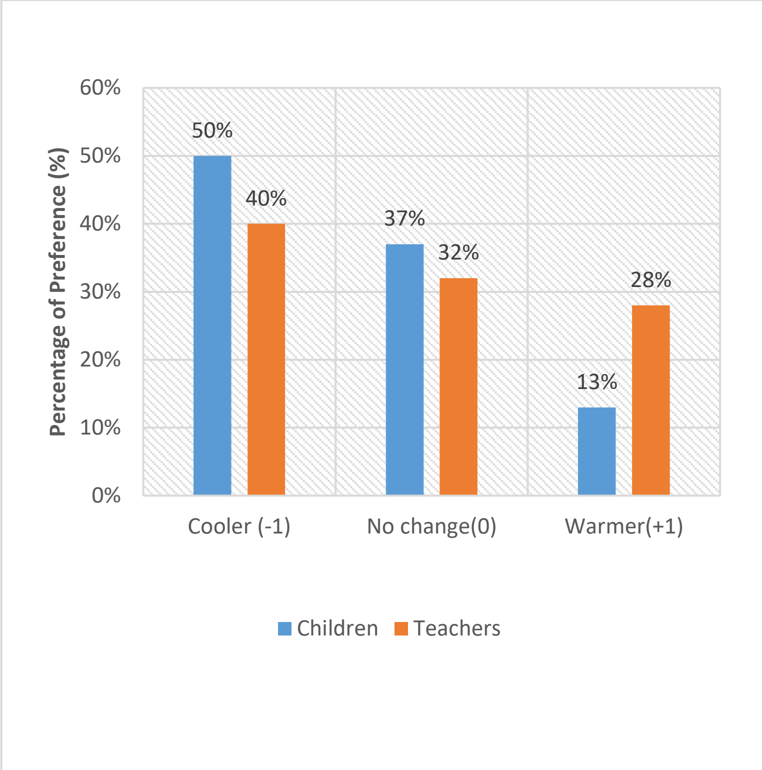

Figure 6.5: Comparing thermal preference of teachers and schoolchildren

Table 6. 13. Comparing comfort perception of teachers and schoolchildren

Participants	**Mean Indoor Operative Temperature (ºC)**	**Neutral temperature(ºC)**	**Preferred temp(ºC)**	**Comfort Range(ºC)**	**R Square**	**Sensitivity to temperature changes**
Pupils	29.1	28.8	27.4	25.8-31.6	0.518	3.4
Teachers	29.1	28.9	*27.9*	28.0-29.9	0.70	1.2

Table 6. 14. Comparing mean thermal sensation of teachers and schoolchildren

CLASSROOM	Season	Operative Temperature (°C)				Mean Thermal Sensation	
		Aver	SD	Min	Max	Students	Teachers
A_{OP}	Rainy	28.6	2.1	22.9	34.7	0.06	0.57
	Dry	29.6	1.5	26.3	35.6	0.31	1.9
A_{EN}	Rainy	29.0	1.4	25.9	33.6	-0.07	0.25
	Dry	29.9	1.8	26.8	35.1	0.67	1.40
B_{OP}	Rainy	29.3	2.1	22.5	37.2	-0.15	0.80
	Dry	27.7	1.4	22.5	30.2	0.09	1.9
B_{EN}	Rainy	29.2	1.6	25.0	30.6	0.36	0.94
	Dry	28.7	1.1	25.8	30.5	0.29	1.4
Cop	Rainy	28.7	2.2	23.7	40.1	-0.15	-0.7
	Dry	28.8	.72	26.5	29.6	0.34	-0.1
C_{EN}	Rainy	29.2	2.3	25.0	39.8	0.12	1.3
	Dry	28.7	.71	26.2	29.5	0.34	0.4
All classroom types	All seasons	29.1	1.8	22.5	40.1	0.17	0.80

6.4.2 Comparing Comfort Range

Results indicated that the children were more adaptable to the indoor thermal conditions compared to their teachers considering the comfort bandwidths, the comfort limits and sensitivity to temperature changes. For the 80% acceptability (±0.85), the comfort bandwidths were 5.8K and 1.9K for the children and the teachers, respectively which indicated a significant comfort band difference of 3.9K. For the 90% acceptability (±0.85), which is a tighter acceptability criterion, the comfort bandwidths were 1.7K for the children and 1.1K for the teachers. This suggests that the comfort range of children are wider than that of the adults as observed in a previous work of (Al-Khatri et al., 2020). The results further suggested that the thermal sensation votes of the children were more spread compared to that of their teachers in the same indoor environment. The diverse activity of the children that produced different metabolic rates and the inability of some of them to adapt as they wished because of some restricted adaptive opportunities likely influenced the diverse result in their thermal sensation. The teachers' activities were similar to one another and resulted in a similar metabolic rate. Equally, all the teachers had the freedom to use adaptive opportunities available in the classrooms. These influenced the clustering of the result of their thermal sensation. The observation in this work about the difference in comfort perception of children and adults was also highlighted in the previous works of some thermal comfort researchers. For example, Humphreys (1977) found out that the levels of responses between children also have a lot of variance and classroom activities are more diverse than adult activities over a typical day. (Mishra & Ramgopal (2013), also observed in a review paper on field studies on thermal comfort that children have different levels of thermal sensation, different metabolic rates, different clothing restrictions, and different sensitivities to temperature changes.

Furthermore, a check on the summary Table 6.13 shows that differences also existed in thermal perception between these two age groups, considering the upper limits and the lower limits of the comfort temperature. For instance, while the upper limit of the children was 31.6°C that of their teachers was 29.9°C, a difference in comfort temperature of 1.7K considering the 80% acceptability (±0.85). This suggested that the children accepted higher indoor temperature in the classrooms by up to 1.7K more (higher temperature) compared with the teachers who shared the same classroom environment with them. Also, the children were able to accept lower indoor temperature by 2.2K more (lower temperature) compared to their teachers, considering the 80% acceptability (±0.85). The result is in agreement with the findings from previous works that children likely prefer a cooler temperature than adults (Yun *et al.,* 2009; Hwang *et al.,* 2009; Shamila Haddad et al., 2017; Al-Khatri et al., 2020). In addition, the comfort range of the children from this study was by 3.9K wider than that of their teachers considering the 80% acceptability limit (±0.85).

6.4.3 Comparing Coefficient of Determination (r^2)

The coefficient of determination (r^2) is another way of checking how sensitive building occupants are to variations in indoor temperatures. From the table, it is observed that the regression results from the regression of mean thermal sensation votes and the indoor operative temperatures produced r^2 with value 0.51 for the children and 0.70 for the teachers. The value from the children is low, while that from the teachers is high. However, for surveys involving human behaviours an r^2 value as low as 0.40 is often considered a strong correlation (Mishra & Ramgopal, 2015). Lower r^2 indicates better adaptation to indoor thermal conditions. The lower value reported by the children suggested that the studied children were more tolerant of the changes in the indoor thermal conditions compared to their teachers. This means that a change of 1.9K in the room temperature changed the children's thermal sensation by 1 scale unit. While it needed a change of 1.4k to change the thermal sensation of the teachers by 1scale unit. The results indicated that teachers (adults) were more sensitive to temperature change than are the schoolchildren.

Some thermal comfort research works on children reported similar low r^2 values. For example, Teli et al in UK primary schools reported r^2 of 0.545 (Teli et al., 2012). Trebilock & Figueroa, (2014) investigated the thermal comfort of pupils in Chile during winter and summer periods and produced r^2 of 0.0931 and 0.2971, respectively. Also, Karyono & Delyuzir (2016) got an r^2 of 0.37 in a state primary school and 0.52 in private primary schools all in Tangerang Indonesia. These were indications that the children's thermal responses had larger variations than that of adults. Furthermore, in several comfort studies in NV buildings, the coefficient of determination (r^2) is usually quite low, such as in a study by Rijal et al., (2015) in Japan, in which the r^2 of most of the studies were less than 0.5, and by Feriadi & Wong (2004) in Indonesia, where r^2 was less than 0.2.

6.4.4 Comparing Thermal acceptability and Comfort Temperature

The comparison of the thermal acceptability between the teachers and the schoolchildren, shown in Figure 6.6, indicates that while more than half of the children accepted the thermal conditions, more than half of the teachers did not accept it at the mean indoor operative temperature of 29.1°C, for the combined classrooms all season. For the comfort votes, shown in Figure 6.7, while 70% of the children indicated being comfortable, 64% of the teachers felt they were comfortable.

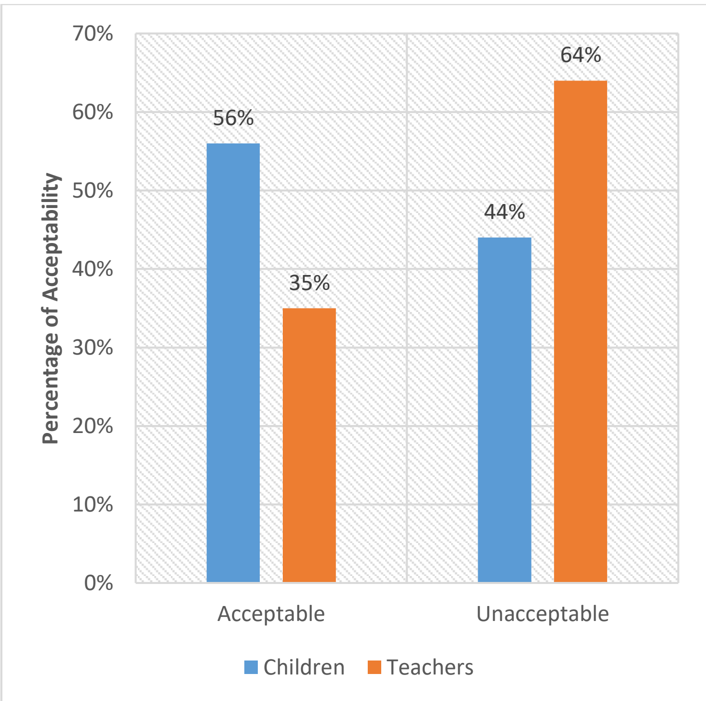

Figure 6.6: Distribution of thermal acceptability

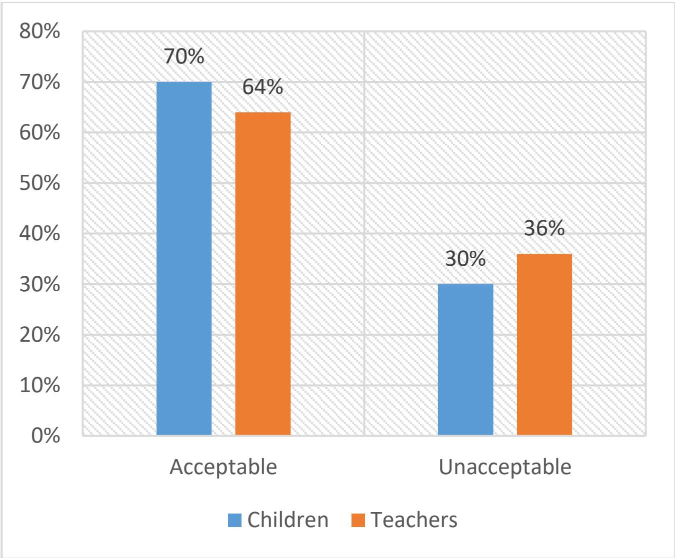

Figure 6.7: Distribution of comfort temperature

6.4.5 **Comparing Humidity Acceptability**

No significant difference in relative humidity acceptability between the teachers and their schoolchildren was found. Relative humidity acceptability of the schoolchildren was 83%, while that of their teachers was 81%.

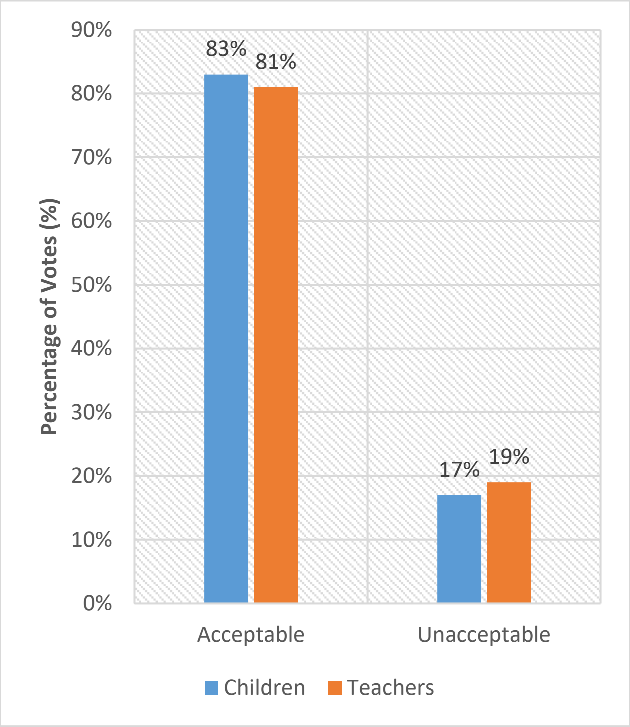

Figure 6.8: Distribution of humidity acceptability

6.4.6 **Comparing Air Movement Acceptability and Preference**

Though the studied children were more satisfied than their teachers with the air flow in the classrooms, however they still preferred more air compared to their teachers. The data obtained by the observing then subjects reveals that the children were not able to take proper advantage of the various adaptive opportunities available in their classrooms. They were not very free to adapt to clothing. For instance, there were instances some of the children who wore sweatshirts in the morning hours, when the environment was cold, still wore them in the afternoon hours, when the temperature has gone up. Furthermore, some of the children were observed not to be free to change their posture during class lessons. Furthermore, the windows (where they were available) were observed to be mostly controlled by their class teachers and, sometimes, by the class monitor of the class.

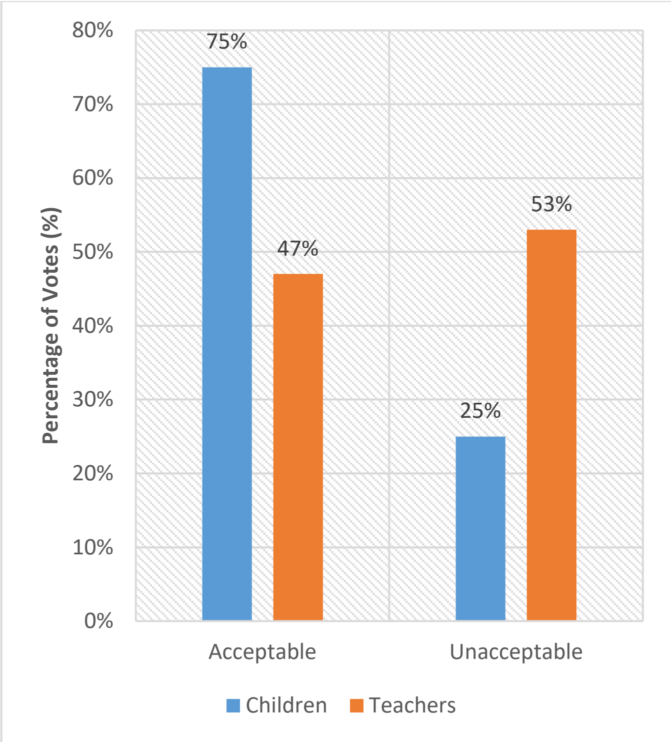

Figure 6.9: Comparing air movement acceptability

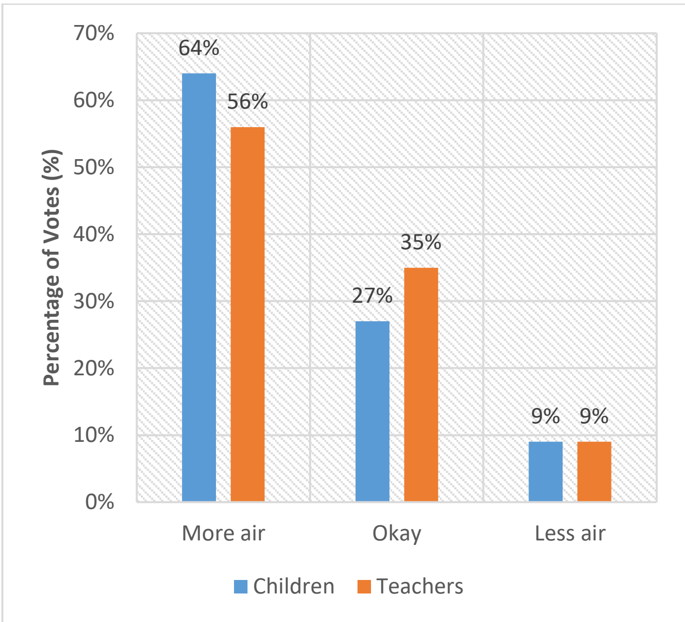

Figure 6.10: Comparing air movement preference

6.4.7 Comparing Results with Previous Works

This work observed disparity in the thermal perception of the schoolchildren with that of their teachers. The finding is in agreement with other related works conducted in other parts of the world that also observed some differences in the thermal perception of the teachers and their schoolchildren. For example, Le et al (2017) found the mean thermal sensation votes of the teachers higher (+0.77) than that of their schoolchildren (+0.33) from a field study conducted in naturally ventilated primary school classrooms in a city in Vietnam. Rivera & Kwok (2019) also confirmed the difference in comfort perception of the teachers and children having observed the tendency of teacher's thermal sensation to tend towards 'slightly cold scales', compared to children whose tendency was towards 'slightly warm' scales.

6.4.8 Summary Comparison

As observed in the literature review, the research on thermal comfort of building occupants championed by Fanger did not include children in the sample of occupants for the investigation of thermal comfort (Nicol et al., 2012). It is of recent that research is being focused on young children for the purpose of assessing indoor thermal comfort. The results from this field work showed some differences between children and teachers in terms of satisfaction with the thermal environment, demonstrating that the children perceived thermal comfort differently from the adults considering adaptive model. This was also observed by thermal comfort researchers (such as Austin *et al.*, 2013; ter Mors et al., 2011; Teli et al., 2013; de Dear et al., 2015; Zomorodian et al., 2016; Jiang et al., 2018) in their separate thermal comfort research. The reasons for the differences in the perception of thermal environments between the school children and their teachers are linked to wide difference in age between these two groups. While the mean age of the children is 9 years that of their teachers is 37 years. Children are known to have different metabolic rate and activity rate when compared to adults, as summarize by Nicol et al., (2012) who posited that the metabolic heat generated for the elderly would have been rather low, because of the age and because of relative inactivity that comes with age.

Apart from such as physiological factors, political considerations may come into play. The general poor state of the classroom structures with hope of an improvement by answering questions could also influence their estimation of their thermal conditions, especially if they are adults. People could automatically link any questionnaire to an opportunity to cry out to the authorities over the poor infrastructure with the expectation of upgrading the building conditions. Thus, the psychological factor is not only affected by the thermal expectations of people but also by their general mental state which is very hard to predict or assess.

Table 6. 15. Comparison of thermal perception of school children and their teachers

	Children	Teachers
Mean Age	9 years	37 years
Neutral temperature	28.8°C	29.0°C
Comfort range	25.8-31.6 °C	28.0-29.9 °C
Bandwidth	5.8	1.9
Upper limit comfort range	31.6	29.9
Lower limit comfort range	25,8	28.0
Sensitivity	0.29	0.87
R square	0.52	0.70
Temp rise per unit scale	3.4	1.2
Mean thermal sensation	+0.16	+0.58
Vote (-1,0,+1)	82%	76%
Neutrality (0)	51%	26%
Thermal acceptability	56%	35%
Comfort votes	70% comfortable	64% comfortable
Air movement	75% acceptable	47% acceptable
Relative humidity	83% acceptable	81% acceptable

6.4.9 **Chapter Summary**

The findings from this work agree with the argument proffered by Humphreys et al. (2015) that there is a tendency for people in warm climates to prefer states that are cooler than neutral. However, additional information from this study indicated that it is not in all cases that occupants in the study area would prefer a cooler environment. Indeed the results indicated that the surveyed children would prefer a warmer than neutral environment in most of the morning hours this survey was conducted.

This study suggests research work on thermal comfort to focus more on diurnal variations in temperatures rather than seasonal variation in temperatures. Results from this study indicated more variations in daily thermal perception than during the seasonal. For example, the difference in the comfort bandwidth is higher when considered on a diurnal basis (2.6K) compared with the difference obtained from seasonal variation (0.6K). This study, together with some previous studies, observed a temperature increase of up to 2.0^{o}C from the morning hours (about 9 am) to afternoon hours (about 1.00 pm).

What is obvious from the discussion of the second objective of this study is that subjects were adapted at the temperatures they were more accustomed to. This conclusion is based on the results of the voting of the young children on comfort vote, where the highest percentage of the subjects voted comfortable at the range of temperatures that prevailed most in the classrooms. Within this range were obtained the comfort temperature, preferred temperature and comfort range of the subjects. There is consistency in the subjects voting when these measures of assessing occupants' thermal perception are analysed and categorized according to season, time of day and classroom type. Based on these categories, the neutral temperatures, preferred temperatures, and the comfort ranges were within this temperature range.

Another observation in this discussion is that the recorded air velocity in the classrooms were generally low with 0.3m/s as the maximum mean value. However, this cannot be confirmed with certainty since the instrument used to record air velocity was not logged continuously as was done in temperature and humidity measurements. However, rigorous spot measurements taken at different positions provided enough evidence about the generally low air velocity in the study area and some information to draw some conclusions. Low air velocity in the warm and humid zones in Nigeria were also observed by thermal comfort researchers such as (Efeoma, 2017); and Okafor, 2016. Furthermore, though ASHRAE standard 55 recommended an elevated air movement up to 0.8m/s (without personal control) and 1.2m/s (with personal control) to enhance thermal comfort, however steady air velocity as high as these recommended values can only be achieved in the study area with the aid of fans. Fans of very low wattage (as low as 3watts) has been shown to yield the equivalent of 3K offset of air temperature Pasut, Arens, Zhang, & Zhai, (2014), while Koranteng & Mahdavi (2010) believes the reduction to be 2K.

This work is consistent with some previous work that found that occupants who live in a warm and humid climate can acclimatize to the local environment. The result also agrees with previous research works on adaptive comfort from hot to humid climates that occupants in naturally ventilated buildings are tolerant towards high fluctuations in temperatures encountered in indoor conditions (e.g Sharma & Ali, 1986; Nicol, 1974; Feriadi & Wong, 2004; Hwang et al., 2009; Zhang et al., 2010; Liang et al., 2012).

Considering the assumption that an increase in temperature by 1^{o}C in the UK during winter to heat indoor spaces causes an increase in energy consumption by about 10% (Humphreys & Hancock, 2007).

The results showed an apparently inconsistency between AMV and PMV, which showed that the thermal sensation of subjects in the indoor space of Imo State climate cannot be simply explained by heat balance indices.

7 Chapter 7: Conclusions

7.1 Introduction

This research was motivated by the lack of information about children's thermal comfort perception in a school setting in a warm and humid climate of Imo State, Nigeria. As a result, this thesis aimed to investigate the thermal comfort perception of the schoolchildren in the naturally ventilated classroom buildings they use for class lessons. There was also a need to investigate the thermal comfort perception of the teachers and to compare the findings with that of the schoolchildren. While trying to achieve these objectives, efforts were made to understand the thermal performance of the two types of classrooms these children use for class lessons. This study allowed a comparison between the two types of classroom buildings used to investigate the thermal perception of the subjects and the comparison between the thermal perception of the children and their teachers. Furthermore, a comparison was also carried out between two different approaches for thermal comfort (rational and adaptive approach) and between the predictions and the observed subjective responses.

This chapter highlights the key findings from the fieldwork and discussed the contributions of this research to the body of knowledge. This chapter concludes by highlighting the limitations of the research and recommends opportunities for future work.

7.2 Final conclusions and contributions to knowledge

Achieving thermally comfortable conditions inside educational institutions, such as in primary schools, is crucial to the health and productivity of the children. To achieve this requires a comprehensive understanding of the student's thermal comfort requirements, which this study attempted to determine.

The most significant contribution of this study is that schoolchildren in naturally ventilated classroom buildings in the warm and humid climate of Imo State, Nigeria are comfortable in conditions that are outside of the comfort zone specifications by ASHRAE standard 55 and International Standard Organization (ISO) The comfort temperature specified by ASHRAE standard 55 during summer is between 26 to 28^{o}C, while the studied children were comfortable in temperatures between 25.8 to 31.6^{o}C. In order words, the studied children can be comfortable at temperatures up to 3.6K higher than the upper limit specified by the standard.

Also, the majority of the children were comfortable at the mean indoor operative temperature of 29.1°C. The finding is in agreement with the previous adaptive comfort research works (from warm to hot climates) which posit that occupants in naturally ventilated buildings are tolerant towards high fluctuations in temperatures encountered in indoor conditions. One of the implications of these findings is that the studied children may not need airconditioned classrooms to be thermally comfortable. They can achieve thermal comfort through adaptation to the indoor thermal conditions. The findings further indicate that naturally ventilated classroom buildings in the study area can help to reduce energy consumption which is a key to achieving sustainability in the building industry. This can be achieved by designing naturally ventilated classroom buildings using passive means (such as using solar shading devices) to reduce the overheating of indoor spaces.

As observed in the literature review, the research on thermal comfort of building occupants championed by Professor Fanger did not include children in the sample of occupants for the investigation of thermal comfort (Nicol et al., 2012). It is of recent that research is being focused on young children to assess indoor thermal comfort. The results from this fieldwork showed some differences between children and teachers in terms of satisfaction with the thermal environment, demonstrating that the children perceived thermal comfort differently from the adults. For example, the upper limit of the comfort range of the schoolchildren was 1.7°C higher than that of their teachers and by 2.2°C lower. While the comfort bandwidth of the children was 5.8K that of their teachers was 1.9K. The schoolchildren experienced a temperature rise per unit scale with a temperature value of 3.4K while that of their teachers was 1.2K. A similar finding was observed by thermal comfort researchers (such as Austin *et al.,* (2013), ter Mors et al., (2011), Teli et al., (2013), de Dear et al., (2015), Zomorodian et al., (2016), Jiang et al., (2018) in their separate thermal comfort studies on children. The reasons for the differences in the perception of thermal environments between the schoolchildren and their teachers are linked to a wide difference in age between these two groups. While the mean age of the children in this study was 9 years that of their teachers was 37 years. Children are known to have different metabolic rate and activity rate when compared to adults, as summarized by Nicol et al., (2012) who posited that the metabolic heat generated for the elderly would have been rather low, because of the age and because of relative inactivity that comes with age. Other important research findings from this study are summarized as follows:

- Findings from this work are consistent with previous works which indicate that there is a tendency for people in warm climates to prefer states that are cooler than neutral.

However, additional information from this fieldwork indicated that this notion is not always the case. The result indicated that the school children preferred a warmer than a neutral environment in most of the morning hours this study was conducted. This information is important because more than 66% of the school day falls within the morning hours.

- A neutral temperature of 28.8^{o}C and comfort range between 25.8 to 31.6^{o}C were obtained using the adaptive comfort zone considering thermal sensation in the range -0.85≤ to ≤+0.85 for an 80% acceptability limit.

- The correlation between the neutral temperature and the mean indoor operative temperature in this study agreed with previous research works which indicated that people who live in warm and humid climates are acclimatized to the local temperature they are used to. The result in this study showed an inconsistency between Actual Mean Votes (AMV) and the Predicted Mean Votes (PMV), which indicated that the thermal sensation of the subjects in indoor classroom spaces in the warm and humid climate, Imo State cannot be adequately explained by heat balance indices.

- The result of this work indicated more variation in daily thermal perception than during the season. For example, the difference in comfort bandwidth was higher during the day (2.6K) when compared with the mean seasonal variation (0.6K). This study, therefore, suggests more research work on thermal comfort to also focus on diurnal assessment.

- The regression gradient from this study (0.29) is consistent with the findings from most previous thermal comfort studies in naturally ventilated classrooms that reported a similar regression gradients. The regression gradient of children is usually lower than that of adults, which implies that children are less sensitive to temperature changes than adults.

- Finally, the result from this fieldwork indicated that the thermal performance between the two types of classrooms differed significantly

7.3 Limitations and opportunities for future research

The current study found that the thermal comfort requirements of schoolchildren in indoor classroom spaces in the warm and humid climate in Nigeria are lower and higher than those specified in International standards. In order words, children in the study area have a higher thermal tolerance than that recommended by the standards. It also means the classroom indoor spaces have the potential to save energy. A good thermal environment can be achieved by appropriate design and construction of buildings.

The work done in this thesis is an important step to understand the thermal comfort perception of school children in a warm and humid climate in Nigeria. However, because of cost and time the study could not consider private schools. Future work is suggested to be carried out in private schools. Furthermore, there is a need for further research work to be carried out in other states in the same climatic zone. The findings from the surveys will help to confirm the findings from this work and reinforce recommendations made in this thesis for an appropriate thermal comfort guideline in a school setting in a warm and humid climate in Nigeria.

Furthermore, this study is considered to be the first project that investigated the thermal comfort perception of school children in Nigeria. Though the school was considered as the best setting to carry out the investigation, however evaluating the thermal requirements of young children in other settings other than in schools (homes, churches, buses) may provide some useful results.

Publications up to date

Munonye, C.C. and Ifebi, O. 2018, 'Assessing Thermal Comfort in relation to Building Design: Case Study of Naturally Ventilated Studio Classrooms in Warm and Humid Uli, Nigeria': *Academic Journal of Science,* Volume 8, Issue 1, Pages 121-132.

Munonye, C.C. and Ji, Y. 2018, 'Adaptive thermal comfort evaluation of typical public primary school classrooms in Imo State': *African Journal of Environmental Research,* Volume 1, Issue 1,

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Munonye, C.C. and Ji, Y. 2018, 'Rating the components of Indoor Environmental Quality in Student's Classrooms in warm and humid climate, Uli Nigeria', *African Journal of Environmental Research* 1(2) 118-129

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Appendices

Appendix A – Ethics

Research, Innovation and Academic Engagement Ethical Approval Panel

Research Centres Support Team
G0.3 Joule House
University of Salford
M5 4WT

T +44(0)161 295 5278

www.salford.ac.uk/

20 April 2017

Charles Munoye

Dear Charles,

RE: ETHICS APPLICATION ST1617-59 - Thermal comfort evaluation of primary school children in the warm humid climate of Imo State, Nigeria: case study of naturally ventilated open and closed space primary school classrooms

Based on the information you provided, I am pleased to inform you that your application ST1617-59 has been approved.

If there are any changes to the project and/ or its methodology, please inform the Panel as soon as possible by contacting S&T-ResearchEthics@salford.ac.uk

Yours sincerely,

Anthony Higham

Appendix B – The Questionnaire (Complete copy)

THERMAL COMFORT SURVEY OF PRIMARY SCHOOL CHILDREN IN IMO STATE ,NIGERIA IN A WARM HUMID ZONE

Charles Munonye. Email: c.c munonye@edu.salfordiac.uk . Tel: +447404060867

Section A: General Information

Name/Code…………….. Date……….. Time …………………

1. Please tick your gender
   ( ) male ( ) female

2. Please write your age
   ( )

3. How long have you lived in this town?
   ( )

4. Does your classroom have any of these?. You can tick more than one.
   ( ) Air conditioner ( ) Fan ( ) Both Air condition and Fan
   ( ) None.

5. Do you use any air-conditioning system at home?
   ( ) Yes ( ) No

6. Do you ride to and from school in an air conditioned car?
   ( ) Yes ( ) No

7. What were you doing in the past 15 minutes (activity) before this survey?
   ( ) Writers/reading/seated) ( ) Writing/reading(standing).
   ( ) Walking about ( ) Eating ( ) Others.

8. Please list what you are wearing right now?
   ( ) Short-sleeve ( ) Long-sleeve ( ) T-shirt
   ( ) Shorts ( ) Trousers ( ) Athletic
   ( ) Underwear Pants ( ) Socks ( ) Shoes

   ( ) sandals ( ) Skirts ( ) Sweater

SECTION B: Personal Thermal Comfort *(Please tick appropriate box)*

9. How are you feeling the temperature in the classroom right now?

Colder	Cooler	A bit cold	Okay	A bit warm	Warmer	Hotter
-3	-2	-1	0	1	2	3

10.Right now I would prefer to be:

Cooler	Okay	Warmer

11.Are the conditions (temperature) in this classroom accepted by you right now?

Acceptable	Unacceptable

12. How comfortable is your classroom right now (General comfort)?

Comfortable	Uncomfortable

13. Do you accept the air movement in your classroom right now?

Acceptable	Unaccepted

14. Right now I would prefer:

More air	No change (okay)	Less air

15. Do you accept the humidity in your classroom right now?

Acceptable	Unacceptable

SECTION C: Personal Controls

16. Which of these controls can you adjust in your classroom? You can tick more than one.

Windows	Doors	Fans	None is available

17. Why do you adjust the control?

Get colder	Get warmer

Thank you for your time in responding to this survey

Appendix C – Sample Publication

Research Paper

BUILDING SERVICES ENGINEERING RESEARCH & TECHNOLOGY

Building Serv. Eng. Res. Technol.
0(0) 1–21

DOI: 10.1177/0143624420911148
journals.sagepub.com/home/bse
SAGE

Evaluating the perception of thermal environment in naturally ventilated schools in a warm and humid climate in Nigeria

Charles Munonye[1] and Yingchun Ji[2]

Abstract

Field study was conducted in naturally ventilated primary school buildings in a warm and humid environment in Imo State, Nigeria to determine the thermal comfort perception of young children (aged 7–12 years) and to understand the thermal conditions in the classrooms. The comfort temperature was investigated in two types of classroom buildings during the rainy and dry seasons from October 2017 to May 2018. Approximately 7050 completed valid questionnaires were collected from 330 young children repeatedly surveyed twice a day. The children answered comfort questions at the same time the indoor and outdoor thermal variables were being measured. Results indicated that the combined 'open-space' classrooms produced a neutral temperature of 28.8°C with comfort range, 25.2–32.3°C. The neutral temperature of the combined 'enclosed-plan' classrooms is 28.1°C with 25.8–30.5°C as the comfort range. The differences in the comfort perceptions may be attributed to the differences in the architectural characteristics of both categories of classroom buildings. High temperature tolerance was shown by the participating children in the study area. This article, therefore, suggests that installing air conditioning in primary schools in the warm humid environment in Nigeria may not be necessary as it could lead to unnecessary energy consumption and carbon emission.

Practical application: This work is part of the main research work that pioneers research on thermal comfort in public primary school classrooms in Nigeria. The findings from this study on the acceptable indoor temperatures in naturally ventilated classrooms in the warm and humid climate in Nigeria are important information for building services engineers and architects. The young children in these classrooms can accept high indoor temperatures. The intention of this information is to discourage high energy usage in heating, ventilation and air-conditioning (HVAC) system in primary school buildings in the study area, while maintaining the acceptable thermal comfort levels.

Keywords

Classrooms, field study, naturally ventilated, thermal comfort, young children

[1]University of Salford, Salford, UK
[2]Salford University, Salford, UK

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Charles Munonye, University of Salford, University Road Manchester, Salford M5 4WT, UK.
Email: c.c.munonye@edu.salford.ac.uk

Introduction

The indoor thermal conditions are one of the study areas researchers are very interested in

Appendix D – Data Logger Procurement

Invoice

Pay Now

Gemini Data Loggers (UK) Ltd
Scientific House, Terminus Road
Chichester, PO19 8UJ. UK.

T +44 (0)1243 813000
E sales@geminidataloggers.com
F +44 (0)1243 531948
W www.geminidataloggers.com
Accounts Tel: +44 (0)1243 813020
Fax: +44 (0)1243 813019

Invoice Address:

Munonye, Charles
13 Edward Avenue
Salford
M6 8DA

Invoice No: 82730 Page 1
Order No: 78198
Customer Order No: Charles Munoyne
Invoice Date: 17/08/2017
Account Code: 1MUN02
VAT No: GB

Ordered by: Charles Munonye
Tel: 07404 060867

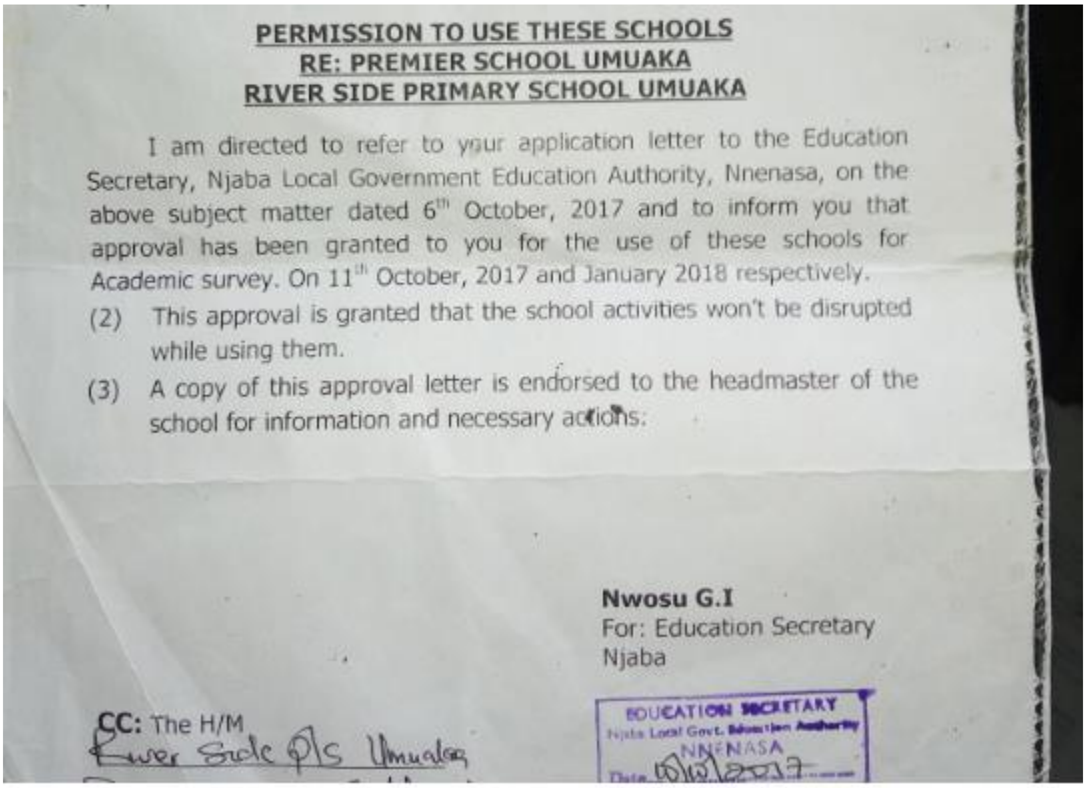
Qty	Product Code	Product Description	Unit Price	Net Price
1	TGU-4500	Ultra 2 temperature/RH data logger	99.00	99.00
1	TGP-4017	Plus 2 temperature data logger	95.00	95.00
1	SWPK-7-USB-ENG	Software & Ultra/Plus/View cable pack, English manual	0.00	0.00
0	M	Email SagePay invoice to c.c.munoyne@edu.salford.ac.uk	0.00	0.00
	DISCOUNT	10% discount	10.00 %	19.40 D

DAP (Delivery Address) Incoterms®2010. WEEE No: WEE/EE0074UR/PRO Battery No: BPRN00216 - www.tinytag.info/weee

Delivery Address:
Charles Munonye
As Invoice Address.

Total Net Amount:	£	174.60
Carriage Net:	£	9.95
Total VAT at %:	£	36.91
Invoice Total:	£	221.46 GBP

Appendix E – Letter of Authority from the Ministry of Education



PERMISSION TO USE THESE SCHOOLS
RE: PREMIER SCHOOL UMUAKA
RIVER SIDE PRIMARY SCHOOL UMUAKA

I am directed to refer to your application letter to the Education Secretary, Njaba Local Government Education Authority, Nnenasa, on the above subject matter dated 6th October, 2017 and to inform you that approval has been granted to you for the use of these schools for Academic survey. On 11th October, 2017 and January 2018 respectively.

(2) This approval is granted that the school activities won't be disrupted while using them.

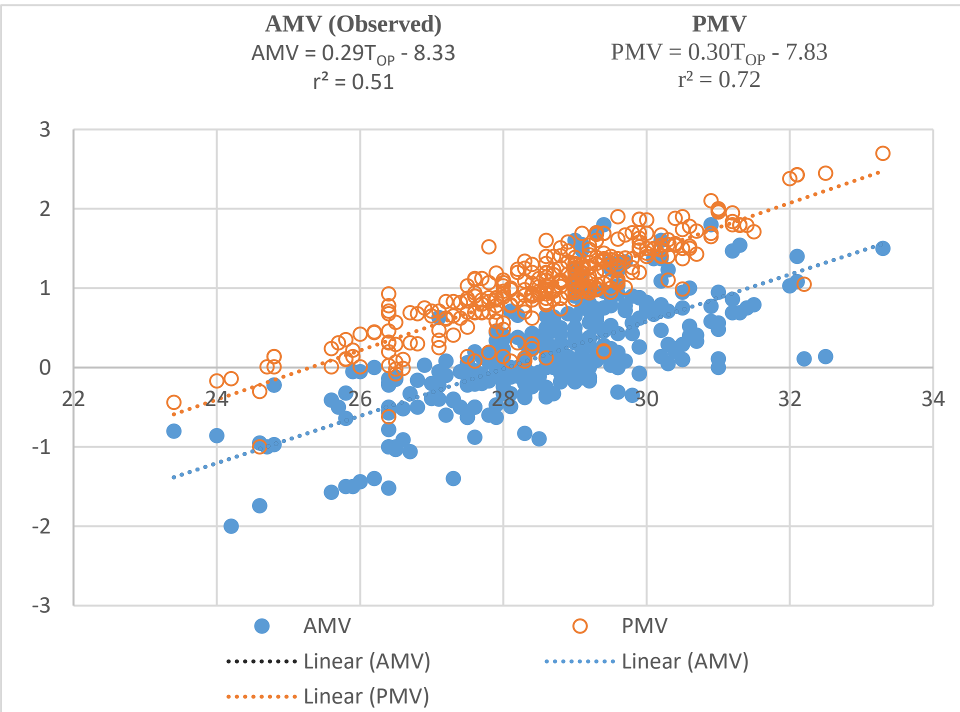
(3) A copy of this approval letter is endorsed to the headmaster of the school for information and necessary actions.

Nwosu G.I
For: Education Secretary
Njaba

CC: The H/M
River Side P/S Umuaka

EDUCATION SECRETARY
Njaba Local Govt. Education Authority
NNENASA
Date 10/10/2017

Appendix F – Linear Regression of AMV and PMV VS OT



Appendix G - Correlation Matrix between TSV and some selected variables

Correlations

		Actual Mean Vote	Relative Humidity	Neutral Temperature	Indoor operative temperature
Actual Mean Vote	Pearson Correlation	1	.142	.830**	.736**
	Sig. (2-tailed)		.261	.000	.000
	N	65	65	65	65
Relative Humidity	Pearson Correlation	.142	1	.150	.108
	Sig. (2-tailed)	.261		.234	.390
	N	65	65	65	65
Neutral Temperature	Pearson Correlation	.830**	.150	1	.785**
	Sig. (2-tailed)	.000	.234		.000
	N	65	65	65	65
Indoor operative temperature	Pearson Correlation	.736**	.108	.785**	1
	Sig. (2-tailed)	.000	.390	.000	
	N	65	65	65	65

**. Correlation is significant at the 0.01 level (2-tailed).

Open classroom rainy season

Correlations

		Actual Mean Vote	Relative Humidity	Neutral Temperature	Indoor operative temperature
Actual Mean Vote	Pearson Correlation	1	.149	.444**	.793**
	Sig. (2-tailed)		.237	.000	.000
	N	65	65	65	65
Relative Humidity	Pearson Correlation	.149	1	.083	-.003
	Sig. (2-tailed)	.237		.513	.983
	N	65	65	65	65
Neutral Temperature	Pearson Correlation	.444**	.083	1	.441**
	Sig. (2-tailed)	.000	.513		.000
	N	65	65	65	65
Indoor operative temperature	Pearson Correlation	.793**	-.003	.441**	1
	Sig. (2-tailed)	.000	.983	.000	
	N	65	65	65	65

**. Correlation is significant at the 0.01 level (2-tailed).

Enclosed classroom rainy season

Correlations

		Actual Mean Vote	Relative Humidity	Neutral Temperature	Indoor operative temperature
Actual Mean Vote	Pearson Correlation	1	-.106	.793**	.595**
	Sig. (2-tailed)		.294	.000	.000
	N	101	101	101	101
Relative Humidity	Pearson Correlation	-.106	1	-.209*	-.156
	Sig. (2-tailed)	.294		.036	.118
	N	101	101	101	101
Neutral Temperature	Pearson Correlation	.793**	-.209*	1	.742**
	Sig. (2-tailed)	.000	.036		.000
	N	101	101	101	101
Indoor operative temperature	Pearson Correlation	.595**	-.156	.742**	1
	Sig. (2-tailed)	.000	.118	.000	
	N	101	101	101	101

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Open classroom dry season

Correlations

		Actual Mean Vote	Relative Humidity	Neutral Temperature	Indoor operative temperature
Actual Mean Vote	Pearson Correlation	1	.205*	.177	.458**
	Sig. (2-tailed)		.039	.076	.000
	N	101	101	101	101
Relative Humidity	Pearson Correlation	.205*	1	-.024	.052
	Sig. (2-tailed)	.039		.815	.603
	N	101	101	101	101
Neutral Temperature	Pearson Correlation	.177	-.024	1	.435**
	Sig. (2-tailed)	.076	.815		.000
	N	101	101	101	101
Indoor operative temperature	Pearson Correlation	.458**	.052	.435**	1
	Sig. (2-tailed)	.000	.603	.000	
	N	101	101	101	101

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Enclosed classroom dry season

Appendix H -Thermal Preference scale

Season	Colder		Warmer	
	Morning	Afternoon	Morning	Afternoon
Rainy (%)	42.4	86.8	57.6	13.2
Dry (%)	48.8	96.6	51.2	3.4

Appendix I - Typical 'open space' (left side) and 'enclosed plan' (right side) primary school classrooms in two sampled schools.

Appendix J – Cross validation data (Used to calculate operative temperature)

	July	August	September
Globe Temperature (^{0}C)			
Mean	29.3	29.0	29.2
S.D.	1.6	1.6	1.5
Min	23.9	25.1	25.1
Max	34.8	35.2	37.5
Air Temperature (^{0}C)			
Mean	29.2	29.0	29.1
S.D.	1.7	1.6	1.4
Min	24,0	24.8	24.8
Max	34.9	35.3	37.4