CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Building envelopes are essential modifiers of the microclimate; as a modifier of microclimates, building envelopes isolate spaces from environmental temperature and humidity fluctuations. They shelter spaces from precipitation and prevailing winds, and also, enhance natural lighting. A third of the energy use globally is consumed by buildings; they account for over 40% of energy use over and above any other industry world over (Wagner, 2011).

Buildings well suited to their climate possess appropriate features making them fit for users and their task performance. Buildings, the environment and related facilities produce more carbon dioxide (CO_2), generate more pollution, consume more energy, and use up more natural resources than any other sector. They are, therefore, at the crux of discussions related to energy efficiency, conservation and sustainability as a whole.

In historical times, buildings were constructed with readily available materials and built for comfort and protection from the unfavorable weather. Therefore, materials used were sourced locally from their environs, and required little or no energy to construct them. With the advent of technology, the world became a global village and the boundaries of communication were broken. People can now live, interact, work and relate with the world at any given location. Building designs became more diverse as building styles were adopted from across nations irrespective of the climate in which they were located. This resulted in higher energy consumption in order to achieve thermal comfort. In the light of the global energy crisis, the need for buildings to become more passive, and use less of active energy became more evident. Deliberations on sustainable techniques became a front burner issue, as the world is heaving under the pressure created by acquisition of more energy and resources. Researches on building performance therefore, became more paramount.

Building performance is the totality of building's operation and it is measured in 3 aspects; the environmental, energy and thermal. A total balance of all three aspects will provide a solution that is in synchronization with its environment, offering comfort to its users and ensure savings in energy and cost. The thermal aspect of performance is the ability of a building to offer thermal comfort to its occupants. In the quest of thermal comfort, various means have been adopted with the inclusion of the use of a proper architectural design, and the selection of an appropriate building envelope and components. Teli, Jentsch and James (2013) also said that the use of ecofriendly, low thermal conductivity materials for living and work spaces, both at design and construction stages will address the problems of heat stresses due to climate change. Thermal performance is, therefore, a product of choices made by designer's right at the initial stage of the design process.

In the tropics, people are more prone to episodes of heat discomfort and heat stresses – adults and even children are, likewise, affected. In Nigeria, specifically, the epileptic supply of power from the grid has necessitated the constant use of alternative power supply (the generator, inverter system or the solar panel) to achieve thermal comfort in many homes. Yet, a sustainable approach to development remains a 'buzz word' in construction, and also, remains cosmetic in its approach in the provision of buildings. Such are the current issues evident in the nation Nigeria.

Presently, buildings in Nigeria are being constructed without much consideration for their impact on occupant's health, productivity and comfort, (Adebamowo, 2007); 'This is of great importance.

Buildings often have poor indoor climate which affects comfort, health and efficiency. These problems are found in dwellings as well as work spaces. The indoor climate has to be put in perspective in public buildings, such as hospitals, and schools'.

School buildings are meant to be designed to ensure that human comfort conditions are easily and efficiently maintained through the variety of passive and active means available. Since children, spend most of their time indoors in school buildings, the indoor environments are therefore, of primary importance (Aynsley, Harkness, & Szokolay, 1996). Heat stresses have an impact on learning capacity. At high temperatures, children become irritable and are unable to concentrate and can exhibit aggressive behaviors. Children are more susceptible to heat stresses as they have a higher surface area to volume ratio and warm up quicker than adults, however, cultural factors and acclimatization can help minimize this.

In Nigeria, performance of pupils in schools has been on a decline (Odia & Omofonmwan, 2007). Problems facing education in Nigeria for decades, especially since Independence, have been - high rates of school enrolment, high dropout rates, inadequate facilities, increased school expenditure, mass failure in public school examinations, and poor quality of school leavers. In the regionalization of the educational sector in 1954, the Southern part of Nigeria ran a system of 7-5-3 (7 years of primary education, 5 years in secondary and 3 in tertiary institution) while the North operated 8-6-3 (8 years in primary, 6 in secondary and 3 in tertiary school). The systems were later unified giving rise to 6-5-2-3 (6 years in primary, 5 years in secondary, 2 years higher school certificate, and 3 years in University), which later became 6-5-4 (6 years in primary, 5 in secondary and 4 years in tertiary education) and then 6-3-3-4 (6 years in primary, 3 in junior secondary, 3 in senior secondary and 4 in tertiary education), which currently has been reviewed to 9-3-4 in 2006

(9 years of basic education, 3 years of secondary and 4 years of tertiary), (Uwaifo & Uddin , 2009). The educational system is changing (pedagogy, and tenure); the implication therefore is that pupils will remain for a longer period of time in primary and junior secondary (basic 9), will require larger or flexible spaces as well as associated functions for Junior secondary in primary schools, (Lawanson & Gede, 2011).

According to statistics, a total of 10,674 public school facilities are in good state while 581 are under construction and 425 have unusable facilities. In Lagos, 991 primary schools are available for over 462,284 primary pupils, 318,064 pupils for 308 junior secondary schools and 307 schools for 253,724 secondary school students making a total of 1,606 schools for 1,034,072 pupils (Lagos Private School Census 2010-2011 Report). This is grossly inadequate and a far cry from being substantial. With a population of about 1050 primary schools, (Lagos, 2013) in Appendix G, the number of pupils per classroom is over 50. This could have impact negatively on the performance of pupils. Deliberations have been made that the poor performance of pupils is due to poor teacher motivation, differential access to facilities, poor funding, poor school climate, and so on. Despite the increase in the provision of millennium structures in many public schools in Lagos; much is left to be desired because government schools have not kept the pace with the high demands (Härmä, 2013).

The focus of this research is on government-owned schools because they serve a greater percentage of the populace; they have standardized systems, curriculum and structure which will enable easy comparison. Class II Field experiment, which involves the measurement of both objective and subjective variables, protocols for thermal comfort consistent with ISO 7726 and ASHRAE standard 55-2010 was adopted for the research methodology,(Ogbonna & Harris, 2008).

Ogbonna and Harris (2008) carried out a parallel research in sub Saharan Africa, with students in University of Jos. The results showed a neutral temperature of 26^0C that was similar to the prevailing outdoor mean temperature, which is consistent with the adaptive theory. The inclusion of variability to the PMV model are therefore necessary for the tropics Decisions therefore on architectural design concepts and specification of materials need to emanate from the awareness and in-depth knowledge about the prevailing climate, thermal comfort, and the performance of building envelopes and its components.

The need therefore for climate sensitive approaches and environmentally responsible construction of school facilities is not far-fetched. Therefore this study aims at assessing the thermal performance of the building envelopes of public primary school classrooms in Lagos Metropolis. Standard approaches should be resorted to in the provision of conducive and comfortable classrooms in Lagos Metropolis and in Nigeria at large.

1.2 STATEMENT OF THE PROBLEM

The assessment of a building's performance amounts to several benefits of which enhanced thermal comfort of occupants is key, in order to establish a productive, and healthy environment (Olsen & Iverson, 2006). Buildings are meant to be designed to ensure that human comfort conditions are easily and efficiently maintained through the variety of passive and active means. In Nigeria, no relation is made between the thermal comfort of school pupils and their classroom architectural characteristics. Since children, spend most of their day time indoors in schools, the classroom's indoor environment is therefore paramount.

Previously, studies have investigated the relationship between school environment and poor academic performance, including problems with student-teacher ratio, school location, school population, classroom ventilation, poor lighting in classrooms, and inconsistent temperatures in the classroom with student health problems, student behavior, and student achievement [Crandell & Smaldino, (2000); Schneider, (2002); Ogbonna & Harris (2008); Djongyang & Tchinda (2010); Bakó-Biró, Clements-Croome, Kochhar, Awbi, & Williams, (2012); Hwaish, (2015)]. A substantial amount of research exists on thermal comfort in offices but little research on schools, and much less for children in the primary levels (ages 6-11), (Teli, Jentsch *et al* 2013).

Furthermore, building performance has been analyzed with respect to the mechanical aspects; literature reveals that the effect of architectural and thermal properties of buildings is almost not considered in most field studies (Zomorodian, Tahsildoosta & Hafezia, 2016). Hence, there is a paucity in this regard when compared to the volume of researches on mechanical characteristics, Heating, Cooling, and Ventilation Systems, (HVAC), for Africa, and even more so, in Nigeria. A recent review of thermal comfort studies showed a few survey researches carried out in the sub-tropical and tropical regions, and much more in the temperate regions; most of which were carried out from the ages of eleven and above (11-17), which coincides with the secondary school level in Nigeria. Such surveys were in Singapore Taiwan and Japan, and the cases studied were buildings that were naturally ventilated (NV), and a few in a combination of both natural and mechanical combination (mixed mode).

Furthermore, in thermal comfort studies, a wide disparity exists in thermal neutralities observed in studies conducted within the same climatic zones. Therefore, similar results cannot apply to places even within the same region. This emphasizes a need for micro-level comfort studies which is the focus of this research.

1.3 AIM AND OBJECTIVES OF THE STUDY

The aim of this study is to assess the building envelopes and thermal performances of public primary school classrooms in Lagos Metropolis.

The objectives of this study are to:

1. Identify the characteristics of the primary school building envelopes in Lagos Metropolis.
2. Evaluate the thermal performances of the primary school classrooms in Lagos Metropolis.
3. Determine the relationship between the building envelopes and the thermal performance of the classrooms.
4. Assess the impact of thermal performance on pupils' comfort.
5. Develop a model predicting relationship between thermal performance and the pupils' comfort.

1.4 RESEARCH QUESTIONS

1. What are the characteristics of the different public primary school classroom envelopes in Lagos Metropolis?
2. What is the thermal performance of the public primary school classrooms in Lagos Metropolis?
3. Is there a relationship between the building envelope and the thermal performance of the classrooms?
4. Is there a relationship between the thermal performance and the pupils' comfort in the study area?

5. Is there any model that can predict the relationship between the classroom building envelope and the pupils' comfort?

1.5. HYPOTHESES OF THE STUDY

HYPOTHESIS 1:

H_0: There is no significant difference between the indoor temperature of the various primary school classroom envelopes and that of the ASHRAE 55 standards.

H_i: There is significant difference in the indoor temperature of the various primary school classroom envelopes and that of the ASHRAE 55 standards.

HYPOTHESIS 2:

H_0: There is no significant difference between the relative humidity of the various primary school classroom envelopes and that of the ASHRAE 55 standards.

H_i: There is significant difference in the relative humidity of the various public primary school classroom envelopes and that of the ASHRAE 55 standards.

HYPOTHESIS 3:

H_0: There is no significant difference between the air velocity of the various primary school classroom envelopes and that of ASHRAE 55 standards.

H_i: There is significant difference in the air velocity of the various public primary school classroom envelopes and that of ASHRAE 55 standards.

HYPOTHESIS 4:

H0: There is no correlation between building envelopes and thermal performance of the public primary school classroom envelopes.

H1: There is a positive correlation between building envelopes and thermal performance of the public primary school classroom envelopes.

1.6 SIGNIFICANCE OF THE STUDY

According to the sustainable development goals (SDG) 4, "*to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all, i*t is essential that pupils' comfort be investigated so that this goal can be achieved for developing countries where their educational system requires attention.

The relationship between comfort and productivity is not far-fetched. For optimal efficiency, the body's energies have to be harnessed in an efficient manner to ensure productivity, not avoiding the discomforts accrue to the condition of the buildings in which they are situated (Vischer, 2005). For children, the thermal aspect is a highly significant factor amongst the variables for comfort in classrooms, especially for the tropics. Others are noise, illumination, IAQ, ergonomics, (Salleh, Kamaruzzaman, Riley, Zawawi, & Sulaiman, 2015).

To this end, the assessment of the building envelopes of existing classroom facilities in Lagos Metropolis, is of import, to determine their thermal performances and make the relevant information available for future design proposals of 'supporting environments' that foster proper acquisition of knowledge in a climate that is constantly changing. This is the need this research seeks to address. This research will ensure standard provision of school facilities suited for comfort and productivity of pupils. The stakeholders such as the Government, investors and clients will be presented with comparable models, data and information to aid in retrofits of existing schools and designs for new classrooms.

1.7. SCOPE AND DELIMITATION OF STUDY

The study is focused on the thermal performance of building envelopes of public primary school classrooms in Lagos. One of the core Universal Basic Education (UBE) objectives is, "to reduce drastically the incidence of drop-outs from the formal school system, through improved relevance, quality and efficient educational systems." (UBE Act, 2004). This research will help expedite other actions towards this.

The various school building envelopes studied were based on their forms and structural types- bungalow, one and two storey classroom blocks. The geographical spread consists of the Educational districts which are zoned into six areas to monitor and administer the day to day running of schools. These include: District 1(Alimosho, Agege and Ifako Local Government Area), District 2 (Ikorodu, Shomolu and Kosofe LGA), District 3 (Epe, Ibeju-lekki, Eti-osa and Victoria Island LGA), District 4 (Surulere, Lagos Mainland and Apapa LGA), District 5 (Amuwo-odofin, Badagry, Ojo and Ajeromi/Ifelodun LGA) and District 6 (Ikeja, Mushin and Oshodi-Isolo LGA).

The thermal performance of the buildings was deduced via calculations from the environmental factors considered which were: the air temperature, humidity, mean radiant temperature and the air velocity. The emphasis is on Lagos Metropolis. It is a prime area because of the concentration of commercial activities, technology, industry, as well as infrastructural support for businesses. It also has the highest concentration of public school facilities from which samples can be drawn to make valid inferences. The state arm of the government is responsible for the running of the public primary schools in Lagos.

The research is based on public schools as they have a standardized curriculum, are purpose-built, and have management systems as well as standard uniforms and which makes for similar variables which will aid easy comparison for useful deductions. All these facilities are designed as non-air-conditioned classrooms and will be considered as naturally ventilated buildings in this thesis. The thermal state of pupils was difficult to decipher at the lower classes, those in the higher classes primarys (4-6) were more coherent. This is further complicated by restriction to access in some of these public schools, especially those in District 3 (Ikoyi) and 5 (Agboju-Lagos) because of current political unrest in those areas.

This research is also limited to the Architectural parameters of the building only which involves the building layout, the material components of the building envelope such as the walls, roofs, floors, doors and windows, with their corresponding thermal performances (e.g. air temperature, humidity, mean radiant temperature and air velocity variables).

1.8. STUDY AREA

Nigeria ranks about the tenth largest nation globally, with an estimation of about 123,337,822 people. It is located on latitude of 9.0820^0N as well as 8.6753^0E and bounded in the West by republic of Benin, on the East by Cameroon and on the North by Niger, as shown in Figure 1. Nigeria varies significantly in landmass, climate and vegetation as one navigates across these cardinals. It lies within the Sub-equatorial rainforest and is of the low-wet climate type of the tropics. The warm humid zone in Nigeria is within the sub-equatorial rainforest with basically two distinct seasons- the wet and the dry seasons.

Lagos is one of the fastest growing cities in the world, at 77 persons per hour, (United Nations, 2014). It is bounded by the Atlantic Ocean on the South, Ogun state on the Northern and Eastern boundaries, and republic of Benin on the West. It is located on latitude of $6^{0}22^{1}$ N and $6^{0}52^{1}$ N as well as $2^{0}42^{1}$E and $3^{0}42^{1}$E. Lagos comprises of about 83% landmass and 17% Lagoons and waterways.

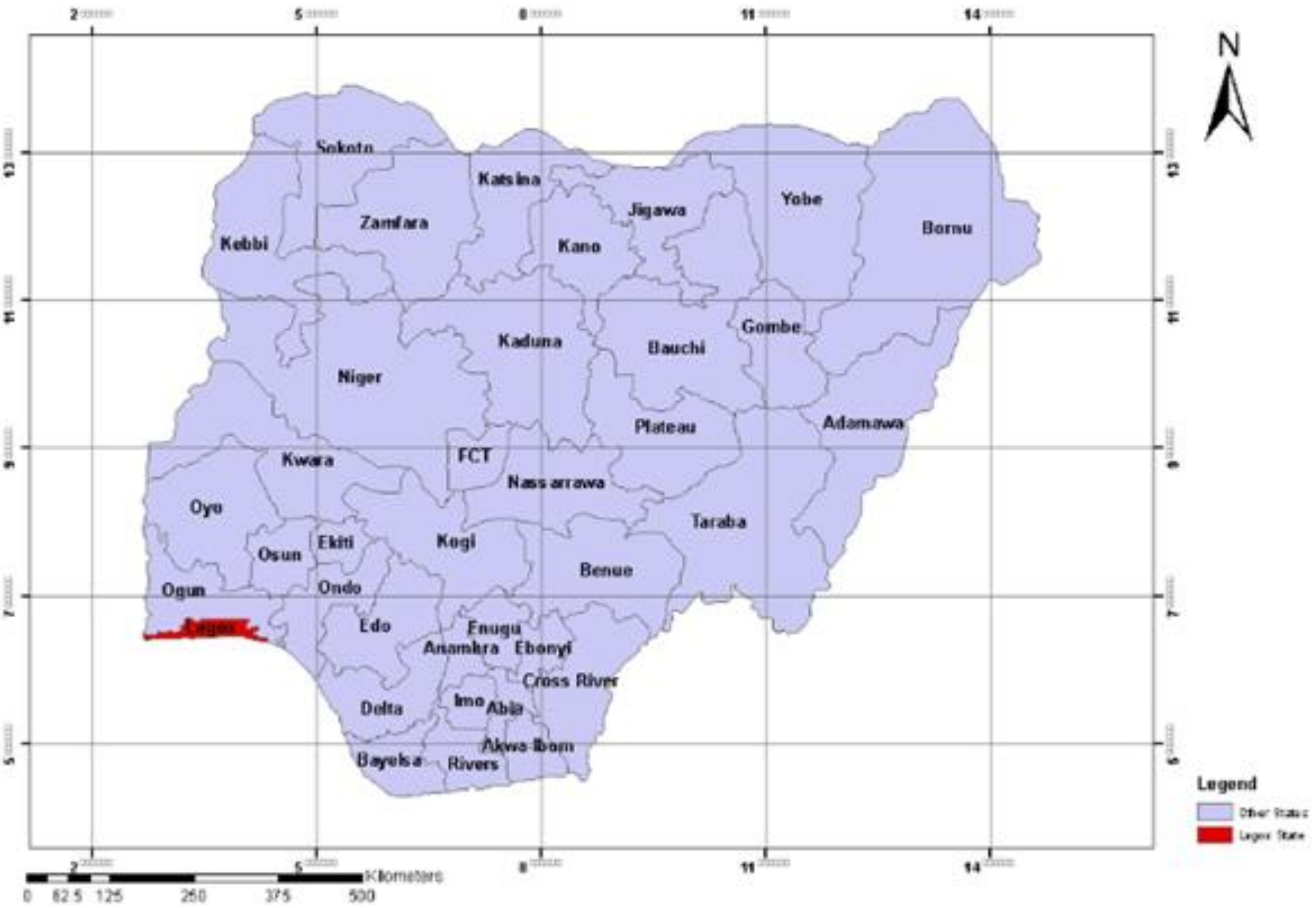
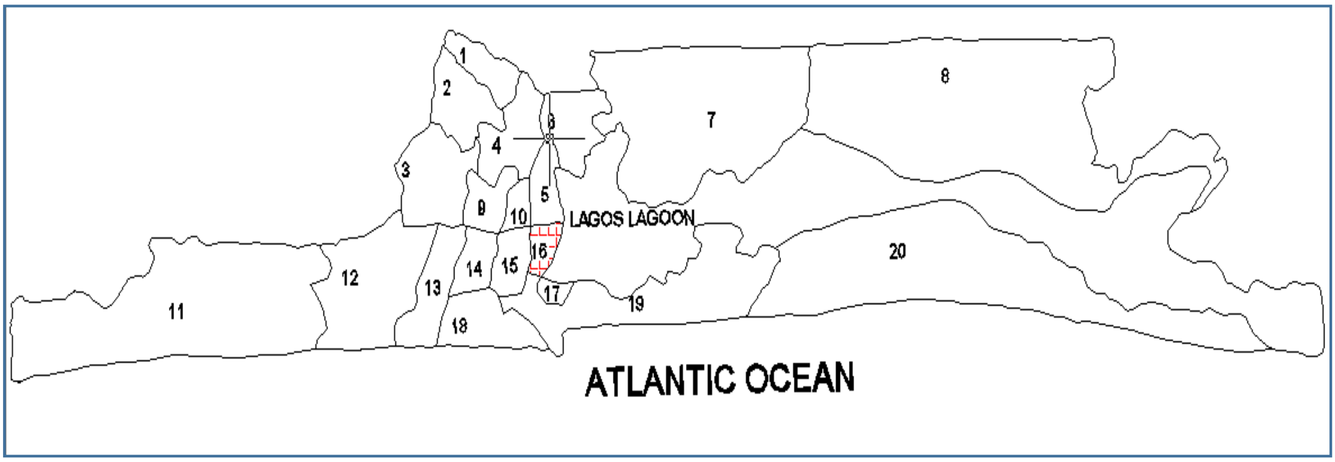


Figure 1: Nigerian map showing the position of Lagos

Source: Department of Surveying and Geo- informatics, University of Lagos

It is characterized by warm seasons for most of the year within June and September on till October, and the dry season in Middle July till August. Average mean temperature ranges between 26-28^{0}C, with high temperature at 31^{0}C, especially in February and March. Its peak is in January and the lowest measurement is 21^{0}C. Due to climate changes, values may be significantly higher. Over 60% of annual rainfall measured in the first half of the wet season. No month is completely without rainfall measuring as much as 25.4mm even in the dry season. Humidity levels are relatively at 75% especially in coastal regions of Lagos; this ranges from 90% at peak periods and 56% at low periods. Lagos Metropolis is divided into sixteen Local Government Areas namely; Lagos Mainland, Surulere, Ikeja, Amuwo-Odofin, Kosofe, Ojo, Oshodi-isolo, Somolu, Mushin, Eti-Osa, Agege, Ifelodun, Alimosho, Epe, Ifako-Ijaye, Ibeju-Lekki, Lagos Island, Apapa . Lagos and its boundaries are shown in Figure 2.



1-Agege	**5**-.Shomolu	**9**-Oshodi- Isolo	**13**-Amuwo Odofin	17-LagosIsland
2-Ifako- Ijaye	**6**-Koshofe	**10**-Mushin	14-Ajeromi Ifelodun	18-Apapa
3-Alimosho	7-Ikorodu	**11**-Badagry	15- Surulere	19-Eti Osa
4-Ikeja	**8**-Epe	**12**- Ojo	16-Lagos Mainland	20-Ibeju-Lekki,

Excluding 7, 8, 11, 20

Figure 2: Map of Lagos showing the local government areas.
Source: Aluko (2010)

1.8.1 CLIMATE CHARACTERISTICS OF THE STUDY AREA

The climate of an area impacts on the indoor thermal quality of the space; this depends on the form, design, structure characteristics and constituent of the building fabric. Optimal indoor environments in a building are basically a function of its form, the services it provides and the climate in which it is placed (Roaf, Fuentes & Thomas 2002; Nicol & Humphreys, 2014). A study of the prevailing climate in the study area is therefore pertinent to this research.

From the descriptions in succeeding subsection, the city of Lagos has a tropical climate. Specifically, it has been classified as warm and humid. The warm periods are more than the cold periods in Lagos. The Köppen-Geiger climate classification is 'Aw'. The temperature is at an average of 27.0 °C, with the highest over 30^0C, occurring in December to February. The average annual rainfall is 1693 mm (Climate-data.org). Humidity levels are high, especially at coastlines and in highest period of rainfall in June. The hot discomfort persists for about eleven months in the year, hence the need for adequate ventilation to achieve thermal comfort.

Lagos, being warm and humid, poses a great challenge. Evaporation alone can no longer be sufficient to cool the body when humidity is high. Thus, no matter the Window/Floor ratio of the building, cross ventilation, orientation, the principles of passive design in Architecture, will not give the best comfort level. Hence, there is a need for techniques to increase the air flow rate. This could be achieved either by mechanical aids or passive technologies - through stack effect and improvement of wind pressure effect. Lagos is on the average of 1506.6 mm (59.3 in) of rainfall per year, or 125.6 mm (4.9 in) per month. On the average, there are 121 days per year with more than 0.1 mm (0.004 in) of rainfall (precipitation) or 10.1 days with a quantity of rain or sleet per month. The driest weather is in January, when an average of 13.2 mm (0.5 in) of rainfall (precipitation) occurs. The wettest weather is June when an average of 315.5 mm (12.4 in) of rainfall (precipitation) occurs. There is no month in which there is no rainfall occurrence in Lagos (See appendix J).

The least yearly amount of rainfall occurs in the month of December and January. The average measured value in these months is 21 mm. The greatest amount of precipitation occurs in June, with an average of 300 mm in a year a total of about 1506mm of rainfall is experienced. The vegetation in Lagos is sub-equatorial tropical rainforest. These are usually pronounced along water courses or Lagoons. With predominantly high temperature and prevalence of high relative humidity, significant effort in planning should be carried out to ensure and maintain comfort in habitations in Lagos.

The temperatures are highest on average in March (warmest month-very hot), at about 28.5 °C. The lowest average temperatures in the year occurs in August (coolest month, though still warm), when it is around 25.1 °C as shown in Table 2. Average monthly temperatures have a variation of 3.45 °C (6.2°F) which is an extremely low range. There is a variation of diurnal average temperatures of 8 °C (14.5 °F).

1.9 OPERATIONAL DEFINITION OF TERMS

Air to air transmittance ('u' value): it is the rate at which heat is transmitted from the air on one side of the element to the air on the other side.

Solar gain factor ('g' value): this is simply the share of solar energy transmitted through the element inside the building, expressed as a fraction of incident solar radiation. It is expressed as a dimensionless number.

Time lag: this is the time delay due to thermal mass. This can be due to the thickness of the material or its resistivity. The thicker the material, the longer it will take for heat waves to pass through.

Admittance: this is the rate at which the surface absorbs heat to or from the air on one side of the element to the other side, when the temperature of the surface and air temperature is different.

Emissivity: this is the capacity of a surface to emit long-wave radiation relative to the radiation emitted by a "black body".

Absorptivity: the fraction of the striking radiation absorbed at the surface. For long-wave radiation, emissivity is equal to absorptivity but for solar radiation, it is not always so.

Reflectivity: the fraction of the striking radiation which is reflected away.

Solar transmittance of glazing: the fraction of the striking solar energy which is transmitted indoors through the glazing element.

CHAPTER TWO

LITERATURE REVIEW

This section introduces; the thermal performance of school building envelopes, Characteristics of the primary school building envelopes; Building envelopes and the thermal performance of the classrooms; Thermal performance and pupils' comfort; and Thermal performance standards for pupils comfort

2.1 THERMAL PERFORMANCE OF SCHOOL BUILDING ENVELOPES

2.1.1 Thermal Performance and related theories

Thermal performance, an aspect of building performance, is related to the indoor thermal conditions of a building. It is the effectiveness of a building design to offer optimum indoor thermal comfort and energy efficiency. Technically, it is the determination of the indoor temperature variations over a period, to establish the levels of thermal comfort or discomfort; thermal comfort being the condition of mind that expresses satisfaction with the thermal environment, (Fanger, 1986). The other aspects of a building's performance are energy and environmental performance.

2.1.1.1 Building performance evaluation (BPE)

Building performance, according to Olsen and Iverson (2006), is the assessment of a building's performance which amounts to several benefits including enhanced thermal comfort of occupants which is key to establish a productive healthy environment. BPE (Building Environmental

Performance) are processes carried out to evaluate the performance of buildings with respect to their energy, thermal or environmental performance as shown in Figure 3.

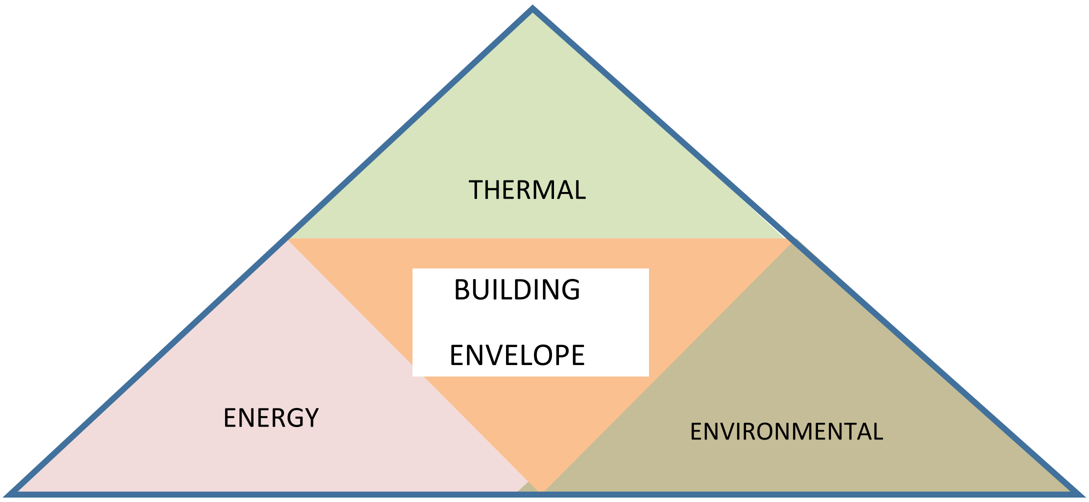


Figure 3: Elements of Building Performance

Source: Kumar (2014)

Building performance has its roots in the impact of buildings on the environment, as a resource and source of its wastes. The protection of the environment therefore has strong linkages with energy conservation and energy efficiency. Therefore discussions on the building envelope and its performance is connected to environmental and energy issues. In the 1990's, energy considerations in buildings started. A number of policies, guides, standards or codes, incentives were therefore developed over the last ten years, such as energy white paper, energy performance of building directive (European Union, 2002) introduction of energy performance certificates, carbon trading to mention a few. These actions add up in the protection of the environment.

The energy performance of a building is the quantity of energy consumed by the building in meeting the various needs of heating, lighting, or cooling of the total building space. Considerations in this field are geared towards the reduction of energy consumption and its associated impact on the environment and depletion of its scarce resources. The environmental performance of buildings is targeted towards carbon usage. The reduction of harmful consumption of fossils fuels which have hazardous after effects on the environment. This is where the building envelope is of central importance.

Furthermore, Beng (1994) Ajibola (1995), and a host of others stated that if a building is expected to perform as it should, its design should have climate as it determining factor. The influence of climate in the indoor environment today cannot be overstressed. When the climate condition of a building is not favourable, it reduces the comfort and performance level of the occupants, therefore for the occupants to perform effectively; their indoor environment must be acceptable. According to Givoni 1976, the environmental parameters: air velocity, mean radiant temperature, air temperature and relative humidity need to be in adequate proportions for occupants of a building to be thermally comfortable.

Also, Givoni emphasized that continuous exchange of air is a principal necessity for comfort because it aids the evaporation of sweat and helps prevent discomfort caused by moisture on the body and clothes. In times past, buildings have been studied, but based on their socio-psychological problems such as the residents' background, culture and societal status or their physical problems like aesthetics, technology and materials but little has been done on physiological issues like thermal comfort.

2.1.2 Parameters For Measurement of Thermal Performance

Climate, building characteristics and materials, indoor occupancy and equipment, and ventilation are significant factors in the determination of the thermal performance of the building structure and the corresponding indoor climate of its interior spaces.

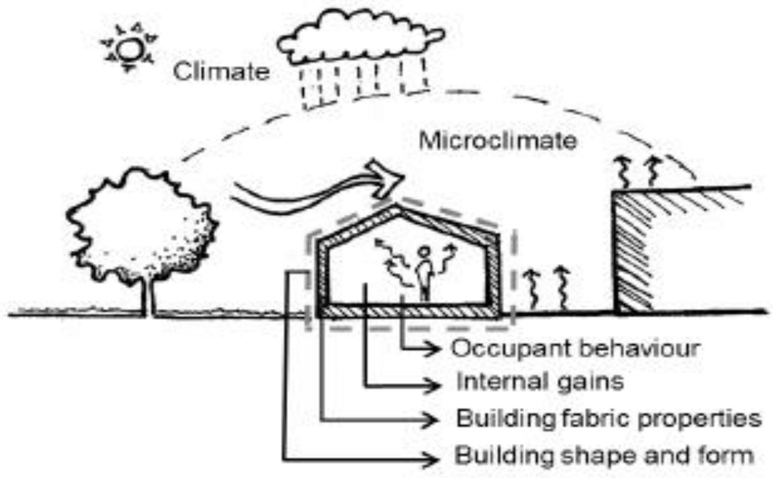


Figure 4: Parameters for Heat Gain or Loss in Buildings

Source: Teli, Jentsch *et al* (2013)

Factors that affect the thermal performance of a building therefore include;

i. Design variables i.e. Building layout, form and dimensions of components, i.e. the geometric relations; the building height, the volume to surface ratio.

ii. Material properties- transmittance, thermal conductivity, thermal resistivity. These are the building fabric properties, i.e. the properties of its construction materials.

iii. A building's usage data i.e. internal heat gains from equipment, individuals. Occupant behaviour and preferences, e.g. closing blinds, opening windows, controlling cooling/heating systems

iv. Weather data i.e. air velocity, mean radiant temperature, air temperature, and humidity. Microclimatic profile: The Local scale climate which is affected by the surrounding surfaces; the topography; vegetation.

However because this research is on the performance of building envelopes of public primary school classrooms, the building's usage data (Internal heat gain, occupant's behaviour) was not taken into consideration.

Design variables

The layout and form of a building affects the thermal performance. It is best for the building plan to be a single and long building with a single row of classrooms and openings on opposite walls so as to achieve cross ventilation in all classes independently. The open plan design for classrooms is more desirable than having separated classrooms; i.e. the classrooms can be flexible so as to aid ventilation. However, it does not allow for economy of space where there are site constraints and with the inflation in the prices of land it will be unrealistic to design such type of buildings for public primary schools. When it is difficult to therefore have single classroom independent on each other for cross ventilation, it has to be made sure that air can flow in and out of every classroom. For taller buildings, cross-ventilation is achieved more on higher floors than on the ground floor where wind flow is obstructed by vegetation and other structures,(Givoni 1972, 1994).

Openings are a large determinant of the thermal comfort of occupants therefore the dimension affects the rate of ventilation. With a minimum of two openings on different walls (windward and leeward side), cross ventilation can be achieved. The use of large openings in all walls will greatly aid cross ventilation but will also increase the indoor temperature of the classroom if the openings are not shaded from solar radiation. Therefore, openings in order not to further increase discomfort while trying to lower it, must be shaded effectively. Verandas can serve as shading even for a one or two storey building and the shaded area can therefore serve as a place for recreational activities for the pupils during break. When it is impossible to have a full wall facing the wind direction, effective cross ventilation can be created by having more than one window on the windward side. These windows should be preferably high and narrow with projections on alternate sides.

Material Properties

In a building, materials are structured to create building elements with definite width: the exterior of the building consisting of the roof and external walls, and the interior of the building which majorly consists of the floor and partitions. The effect of building elements on thermal performance therefore is determined by the thickness, location within the building envelope and the physical properties of the building elements. There are basically two thermal properties of building materials that determines their effect on the thermal performance of the envelope and their effect on heat flow: their heat capacity and their thermal resistance (R-value).

These thermal properties depend on the thickness of the layers the material was composed of and their properties. The basic properties of building elements are specific heat, conductivity and density. Furthermore, the surface of these building elements absorbs solar rays striking it and also reflects some of it. Glazed materials transmit part of this striking radiation. So the properties of building materials in relation to radiation are: absorptivity, transmittance, emissivity and reflectivity. The values of the thermal resistance per thickness of the different building materials used in this research are seen in Table 1.

Table 1: Values of Thermal Resistance of Various Building Materials

Materials Description	Per mm Thickness	For Listed Thickness
Sheathing Materials		
Soft Plywood	0.0087	
Mat-formed Particle Board	0.0087	
Insulating Fibre-board Sheathing	0.0165	
Gypsum Sheathing	0.0062	
Sheathing Paper		0.011
Asphalt Coated Kraft Paper Vapour Barrier		Neg.
Polyethylene		Neg.
Cladding Materials		
Fibre-board Siding	0.0107	
Plywood Siding- 9mm- Lapped		0.103
Brick		
-Clay or Shale- 100mm		0.074
-Concrete and Sand/Lime- 100mm	0.0014	0.053
Stucco		
Metal Siding		
-Standard Profile		0.123
-Standard Profile with Backing		0.246
Roofing Materials		
Asphalt Roll Roofing		
Asphalt Shingles		0.026
Built-up Roofing		0.078
Wood Shingles		0.058
Crushed Stone- Not Dried	0.0006	0.165
Insulation		
Mineral Wool and Glass Fibre	0.0208	
Cellulose Fibre	0.0253	
Vermiculite	0.0144	
Sprayed Asbestos	0.0169	
Expanded Polystyrene	0.0277	
Rigid Glass Fibre Roof Insulation	0.0277	
Natural Cork	0.0257	
Rigid Urethane	0.0420	
Mineral Aggregate Board	0.0182	
Fibreboard	0.0194	

Source: Energy Efficiency in Building Thermal Systems

2.1.3 Mathematical calculations for thermal performance

In order to determine the value of the thermal performance of a building envelope, the estimation of the cooling loads is required. Buildings thermal performance can be accessed via statistical calculations and measurements of environmental variables. Since, the indoor thermal comfort of a building is based on the premise that heat lost must be equal to heat gained by the building; therefore, the individual components can be calculated. The sum of all components will then be equal to zero (Teli, Jentsch *et al* 2013).

There are various methods available for assessing a building's thermal performance. These methods are steady state method, dynamic method and correlation method. This survey employed the use of a simple method that can be calculated with ease and can also be comprehended easily.

The rate of heat conduction (Q_{cond}) through any building element such as roof, wall, window or floor can be written as;

$$Q_{cond} = A\ U\ \Delta T \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where,

A = surface area (m^2)

U = thermal transmittance ($W/\ m^2$- K)

ΔT = temperature difference between inside and outside air (K)

For heat loss, the temperature difference will be negative and positive for heat gain.

It can also be given as:

$$\text{Heat loss or thermal energy}\ \varphi = \frac{A}{R}(\text{TETD}) \quad \ldots\ldots\ldots \quad (2)$$

Where,

φ = cooling load (W) (kcal/h)

U = overall heat transfer coefficient (W) (kcal/m^2h°C) and U $= {}^{1}/_{R}$

A = area of each envelope element (m^2)

TETD = total equivalent temperature difference (°C)

For the entire building, the rate of heat conduction (heat loss) is calculated for each element and then summed up. The heat flow rate by conduction is therefore the sum of all the products of the U-value and area of all the building components multiplied by the difference in temperature. This is given as:

$$\varphi = \sum_{i=1}^{n} U_J A_J (TETD) \qquad \text{……….(3)}$$

Where,

j= building component

n = number of components

When the value of zero is greater than 1, the building will be hot, when less than zero the building will be cooler.

Furthermore, **X** is taken as each component's thermal performance,

$$\boldsymbol{X_1} + \boldsymbol{X_2} + \boldsymbol{X_3} + \boldsymbol{X_4} + \boldsymbol{X_5} \qquad \text{………(4)}$$

Heat flow through conduction can be calculated thus;

Surface area (m^2) x transmittance value (W/m^2) x temperature difference (^{O}C),

$$\mathbf{X(m^2)x\ T(W/m^2)x\ \Delta T} \qquad \text{……………(5), (Edwards, 2012)}$$

The value of thermal performance of the building envelopes can be subjected to statistical analysis with the subjective measurements taken in order to establish if there is a significant relationship between the two variables.

2.2 CHARACTERISTICS OF PRIMARY SCHOOL BUILDING ENVELOPES

A building envelope is a thermal barrier that plays a significant role in the regulation of the indoor temperature levels, and consequently determining how much energy will be required to achieve thermal comfort. An appropriate building envelope is one which is suited to its location and climate sensitive as it offers comfort to its occupants. A building's envelope offers basic services such as; structural support, climate control and aesthetics.

2.2.1 Size, Form or Layout of Classrooms

2.2.1.1 Size of Classrooms

Urban growth has resulted in high demand of public facilities. Educational facilities in urban areas are overstretched to meet the increasing number of school aged pupils. The design and construction of educational facilities are usually in modules, to facilitate easy repetition, economy of space and speed of construction (Wong & Khoo, 2003). Research on educational buildings in Sao Brazil, stock plans were used to cover for the deficits in classroom provisions (Wong & Khoo 2003). A 'stock plan' was the basic standard used for classroom provisions which had a minimum space requirement of 7m x 7m as (minimum size).

Furthermore, the window size in proportion to floor area is $^1/_5$ for illumination, so also ½ for ventilation, blackboard in left hand orientation, and artificial lighting of 500lux. This guaranteed the construction standard and economy of costs for large scale production, (according to the State Foundation for the Development of Education, FDE's standard measurements). However, Wong and Khoo (2003) opined that many school buildings in Brazil still lacked a robust standard, which includes architectural quality to provide adequate learning environments as the stock plan designs were not subjected to specific processes of analysis of POE (Post Occupancy Evaluation), but were mainly at the designer's whims and caprices.

According to the Supreme Education Council in Qatar, a primary school area should not be less than 2750sqm. Each classroom with each pupil having at least 2sqm to him/her should have a- total number of pupils not less than 25, therefore it should not be no less than 50sqm. Also the council stated that classrooms should be quadrilateral so that all the pupils can have good view and these classrooms must be appropriately lit and well-ventilated (SEC standards). Furthermore, for primary schools in Tullamore, Co. Offaly, natural day lighting was exploited when designing the classrooms so that there is little or no dependence on natural lightening. So, windows were double glazed, easy to maintain and clean (Technical Guidance Document TGD-022).

For Rwanda, the design of a classroom must be comfortable, accessible, flexible and adaptable and provide sufficient space to ensure children's dignity, health, safety, well-being for successful learning. The maximum number of pupils per classroom is 46 and a minimum of 1.2m² per pupil

(Rwanda Ministry of Education). In South Africa, the average space allocated to a pupil is $1.2m^2$ to $1.5m^2$ and each class has a maximum of 40 pupils. Natural day lighting is of high importance to public primary school so that there is no need to depend on artificial lighting and glare should be avoided. Also, ventilation should be natural and should include permanent wall vents and windows so as to reduce the risk of spreading diseases (South African Schools Act, 1996).

UNESCO (2000) standards for primary school classroom layouts in Bhatan, Asia, cuts across, size, ages, proportions, ratio of heights or wall placements to ensure effective teaching and learning in primary schools as shown in Figure 17. The average standing height measurement of each pupil is 132 cm. Distances from the blackboards is 2.00m, and spaces between rows are 0.95m. These standards come in dimensions for all class levels and for all range of activities carried out in pre-primary and primary school levels. The standard classroom size for primaries 1-3 is 40 pupils per class, with $1.00m^2$ per student. The standard class size for primary is thus 6.20×5.75m. The furniture type is squatting desks to suit the height of the pupils.

The indoor and outdoor activities are closely related; therefore, primary school classrooms are advised to be situated on the ground level. The distance from the blackboard is also placed at a minimum of 650cm as shown in Figure 18. The seating types for preprimary and primary classes respectively, are required to be as low as possible; squatting desks and floor mats are used interchangeably depending on the tasks. For older classes or primary’s four to six, benches and desks are required.

TABLE 2: UNESCO Standards for Classroom Sizes

SUMMARY OF CLASSROOM SIZES					
CLASSROOM TYPE	**OPEN HALL CLASSROOM**			**STANDARD SIZED CLASSROOM**	
PRE –PRIMARY CLASS with six seater tables	N/A	Minimum for 36 students $0.81 m^2$/students	N/A	For 36 students: $1.0 m^2$/student Up to 48 students: $0.75 m^2$/student	For 40 students: $1.00 m^2$/student Up to 48 students: $0.74 m^2$/student
CLASSES 1 TO 3 with squatting desks	N/A	24 students $1.21 m^2$/student	32 students $0.97 m^2$/student	40 students $0.90 m^2$/student	For 40 students: $1.00 m^2$/student Up to 48 students: $0.83 m^2$/student
CLASSES 4 TO 6 with desks and benches	16 students $1.50 m^2$/student	24 students $1.21 m^2$/student	N/A	32 students $1.12 m^2$/student	For 40 students: $1.00 m^2$/student

Source: Spiegeller,(2000).

School design standards in low and middle income countries has it basis in international school design standards such as UNESCO standards (De Spiegleer & UNESCO 1985) but over the years these standards have ceased to serve the teeming population of pupils being enrolled. School building envelopes in Lagos presently vary in typology with respect to size, level, and location. Basic sizes of public school classrooms in Lagos are 6 x 6m, or about $40m^2$(Uduku, 2015). A block of classrooms consists of about 4 or 6 classrooms in one row, measuring a total length of 36 -40 m in length per block. The spacing from the blackboard or aisles of classrooms are varied, although UNESCO standards in Table 2 above subsists. In Lagos, there are four basic shapes of school building envelopes in existence. The Appendix G shows the statistics of pupils in public primary schools in Lagos.

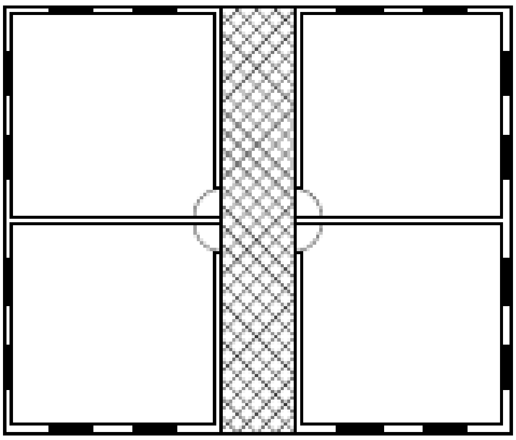
2.2.1.2 Types of school building envelopes

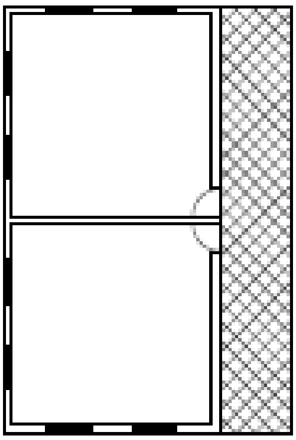
In Lagos are stratified based on the existing forms or layout, material specifications of the elements or components - walls, roofs, floors and windows, and structural type; bungalow, one storey or two storey buildings.

Forms or Layout

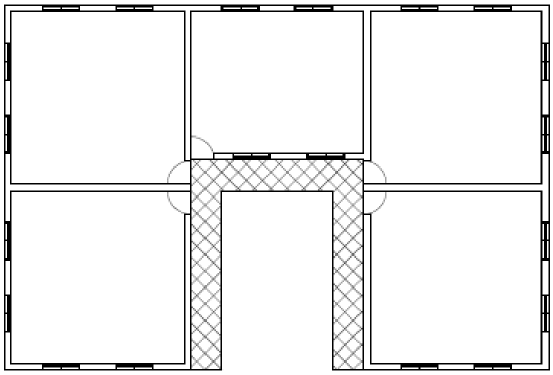
There are four basic layout/forms of classroom blocks in Lagos:

1. Double loaded corridor
2. Single loaded corridor (Linear shaped)
3. Open Courtyard system (U- shaped)
4. L-shaped single loaded Layout

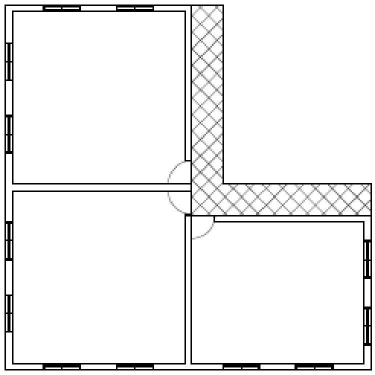




Double loaded corridor Single loaded corridor (linear shaped)



Open courtyard system (U-shaped)



L shaped single loaded layout

Figure 5: Existing Classroom Block Layouts

The different layouts of classrooms are shown in Figure 5. The double loaded corridors offer the advantage of economy of space and compactness however they require more ventilation and illumination, especially in internal spaces. Sen (2011) stated that classrooms should be designed as single banked layouts rather than double loaded layouts, and oriented in the direction of the prevailing wind. However, for urban cities with rapid growth such as Lagos, this is a rather a shortcoming.

2.2.2 Structure and Materials of classrooms

Previously, classroom structures in the late 80's were constructed as dwarf-walled buildings with roofs suspended on wooden or iron pillars. These types of structures allowed for direct exposure to unfavorable elements like driving rain, strong winds, sandstorms and direct glare from the sun. These types of structures are being replaced with fully built-up structures presently. Classroom blocks in Lagos are stratified into bungalow type, low-rise or medium structures which could be one or two storey buildings. Primary schools are usually situated on the ground floor of multistorey structures, except where there are space constraints on the site. Building materials of schools in Lagos range from facing or hollow bricks, hollow cement blocks, precast elements, ply-wood, aluminium and asbestos for roofing sheets, glazed plywood or galvanized iron sheet windows.

Slides of Classroom Blocks with Various Material Components

(A)

Bungalow-type classroom building constructed with hollow cement block walls, asbestos roofing sheet, glass louvres window. The classroom block is of U shaped layout with an open central courtyard. Roof type is mono pitch roof.

(C)

One storey classroom building built in cement block walls with brick facing, grilled metal windows, aluminium roofing in a single loaded corridor layout. It is a single loaded corridor with a deep gallery running along one side of the building. The handrail is raised and in-built on dwarf wall cladded with brick finishing.

(D)

Figure 6A-D: Public primary schools showing structures and materials

Two storey classroom building envelope: hollow cement block wall, glass (louvers) windows, aluminium roofing sheets and a single loaded corridor layout. The building is U-shaped open central courtyard system, with a gallery running all round the perimeter of the courtyard. .

2.2.3 Building Elements: Roof, Wall, Fenestrations, Floor

The building elements of public primary schools are summarized in table 3;

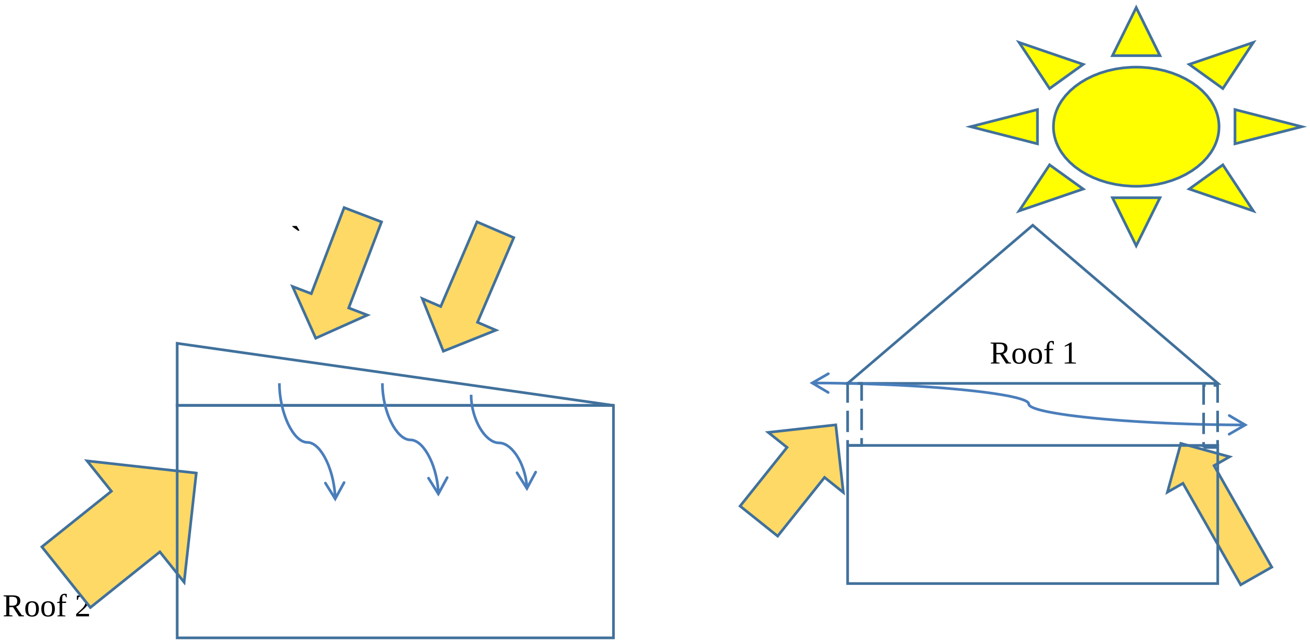
Table 3: Building Elements of Public Primary Schools

	Roof	**Fenestrations**	**Wall**	**Floor**
Materials	Asbestos	Concrete screens	Hollow cement block wall	Cement screed
	Concrete decked roofing	Grilled metal	Hollow clay bricks	Terrazzo
	Long span Aluminium roofing	Galvanized Sheet metal	Precast Concrete wall	Floor Tiles
		Glass windows	Facing bricks	

ROOF TYPES

The roofing system consists of the covering, and the entire volume or carcasses at the top of the building envelope. The roof is the component of the building that is grossly exposed to solar radiation. The importance of thermal performance, therefore, cannot be overemphasized. The roof covering materials have a '**U'** value which makes for transmission of heat through them into the interior space below.

Materials with high '**U**' value should be avoided or coated with reflective coating on the surface. Lighter colours also reflect solar rays better while dark colours absorb them. Flat roofs are indirect contact with the incident rays from the sun (Figure 7). They, therefore, require insulation to prevent the transmittance of heat directly into the interiors.



Roof volumes can be ventilated through screens in double roofs.

Lean-tos and flat roofs have surfaces in direct contact with incident rays of the sun and conduct heat directly downwards

Figure 7: The Effect of the angle of Roof Slope and use of Ventilation in Roofs

Roofs can be doubled by creating a void in between two surfaces and allowing the air in between be ventilated through screens in the exterior walls of the roof. Roof insulation and ventilation, therefore, are necessary in the tropics. Roofing system can also work as a shack through which hot air can rise through the structure and exit through the openings or ‘dormers’ in the roof. This is useful when the roof is accessible and used as an attic space. The attic space can then be an intermediary space where hot air rises through to the outdoors and cool air outdoors comes in through the openings in the lower floors as shown in Figure 8.

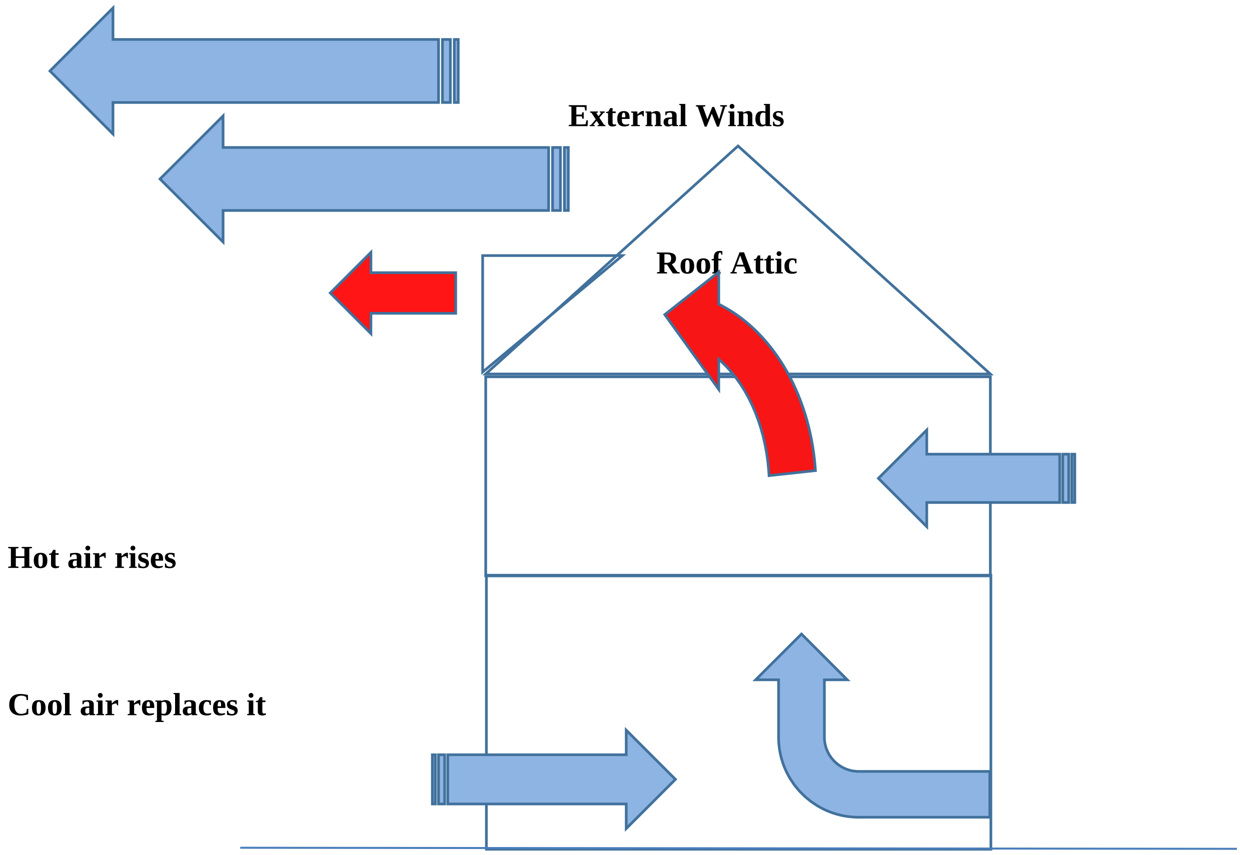


Figure 8: Ventilation through Stack Effect in a Storey Building, using the Roof as an Intermediary Space.

The shapes of roofs also, have an impact on the ventilation around the building and consequently the pattern of air flow within buildings. High vaulted roofs or domed roof tops encourage air to glide freely over them and thereby increasing its speed, hence, cooling occurs faster at the surface of the roof as shown in Figure 9.

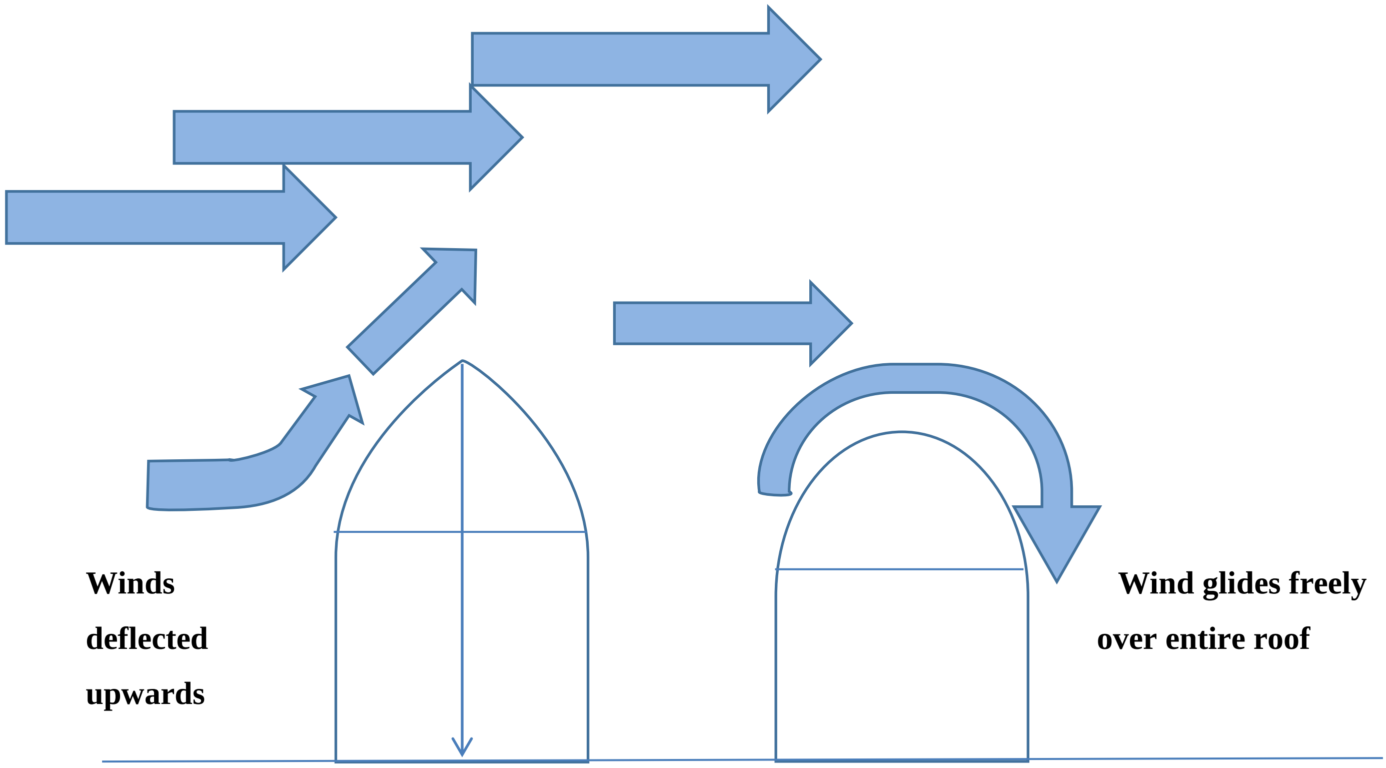


Figure 9: Wind Flow Pattern over Roof Types - pitched has 50%, domed roof 100%

The performance of the domed roof is the best for regarding roof ventilation as air gets around all sides of the roof at once and at a faster rate, followed by the pitched vault or hipped roof, which does fairly well. Flat roofs with high parapets are usually poorly ventilated as stagnant masses of hot air remains just above it as shown in Figure 10. High parapet walls therefore aid heat retention on roof top surfaces.

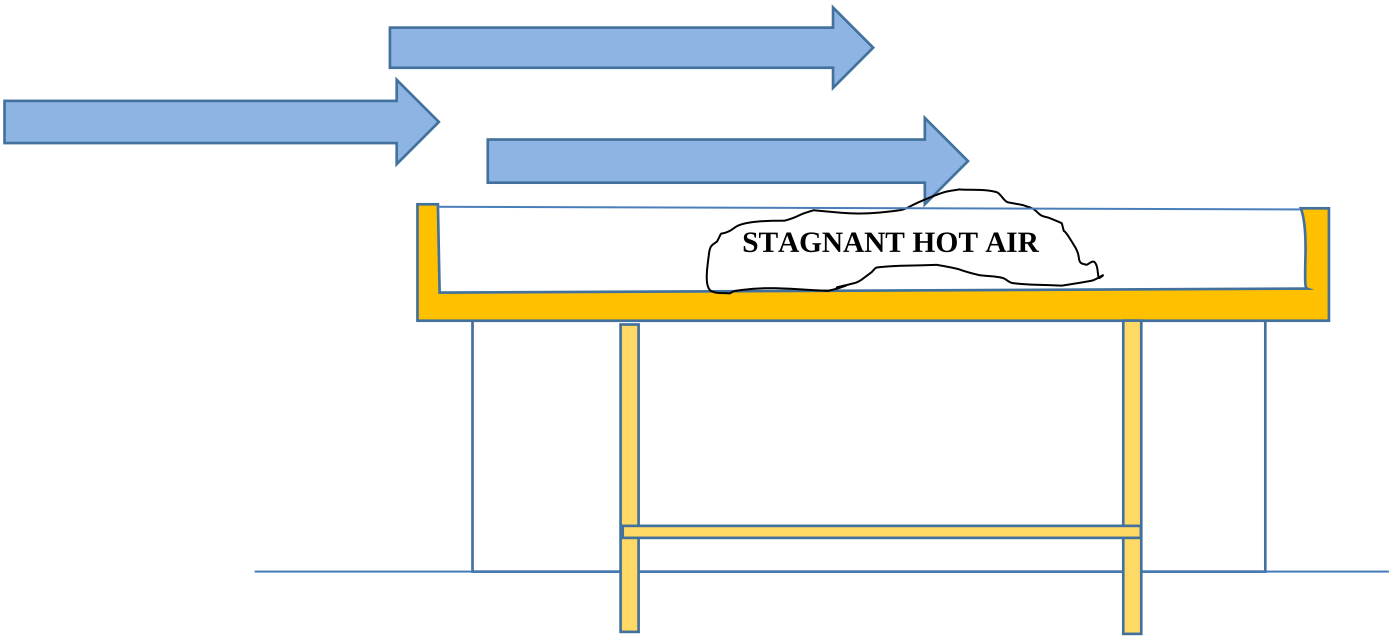
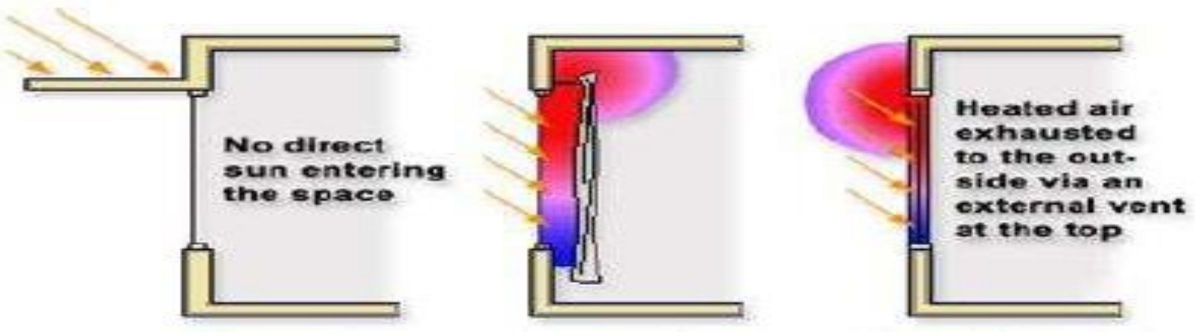


Figure 10: Stagnant Hot Air above Parapet Roofs

FENESTRATIONS

Windows

Windows perform a dual function of ventilation and illumination. Their effect on thermal performance is critical next to that of the roofs. They are responsible for 25- 40% of internal heat gains. Sun- shading devices are helpful in reflecting the heat outdoors before being transmitted into the building. External shading is preferable as indoor blinds and venetians do not totally exclude the solar radiation and keep it outdoors as shown in Figure 11.



External Shading **Internal shading** **Blinds in double glazed unit**

A **B** **C**

Figure 11: Effects of internal versus external sun shading as shown in A, B, and C

Source: Effects of internal versus external sun shading Retrieved from www.wikinturlfrequency.org, on the 9th of February 2017

Sun shade **A** gives the best method for solar control, while **B** (the internal blind and venetian), which is commonly in use in Lagos, is not effective, because the hot air outside is transmitted inwards before being reflected and part of it is absorbed. Option **C** though good, but for warm humid areas where ventilation is needed for most parts of the year, is not applicable.

In a situation where sun shading cannot be feasible, reflective glass is a suitable alternative. There are also double walled windows, with a vacuum in between to serve as insulation, where cooled air can be passed through a vent or pipe.

Ventilation can be encouraged to flow through buildings through proper orientation and the knowledge of basic concepts of cross ventilation through windows.

Basic Concepts

Cross ventilation is ventilation by placing openings in opposite walls of an enclosure. It has 3 effects.

- Supply of fresh air – replacing used internal air
- Body cooling and structural cooling (body cooling for comfort through air movement). Achieved by evaporation of sweat.

Air movement refers to the circulation of air within a space; and not necessarily associated with ventilation.

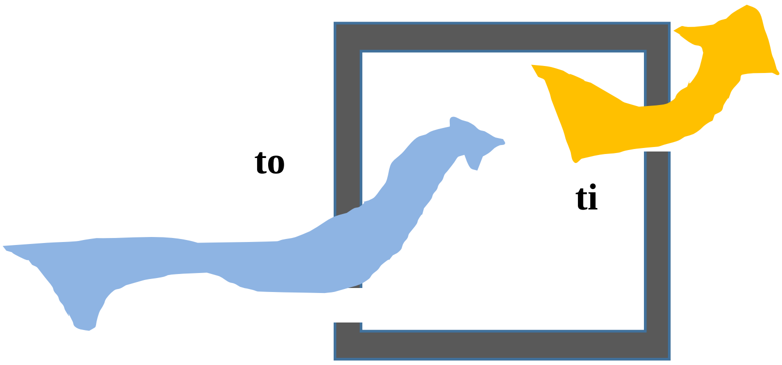
AIR FLOW THROUGH BUILDINGS

This can be achieved through

- Stack effect – due to difference in temperature between the air within and outside the building
- Air movement induced by wind pressure
- Mechanical means

STACK EFFECT: This is the movement of air when there is a significant difference between the temperature of the air within and outside a building which possesses appropriate air inlets and outlets. For example; if the air temperature outside is lower than that inside, then cold air will enter through the lower inlet while hot air rises and exits through in upper outlet as shown in Figure 12.

to < ti



where, **to**= temperature outside

ti= temperature inside

to > ti

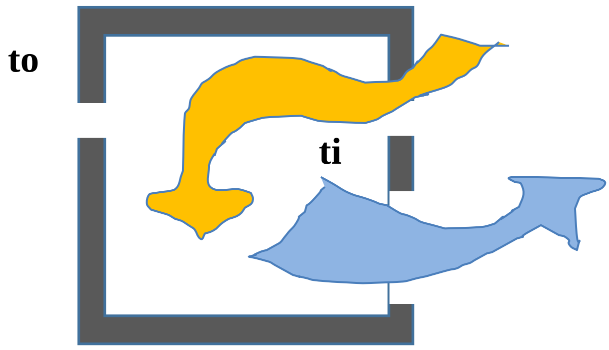


Figure 12: Pattern of airflow through Buildings

The rate of ventilation (V) increases with increase in the ratio of the area of the outlet to that of the inlet. Stack effect can produce air movement for even small differences in temperature and height. For places like Lagos, stack effect cannot be relied upon because of small differences in temperature of inside and outside air, whereas in hot/dry climate, especially in hot seasons, stack effect can produce structural cooling especially at night.

Inlets should be on the windward side and vice-versa for better effect, also bigger outlets as shown in Figure 13.

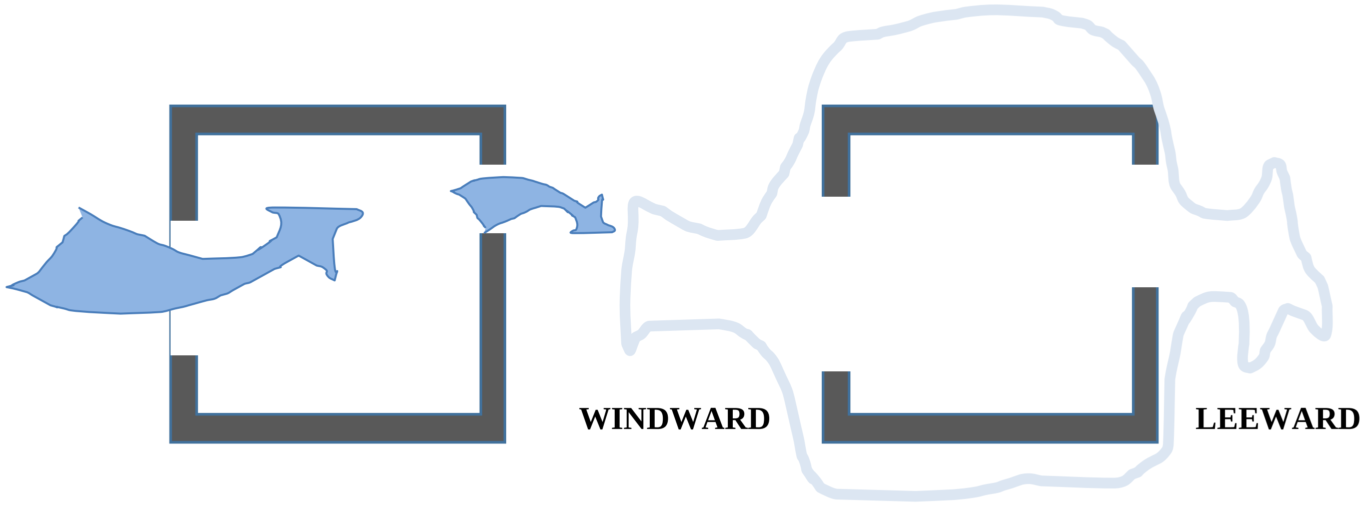


Figure 13: Effect of Wind pressure

WIND PRESSURE: This is the major force responsible for air flow through buildings wind pressure and stack effect together will help create air movement within building (stack alone often has little effect on body cooling).

Design of buildings in the warm/humid climate should aim at maximizing wind pressure for air movement, especially, in the southern part of the country. Where this fails, then mechanical aids will be employed. When wind strikes a building, as in Figure 13, it is slowed down but at the same time, it exerts pressure on the building. The slowing down of the air forms a relatively stagnant air mass on the windward face of the building. The wind is deflected above and around the mass, travels some distance, before it regains original direction due to its tendency to maintain a straight path (momentum).

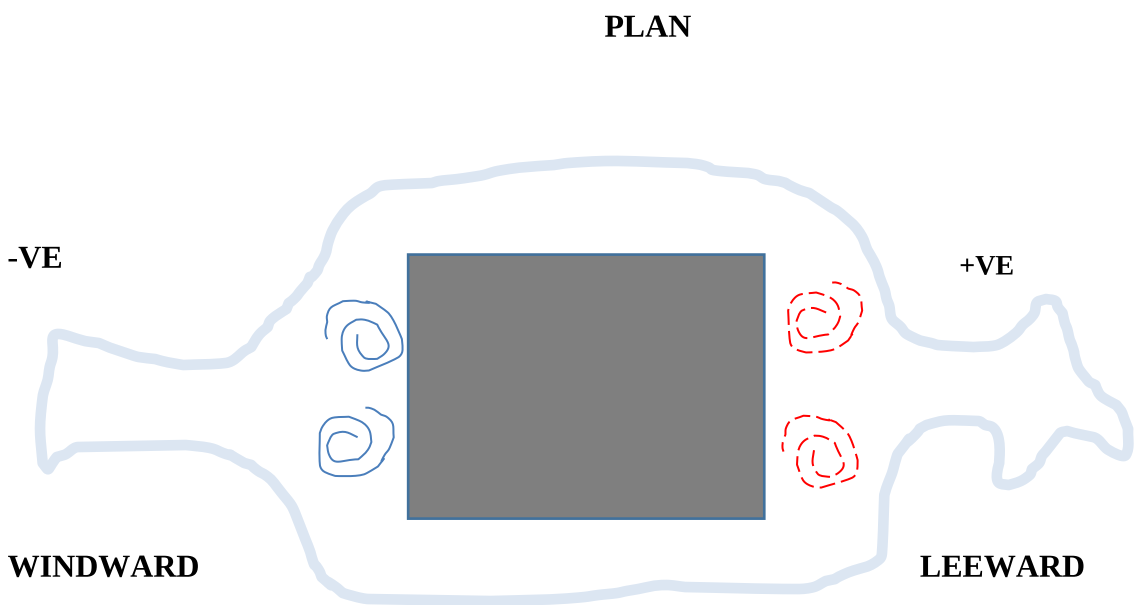


Figure 14: Pressure and Suction at windward and leeward sides

Stagnant air masses are thus formed on other surfaces of the building, although at reduced pressure, resulting in suction. The combined effect of pressure on the windward side and suction on the leeward side is to encourage air flow through the building. This will occur when there is an inlet on the windward side and outlet on any of the leeward sides.

MECHANICAL AIDS: these provide comfort by air movement, humidification/dehumidification, cooling, heating. Examples are fans, evaporative coolers, air conditioners and heaters.

WALLS –ORIENTATION AND MATERIALS SPECIFICATION

Walls are vertical components of a building envelope that encloses the space to be used. Whatever the function of the space, the quality, materials thickness, and finishes of the walls can provide functions such as acoustics, security, thermal comfort, aesthetics, ventilation, heat storage (thrombie wall). Wall materials have different thermal conductivity and specific heat capacity; wood, brick, hollow cement blocks, and plasterboard. This in effect impacts the rate of conduction of heat from the air one side of the wall to the air on the other side. Thermal masses are walls that have a high thermal lag for up to twelve (12) hours in the day. These are useful for composite climates of extreme hot and cold during the day and night.

Thrombie walls are used to conduct heat from the sun for several hours and release them slowly into the interior for heating in temperate regions. The orientation of walls with respect to the position of the sun has significant effects on thermal performance. Shorter widths should be placed in the East- West direction to reduce heat transmission into the building. This is necessary for solar control in the tropics. Windows on this axis also could be treated with sun shading devices or structurally, with verandas, or balconies, Adebamowo (2007) as shown in Figure 15.

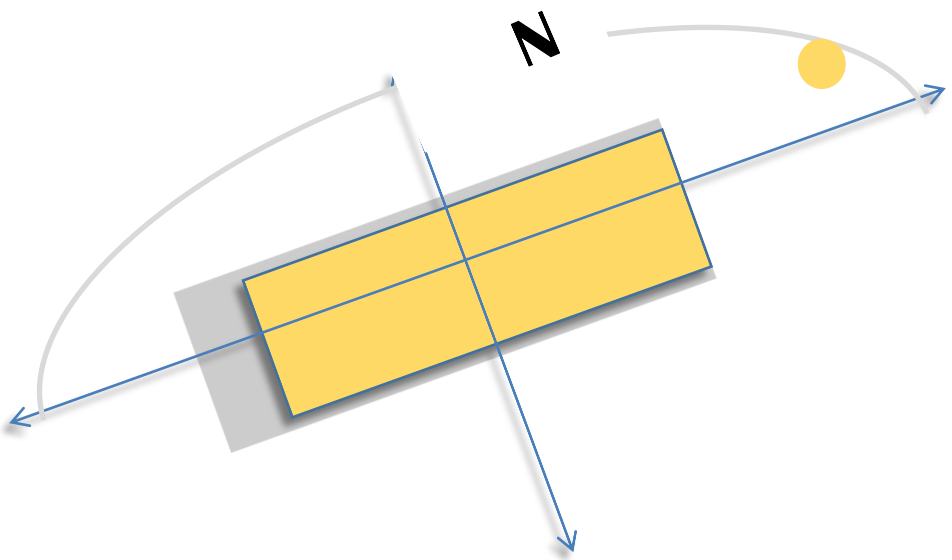


Figure 15: Orientation of Buildings for Solar Control in the tropics

FLOORS

Conduction of heat through internal floors is usually considered negligible in thermal comfort calculations. However, it is noted that the thermal sensations observed on different floor finishes is varied. For instance, the temperature felt on wooden laminate floors, tiles, terrazzo, carpets or rugs differ considerably. They also have certain influence on acoustics and reflectivity of sound and light rays incident on them.

2.3 THERMAL PERFORMANCE AND BUILDING ENVELOPES

Thermal performance is the effectiveness of the design of a building in providing optimum indoor thermal comfort and energy efficiency. Technically, it is the determination of the indoor temperature variations over a period, to establish the levels of thermal comfort or discomfort. It requires the modeling of the energy transfer between the building and the environment. Thermal performance refers to the ability of the building to provide thermal comfort to the occupants in the indoor environment; thermal comfort, being the condition of mind that expresses satisfaction with the thermal environment, (Fanger, 1986, RAA-C.E, 2013).

A building's indoor thermal comfort is established by the interactions between the climate, the building, and the occupants of the space, (Katafygiotou, & Serghrides, 2014). This helps determine the effectiveness of the design, and influence choices of new building designs options for comfortable indoor provisions. In their research, Katafygiotou and Serghides (2014) posited that one of the greatest challenges of modern design of buildings is to create thermally comfortable spaces through the study of various factors contributive to comfort. These factors can have direct or indirect impact on the satisfaction of users; for instance, the building layout, external site conditions - terrain or landscape, orientation, envelope material selection, fenestration type, distribution and shading device, ventilation type - either mixed -mode (mechanically) or naturally ventilated, have a substantial impact on the comfort levels experienced in a building.

A building may appear to be performing optimally, but this can only be verified. Its performance also could decline over time when not actively planned for (ASHRAE, 2012). It is therefore pertinent that a building's performance be evaluated periodically, to ensure its efficiency, the productivity and health of its occupants. A climate responsive approach in design and construction of buildings is pivotal in ensuring the comfort and satisfaction derived from using spaces; it also has huge benefits in energy conservation.

Buildings in direct orientation to the sun will gain heat quickly except shaded naturally by foliage or trees, green landscapes, or open spaces, which will allow for natural ventilation, without deflection by obstacles, man-made or natural. The presence of water or water bodies' cools hot air before penetration into the building as the hot air aids evaporation of water, which further cools it before it penetrates the windows. Foliage also traps moisture and allow the same to occur in cooling the environment. Buildings in valleys have the advantage of shade and winds from mountain sides but they could also experience a phenomenon called temperature inversion, which is the inverted layer of cold air above hot air without dilution, and this can be persistent for weeks on end and can be very uncomfortable.

2.3.1 Relating Thermal Performance with Building envelopes

Thermal performance and energy efficiency in buildings is currently a global issue. Buildings are being weighed against established standards and performance criteria, so as to determine how sustainable they are in the face of a changing climate, diminishing environmental resources and global warming. Building design solutions with this perspective in view alone are fit for the future. Day and Gunderson (2015), in their research on high performance buildings stated that the most important environmental factors in a building is the thermal and visual comfort. They stated that people are usually more productive and satisfied when they perceive their environment as suitable or comfortable.Unlike a parallel research on classrooms in India, it was discovered that there was no long term (up to 1 year) micro-level studies on thermal comfort in schools, Mishra and Ramgopal (2015), therefore embarked on a study in the hot – humid tropics on classrooms and discovered the neutral temperature to be 29^0C, and the comfort zone had a broad band of 9^0C (between 24-31^0C).

A vast body of literature exists in the field of thermal comfort studies. Several criteria have been termed responsible for the attainment of thermal comfort in building performance. It is marked that there is a significant effect of orientation on thermal comfort in buildings. Koranteng and Simons (2011) presented that building form and orientation, regardless of technology advancement, are vital in the sustainable performance of buildings. It was elaborated that many folklores, myths, social norms and ancient beliefs of man sought to devise these means; interactions between the man, his environment and climate in order to enhance his health, comfort and productivity.

Traditional custom was able to achieve this with different folklores, and instructions governing orientation of homes and resting places as well as the use of available materials. For instance, for the Chinese, placing the main entrance of public/private buildings in the South is a major design principle, (Koranteng & Simons 2011). Similarly, other researchers proposed that for the tropics, orientation of buildings should be South, so as to take advantage of prevailing winds, (Wagner *et al*, 1980; Koenigsberger, Ingersoll, Mayhew, Szokolay, 1973; Szokolay, 2004; and Ferstl, 2003). Hikmat and Al-Momani (2004) also asserted that, the effects of building layout - relating to solar orientation is a factor to be considered in schools designs. This is to ensure an environment that aids learning for both students and teachers. In considerations for thermal comfort, constant references have been made to solar radiation which shows that it is a factor that cannot be ignored.

With the advent of technology and industrialization, many of these principles have lost usefulness in the modern construction. This is because more versatile materials have been considered. While buildings have become compact (inward looking), flexible, light, and transparent (curtain walling). Now, there exists a limitless expression of what man can achieve with modern materials. But the more detached the buildings from their environment, the higher the requirements to attain thermal comfort, and energy consumption of the buildings.

Salmon (1999), opined that a building, irrespective of its orientation, should possess passive principles which keep buildings cool regardless of the external influences. That is, asides the external impact, if the building itself is not equipped with solar control measures for insulation against heat, and cool temperature enhancements, regardless of a proper orientation, it will still be uncomfortable.

Furthermore, in the hot dry climate of Dahnah in Lybia, Elaiab (2014) discovered that insulation is key in hot climates 63% of heat gain and 60^0C of indoor temperature could be reduced if suitable material selection was adopted; this would aid in thermal deflecting external heat. In the tropics, keeping the heat outdoors is a primary need for comfort in buildings.

High thermal mass, which is known as structural cooling, could aid in retaining heat on the exterior for at least 11 hours while light walls conduct heat quickly inwards and can dissipate them outdoors with the inclusion of effective ventilation. Al Sanea (2002) interestingly, rejoined that roof insulation for example, polystyrene of 5cm thick, when placed alongside the inner surface of the roof falls will greatly reduce heat loads for up to one third ($^1/_3$) of its value compared with a non-insulated roof of the same type.

Similarly, a research done on fenestrations by Adebamowo, Godwin and Oginni (2011) in their analysis of the Bookshop house in Lagos Island, made significant savings through sun shading devices in the windows of the building. Katafygiotou and Serghides (2014), in the study of classroom envelopes in Cyprus, analyzed the envelope materials, characteristics, and thermal conductivities. Their discussions showed that the choice of materials in Cyprus classrooms was only based on availability, climate and cost, considerations for comfort and enhancement of learning were lacking. Hence, the constituent materials created an indoor thermal atmosphere that had considerable negative influence on the thermal performance of the classrooms.

The role of material specifications in building envelopes is therefore, crucial in the achievement of thermal comfort in indoor spaces. Each constituent element has its own 'U' value- which is the rate of transmittance of heat from the air on one side of the component to the air on the other side. It was concluded that components with high 'U' value will transmit large amount of heat indoors, except when laid with insulation, or a void is included, through which air is passed to dissipate the conducted heat. This resonates with the discussions of Hikmat, Hind and Hindsight (2009).

Furthermore, Krugar and Zannin (2004), on their right retorted that dimensioning of openings for lighting and ventilation as well as solar orientation far outweighs other physical characteristics of building envelopes in determining the thermal performance of classrooms. In their research into classroom building performance, they proposed that the correct choice of design options (any one or a combination of the listed principles) will lead to improvements in thermal performance and result in savings in energy use. Choice of design options for one variable (principle) also may contradict the efficiency of the other. For instance, maximizing the use of day lighting could lead to higher indoor temperatures and the use of lightweight materials and large fenestrations alike, which will increase impact of solar radiation in the spaces.

Elaiab (2014), in a research in Dahnah Lybia, established that glazing is a main factor in passive solar design. Windows are responsible for over 25-35% of total heat gain in buildings - the window material, orientation and window to wall area ratio (WWR), therefore, the lower the window to floor ratio, the better. Next to the external walls, which are responsible for over 35-40% heat gain, windows are significant. Nonetheless, a research in Ibadan, by Lawal (2014), concluded that adobe walls, plastering and ceilings have positive impact on thermal performances of the buildings surveyed in his analysis. The use of reflective materials and thermal lag culminates in the savings of cooling loads in buildings.

All environmental factors and components of building envelopes have significant impact on its thermal performance and the indoor thermal comfort experienced by the users. Thermal performance is also an iterative process (it can be recurrent and therefore, cumbersome), however, this can be simplified by using simulation tools for cost, economy and resource or material efficiency, (Lapinskienea &, Martinaitis, 2013). The use of tools like ENERGYPLUS, DESIGNBUILDER, SIMAPRO as user friendly tools in simulating design options, at conceptual stages, is encouraged. This results in a more definite and conclusive method in determining thermal performance in buildings.

The knowledge of thermal performance is useful as it enables architects or built engineers make informed decisions in the choice of suitable building materials for construction. Calculation of temperature variations in buildings is used to determine discomfort periods and design solutions to prevent them. This makes the design more effective, and the building more efficient.

The thermal performance of buildings can be determined for use in design decisions or for the computing of energy consumption in buildings. This can be carried out by correlating both the subjective preference (TSV) of the users with the measurement of the factors of thermal comfort (Air temperature, Mean radiant temperature, Relative humidity, Air velocity).This can be achieved through the statistical calculations proposed by Fanger (1970), or by entering the building's information into a computer simulation programme to determine its performance, and then correlating with the measured thermal comfort votes of the respondents.

A clear relationship exists between the building envelopes and its thermal performance.

This relationship is illustrated as shown in Figure 16.

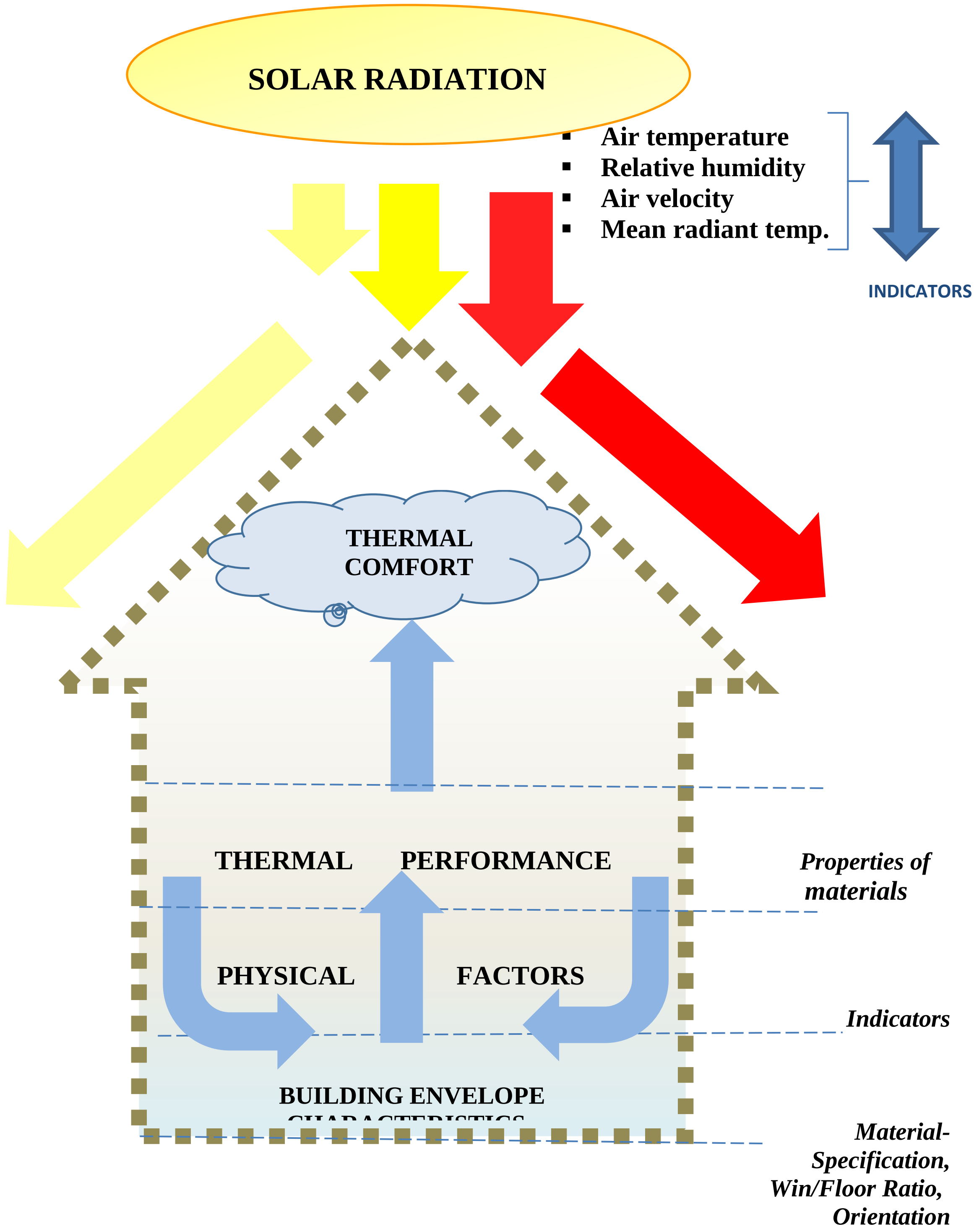


Figure 16: The Relationship between Building Envelopes and Thermal Performance

The building and its characteristics form the base of the diagram, showing that it is the first point of call in the determination of the indoor thermal condition of the space. These parameters include; its orientation, material specifications, window to floor ratio, (WWR), orientation and external features. The proceeding level is the level of the physical factors (air temperature, humidity, mean radiant and air velocity) from which (along with the properties of the materials) the thermal performance of the space can be deduced. The thermal performance of the building predicts the indoor thermal condition of the space, which can be ascertained by the thermal comfort level derived within that space. The major source of heat gain is from the sun therefore solar control is indispensable in the tropics. The attainment of a high level of comfort in buildings (residential and public) depends on the amount of solar radiation excluded from the interior space (Ajibola, 2001).

According to Hwaish (2015), there are several strategies, and not limited to these, which can be adopted as measures towards eliminating heat gain and eventually energy savings through design and appropriate building materials. These are; new dimensions and layout of inner spaces and structural additions , selection of building materials and specified structural details , redesign of the envelope , usage of alternative building material, insulting the structure against heat gain appropriate ventilation system, shading and enhancing of external microclimate ,optimum building orientation, and optimum window areas. Any of these measures can be adopted depending on if it is a retrofit of an existing building or proposed design. This will involve in-depth knowledge of the impact of building materials on thermal performance by designers and professionals in the built industry.

As stated in proceeding sections, the layout of the envelope primarily influences how the envelope will affect the internal microclimate; that is, if the space is enclosed or an open plan, with or without a courtyard space, deep or narrow. This also determines how much lighting or cooling the building will require; hence, this impacts on the energy consumption of the space. The various forms of classroom layouts and their orientation can have significant effects on the thermal performance, hence energy consumption of buildings. An analysis on school buildings in Haiti by Hallquist (2011), for a warm humid climate revealed the following results in Figure 17;

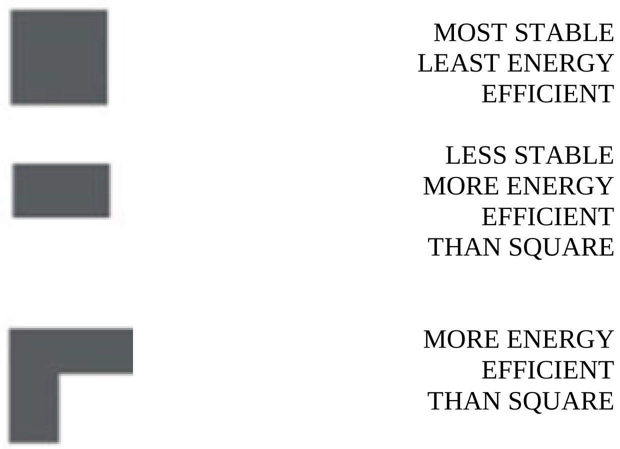


Figure 17: School Building Forms in Haiti

Source: Building Plans. Retrieved from http://fwrc.msstate.edu/housing/images/design.pdf) on 10/10/16

In Figure 17, Hallquist deliberated that the square-shaped form was more structurally stable, as Haiti had a prevalence of strong winds, yet, required a lot more energy in use compared with the other forms. The rectangular layout was more energy efficient as it had shallower (narrow) widths, but it was not as stable as the square. The 'L' shaped layout was yet less stable because it was less compact than the first two options, but more energy efficient because as it was more open than the square. These deliberations were in view of the effect of the form or layout on the energy usage required to achieve thermal comfort in the building.

Also, shapes like L, H, U are self-shading geometry; that is, they create some form of shaded areas with courtyard like spaces, which protect the inner spaces from direct solar penetration. They, therefore, will have less cooling loads than un-shaded forms. This is another reason why the L shape had better performance than the linear shape. Further deductions from this indicate that a compact form will allow a lower amount of heat to penetrate through, because it has lower surface to volume ratio. When the building is more open, it has a larger surface area exposed to solar radiation, through which heat can be conducted into the building.

But a twist exists in this fact. When the form of a building is compact, a greater depth is required for ventilation to penetrate, while an open plan can lose its heat faster because of the larger surface area. The solution lies in enhancing insulation or ventilation of the building. Bearing all this in mind, for warm/humid countries, the use of elongated buildings with orientation towards the North and South, with the shorter side in the East or West axis, having blank walls, is the best (Koenigsberger *et al*, 1973).

The thickness of the walls, whether cladded, or raised above the ground level, type of finishing, placement and number of openings, has far reaching effects on the interior climate as each material has various (U-value) conductivity and thermal properties. Thermal mass (thick) walls possess the ability to withstand heat by warming up slowly before releasing heat into the interior of the space. They are therefore useful for passive heating or cooling; Krugar, and Zannin, (2004) were strongly in agreement with this. When cooling is required, a high thermal mass can delay heat gain for up to 11 hours, and release it slowly in the night; when convective cooling can occur.

The roof type and material can determine how much cooling a building will require. It is in direct contact with sunlight and therefore can conduct heat directly into the building. Roofing structure could include insulation and ceilings that retard or reflect heat upwards. This reduces cooling loads and the need for air-conditioning or mechanical ventilation. With insulation alongside the roof slopes, savings of up to 20% of heat gain can be obtained (Hikmat, *et al* 2009). The surface area to volume ratio applies to roofs also. The larger the surface area of the roof, the more the surface exposed to solar radiation, but with effective insulation, and ventilation of the roof, the heat conducted can be deflected away from the interior space.

For fenestrations, the size, type, location and number of openings (either windows or doors) impact to the thermal performance of a building directly. The WWR (window to wall ratio) is significant in thermal insulation of buildings. The window material and its orientation are also of importance. For the tropics windows should be oriented away from the East- West direction, reduced in size, insulted or shaded to reduce heat gain

2.4 THERMAL PERFORMANCE AND THERMAL COMFORT

ASHRAE defines thermal comfort as the state of mind which expresses satisfaction with the thermal environment; this is the same definition promulgated by Fanger (1986). The human body is in constant relationship with its environment through an exchange of heat. The balance in this exchange is what predicts the level of thermal comfort experienced by the body, (Anand, Deb & Alur 2017) .

2.4.1 THERMAL COMFORT BASIC CONCEPTS

For a human body to be in thermal balance, Heat gain must be equal to heat loss.

HEAT GAIN = HEAT LOSS

The basic concept of thermal comfort is shown in Figure 18. Heat is generated in the body during metabolism, in breaking down of food substances during digestion. This heat is then lost to the environment through evaporation by sweating. This is known as the theory of adaptive thermal comfort. Adaptive thermal comfort states that the human body, given the time and opportunity, will carry out actions to achieve thermal comfort. This could be either voluntary, or involuntary. Voluntary actions include: taking bath, opening windows, taking cold drink, and loosening a knotted tie, while involuntary actions include: sneezing, shivering and sweating.

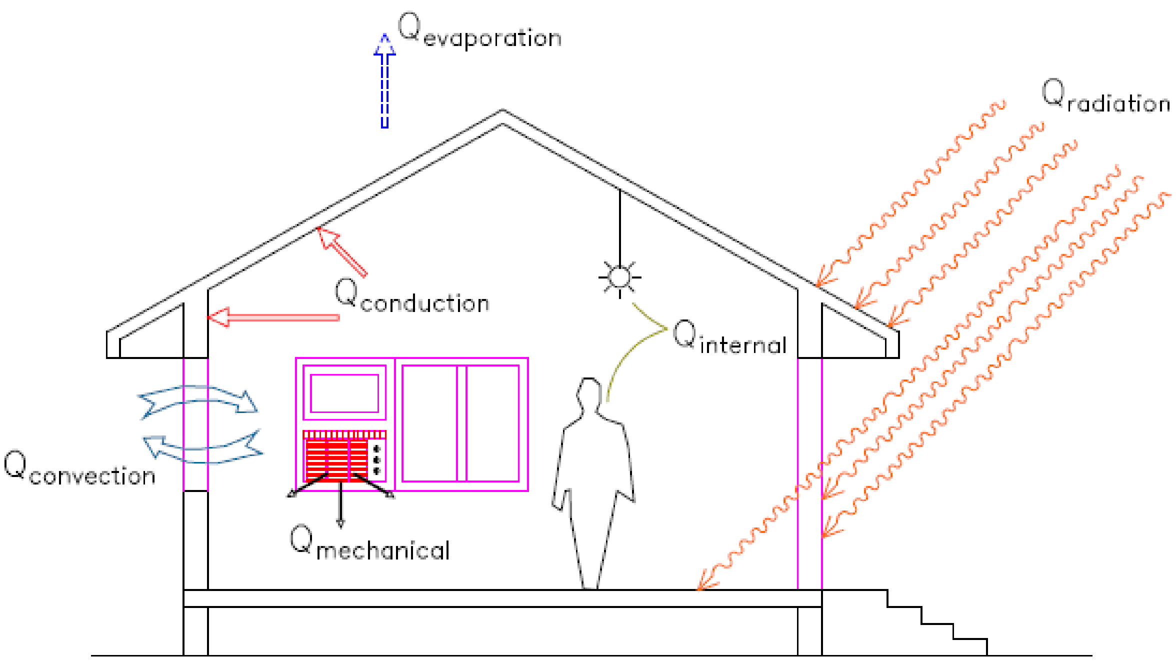


Figure 18: Heat balance of the human body in relation to its environment

Source: Heat exchange process between human body and the indoor environment, retrieved on November 7th 2017, @ http://mnre.gov.in/solar-energy/ch4.

Heat energy, a byproduct of metabolism by the human body, is released to the environment in four basic ways. The various means of heat transfer in human bodies are as shown in Figure 19, namely, the convection, radiation and conduction. This interaction of heat exchange between the body and its environment results in the cold, hot or neutral feeling experienced by the individual.

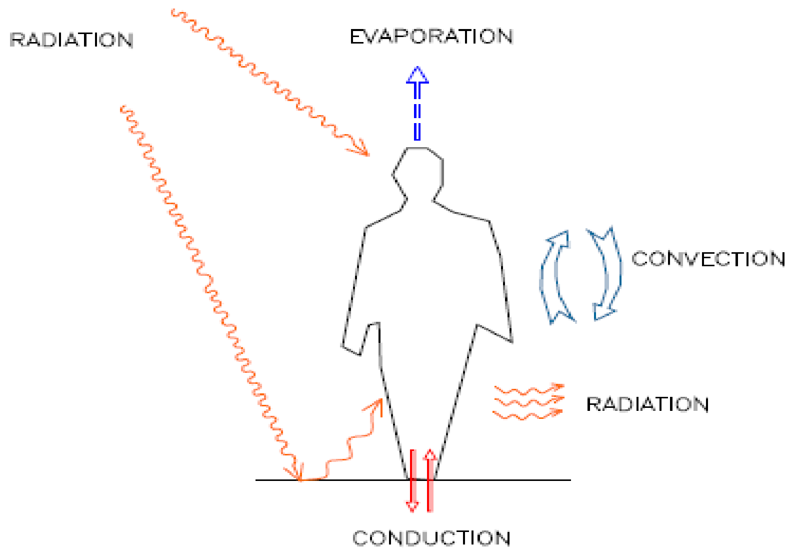


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Figure 19: Means of heat transfer in human body.

Source: Means of heat transfer. Retrieved on 23rd of November, 2017 @ http://mnre.gov.in/solar-energy/ch4

Also, a similar equation exists for the heat balance in buildings

HEAT GAIN INTO THE BUILDING = HEAT LOST TO THE ENVIRONMENT

Buildings gain heat by conduction through the walls, solar penetration, through the windows, internally from equipment and occupants, and through natural ventilation from windows. Therefore, in a state of equilibrium, heat loss or heat gain can be calculated for, given the values of the other factors. We can calculate both for cooling or heat loads as shown in Figure 20.

Ventilation
Mechanical Cooling Convection
Radiative losses
Convective losses
Evaporation

Ventilation
Internal Heat Gain
Conduction

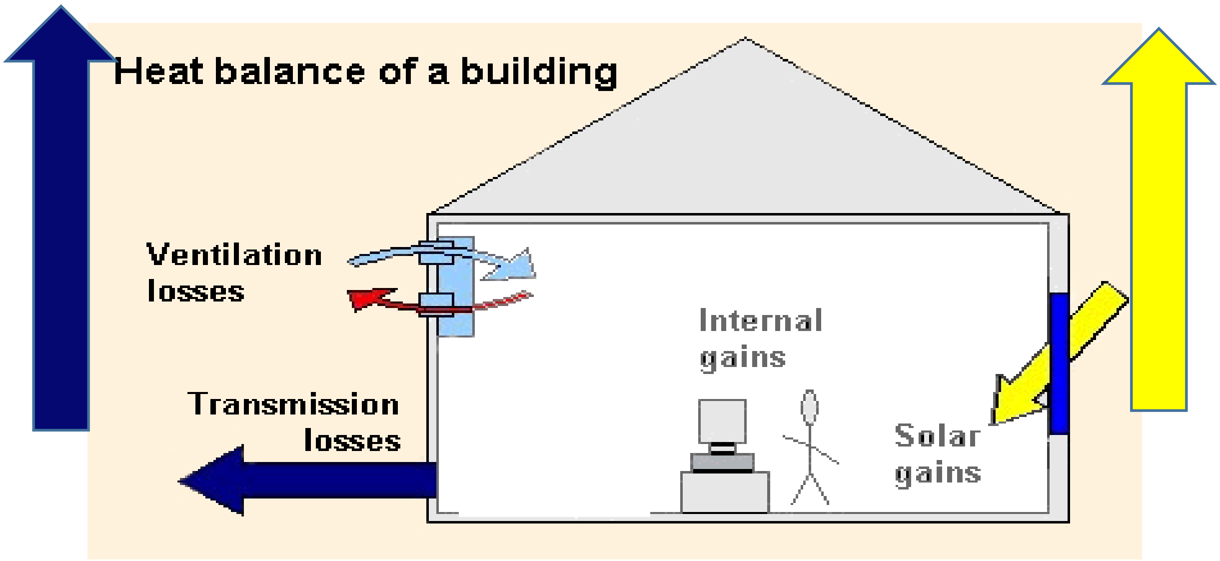


Figure 20: Heat Balance in Buildings

Source: Energy and Buildings. Retrieved from

http://nesa1.unisiegen.de/wwwextern/idea/keytopic/3.htm on 26th December, 2016

In earlier researches, Ogunsote (1991, 2002) made the following recommendation as codes for building materials and elements in the Tropics; for warm and humid climates (where diurnal temperature range is low, high humidity and high temperature exists), a short time lag is required, low thermal capacity materials, high insulation and reflective roof elements should be used. Comfort is achieved through ventilation, and insulation against heat penetration. Table 4 shows the code of properties for walls and roofs to be used in the warm humid climates of Lagos.

TABLE 4: Code of Properties for Walls and Roofs

		Max 'U' Value	Time Lag
Roofs	Rooms for Day & Night Use	1.1	0-3
	Rooms for Day Use	1.1	0-14
Walls	West Wall	2.0	0-5
	East, South, North	2.0	0-5
	Walls in the Shade	2.8	0-14
Floors	Light floors, raised above ground level		
	Heavy floor in direct contact with the ground.		

Source: Ogunsote and Ogunsote (2002)

The various 'U' values for each of the building materials are listed in the tables and this will aid calculations for the heat gain into the building through these various elements. Therefore, classroom envelopes should consist of materials with low 'U' values or compromise with proper solar orientation, lower window to wall ratio, insulation and solar shading to enhance productivity in them.

2.4.1.1 THERMAL COMFORT SCALES

Interests in establishing thermal comfort criteria date back early 19^{th} century. During the Industrial revolution, when significant reforms in construction of housing was carried out. The after effects of ill health and accidents necessitated further studies on housing standards that would ensure safe living and working environments (Kumar, 2016). Thermal comfort is one of the most important parameters of the indoor environmental quality of spaces, and is defined by ISO standard 7730 and ASHRAE standard 55 as 'the state of the mind which expresses satisfaction with the thermal environment in which it is located'.

Measurement of thermal comfort is robust; many methods have been proposed over the years and as the definition states, it is highly subjective. This resulted in the use of different comfort scales or thermal index, which are a combination of the thermal comfort factors (air temperature, relative humidity, mean radiant temperature, air velocity) by different researchers. These scales were created in climatic chambers, and experiments carried out in controlled settings where people were inserted and given questionnaires to fill with variation of each factors. The options ranged from hot (+) to cold (-3). From the statistical results, 30 thermal scales were created, (Kumar 2016). Examples are, ET (effective temperature), CET (corrected effective temperature), P4SR (Predicted Four hour sweat rate), OT (operative temperature), PMV (predicted mean vote), EW (Equivalent Warmth), (RT) Resultant temperature, Bioclimatic chart, HSI (Heat Stress Index), ITS (Index Of Thermal Stress), SET (Standard, Effective Temperature).

2.4.2 FACTORS RELATED TO THERMAL COMFORT

The satisfactory performance of the thermal environment depends primarily on the four environmental factors and two personal factors namely: air temperature, air movement, relative humidity and the radiant temperature of surfaces as well as clothing, and metabolic activity.

Mustapa, Salim, Hagishima & Ali (2015) in their research on two educational buildings disclosed that thermal comfort in free running buildings was achieved at higher temperatures of 27^0C and above in air-conditioned buildings in Cyprus. Respondents were more sensitive to variations and could adapt easily either by taking cold drinks or simply adjusting their clothing to suit their needs. This is the case in warmer climates where there is constant exposure by natural ventilation; this proves of the adaptive model of thermal comfort. It however subsists that free running buildings will require less to achieve thermal comfort as long as adaptation measures are accessible. For schools in the primary levels, this is not likely as pupils are subject to their teacher's choices. The Knowledge of the four environmental factors has enabled the creation of thermal scales for the measurement of thermal comfort, namely: Bedford scale, PMV Fanger (1986).

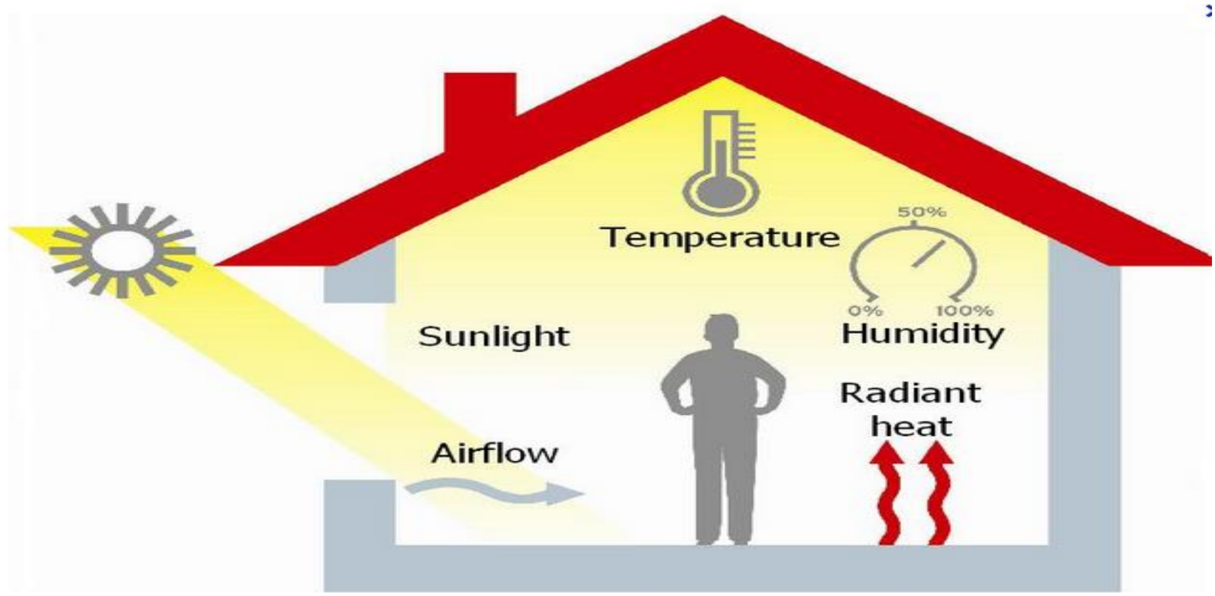


Figure 21: Environmental factors of thermal comfort

Source: Environmental Factors of Thermal Comfort. Retrieved from Http://Therm-Lighting.Blogspot.Com.Ng/2015/02/Q.Html On 26th December, 2016.

2.4.3 THERMAL COMFORT THEORIES

Comfort is the absence of any adverse stimulation to the sense organs (nose, eyes, skin, tongue and ears) through heat sensors in the skin and brain, (Comfort and Health Requirements). Examples are air motion, humidity levels, temperature, radiant heat from surrounding surfaces, odor or smell, noise, aesthetics, dust, acoustics, lighting. The first four having direct impact on the thermal aspects of comfort. The human regulatory system, the building and environmental balance, physiological status and internal equipment all add up to the thermal performance of the building structure.

The impact of the environment on pupils comfort cannot be overemphasized. Though genetics and health are important in setting the course of children's development, the environment a child grows is a major determinant of the extent of this development. (Bronfenbrenner, 1979; Bronfenbrenner and Morris, 1998). The "Environment" includes the following; the home, extended family, the neighborhood, the school, the religious institution (church or mosque). Schools have a far-reaching impact because of the length of time children spend in them daily.

Kumar P. (2016) also stated that, a human's lifecycle in any space is constituted by a cyclic movement of activity, fatigue and then recovery. Recovery is a necessity for mental and physical balance. If spaces tend to limit this process by discomforts or poor support to tasks performance, further activities cannot be carried out effectively. There should be time of recess incorporated in a long stretch of teaching sessions. The environment must enhance recovery for the pupil to be fired up for future tasks. At any level, user's comfort is imperative for the body to carry out tasks without resulting in total mental breakdown or ill health. This is shown in figure 22.

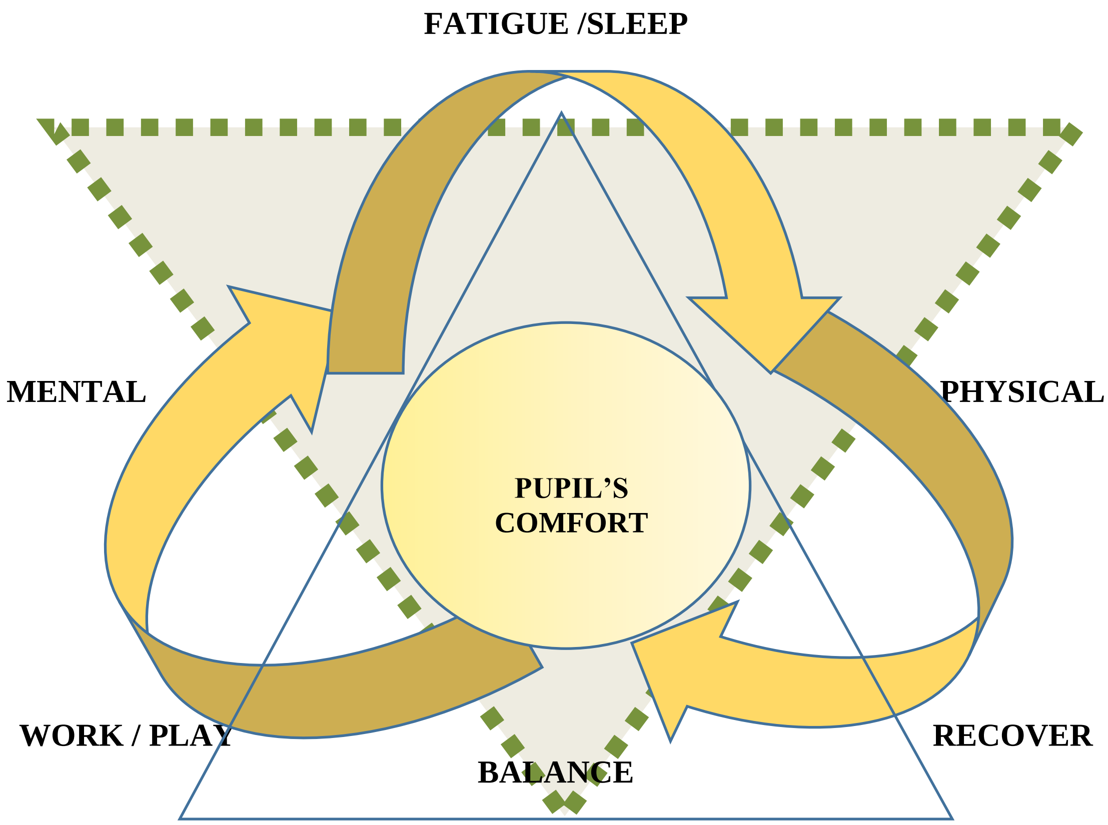


Figure 22: The Cyclical Relationship for Comfort in Humans.

Source: Adapted from Kumar, (2016)

During work or play, the body expends energy, from which the body needs to recover through reduced activity, rest or sleep. After which the cycle can then be repeated all over again. This creates a natural mental and physical balance in the body system. Researches have been carried out on schools and classroom environments and its effect on pupils and their performances (Mendell & Heath, 2005, Wargocki & Wyon 2007). If the environment is inadequate, it can have a far reaching negative effect on the health and performance of the pupils. Under high temperatures children loose composure, also learning capacity drops as children are more susceptible to heat stresses (Aynsley, *et al*, 1996).

Heat stress also has an impact on learning capacity. At high temperatures, children are less likely to concentrate and can exhibit irritable and aggressive behavior. Adults and teachers can similarly be affected. A building's indoor comfort condition is determined (primarily) by the design of the building, and this impacts on the energy efficiency. Figure 23 shows a summary of the relationship between users and energy use. The environment, if comfortable, will enhance productivity, learning and eventually impact on energy consumption.

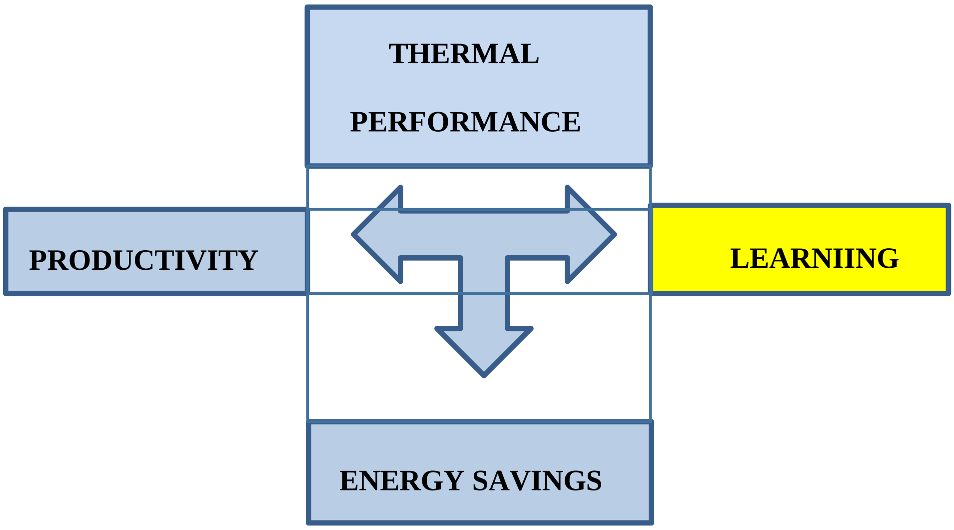


Figure 23: Summary of the Relationship between Users and Energy efficiency

Source: Guili (2012)

A vast amount of research in this field of thermal comfort have been carried out on adults and very little on children, especially from below the ages of 11, (Natephra, Motamedi, Yabuki, Fukuda & Michikawa 2013). This is very likely, as their responses are expected to be faulty or defective as there may be lack of confidence in their ability to use thermal comfort scales. Yet, Humphreys (1977) researched in this and put together a field work research in 1971. He discovered that children below the ages of 7 can understand simply worded, thermal comfort scales.

Since children have a smaller surface area compared to adults, according to Teli, Jentsch, James and Bahaj, (2012), they are likely to warm up quicker and are unable to adapt by themselves in uncomfortable situations; also, they are likely to respond differently in similar thermal environments than adults. In their analysis, they discovered that pupils had a different thermal sensation (22.5^0C) opposed to that of adults with 24^0C as stated in the ASHRAE standards.

2.4.3.1 COMFORT IN CLASSROOMS

There are many factors related to comfort in classrooms i.e. physical, emotional, psychological and all this impact favorably or otherwise on the performance of various tasks within them. Apter (1982, 1984, 2014) posited that the most influential factors on learning processes is the, temperature, noise and seat arrangement. Temperature plays a significant role in determining comfort while performing a task. Research on thermal quality, comfort and students' learning shows that 68 – 74°F and 20 -24°C is acceptable for learning (Earthman, 2000). Ventilation, which is the replacement of used up indoor air with fresh air from outdoors, is also an essential determinant of thermal comfort. It is often highlighted in most studies and measured as the concentration level of CO_2 dispensed in the air.

Ventilation can be enhanced in buildings through cross ventilation, stack effect, wind pressure and mechanical aids. Window positions, number, sizes, and external components also have an impact on the rate of ventilation within spaces. In warm humid settings, cross ventilation alone cannot suffice at high humidity levels, stack effect combined with mechanical or forced ventilation will aid quick evaporation of heat and sweat from the skin's surface. This is achieved when the ventilation flows cross the min activity spaces within the classroom.

In measuring thermal comfort for humans, a climatic chamber will not be sufficient as vast amount of variability occurs in real life situations. Objective and subjective method of measurement will be more accurate and suitable. This is the basis on which ASHRAE standard II field survey is based. This was adopted for the research. The objective method required the use of instrumentation and recording of the four environmental variables earlier listed, (air temperature, relative humidity, mean radiant temperature, air velocity).

Subjective measurement involved the recording of the responses of the pupils (TSV- thermal sensation votes, PMV- predicted men vote) through questionnaire administration, and detailed recording of their activity and clothing levels. The Table 5 shows the various thermal comfort standards for operative temperature and comfort equations based on the adaptive and rational models.

Table 5: Various Thermal Comfort Standards for Operative Temperature and Comfort Equations**.**

Standard	*Thermal comfort approach*	*Operative temperature winter (°C)*	*Operative temperature summer (°C)*	
ISO 7730(2005)	Rational	20–24	23–26	−0.5<PMV<+0.5 PPD<10%
ASHRAE 55(2004)	Rational	20.5–25.5	24.5–28.0	−0.5<PMV<+0.5 PPD<10%
EN- 15521(2007)	Adaptive	Tn=0.302TRMT+19.39; TRMT>10		
Tn=22:88; TRMT≤10				
ASHRAE 55(2010)	Adaptive	Tn=0.31TO+17.		

Source: Zomorodian *et al* (2016)

TRMT: Running Mean Temperature
TO: Outdoor Temperature

Tn = Neutral Temperature

PMV: Predicted Mean Vote.

Users' comfort and satisfaction are some of the most important factors influencing building performance, as people spend about 80% of their time daily in doors, (Mustapa, Salim, Hagishima & Ali, 2015). Comfort is a fundamental need in man's existence. It presence or absence in spaces can be observed through feedback processes naturally occurring as responses in users. These responses could be voluntary or involuntary corresponding with the theory of the adaptive model of thermal comfort, which states that, people, given opportunity and time will result to necessary actions to achieve thermal comfort. It is a natural occurrence.

Comfort and satisfaction can be measured through users' behavioural patterns, adaptations or reactions. Humphreys and Nicole (2008) posited that much attention has not been paid to the way people react to their thermal environment. These reactions could be positively, that is, by changing of clothing, changes of metabolic rate and modifications to the environment itself. It could be negative, by loss of concentration, lower attention span, restlessness, which could also be controlled by some amount of social conditioning.

But on the whole, children's self-regulating system should be observed and the positive actions enhanced or provided for in classroom design parameters. An individual can express satisfaction or comfort in a space that meets his or her physical, psychological, emotional or physiological needs. Pupils require this comfort to achieve the best of their learning process. Energy drawn away from an individual to overcome discomforts instead of being channeled to the actualization of tasks results in the failure of the functionality of that space.

Gauthier and Shipsworth, (2015) also asserted that past field surveys on thermal comfort which dwelt on occupant's behavior by predicting their state of thermal comfort or discomfort, have not sufficiently addressed relations to behavioral pattern. These research assumptions were based on three forms of responses, namely:

Mechanisms of thermoregulation, Psychological adaptation and Behavioural responses. Framework for mapping behavioural responses was drawn for cold climates which included increasing of clothing levels, increasing operative temperature by turning on heaters, increasing number of times for taking warm drinks, going to changing rooms for recess. In contrast, this could be drawn out also for warmer climates in extension to the present research. Humphreys 2007 carried out an earlier research on pupils in the primary levels and he spoke pointedly that children can understand simple worded thermal scales. Previously, researches on schools were not carried out on children, because of the fear of validity of the results. A later research on Australian classrooms suggested by De Dear, Kim, et al, (2015) stated that neutral temperature for children was 22.5^0C, which is much lower than those stipulated by ASHRAE (24^0C), which involved a climate chamber research carried out using adults. It was suggested that children have a lower sensitivity to temperature changes than adults.

This is consistent with a recent research done by Teli, Jentsch *et al* (2013), also in naturally ventilated classrooms. This reinstates that children have a different thermal preference than adults Recent research have now proven this, and thermal comfort research has advanced into behavioural patterns, adaptions and controls in buildings. Therefore this research will sample the pupils and the supervising class teachers alike.

2.4.4 THERMAL COMFORT MODELS

The different thermal comfort models from the literature under consideration are; the PMV, AMV, ASHRAE standard 55, ISO 7730. Although PMV has been established in colder climates and for buildings with HVAC, it can be used in warm climates with the introduction of the ‘e’ expectancy, factor. Researches are required to test if the PMV comfort equation could be applied to (young) children, as the relations between metabolic rate, skin temperature, sweat production and thermal sensation which are the basis of the PMV model might not be the same for children. (Teli, Jentsch *et al* 2012).

A summary of thermal comfort models in the existing literature is presented in Table 6.

Table 6: Summary of Thermal Comfort Models in the Literature

THEORIES	MODELS	AUTHOR / YEAR	SIMILARITIES /LIMITATIONS
Heat balance approach	PMV model (predicted mean vote)	Fanger (1970),	Derived from extensive climate chamber research; responses of over a thousand European and American subjects to the thermal conditions in a well-controlled environment were used to expand this equation into the PMV model. This equation and the PMV model are intended for use in the design of HVAC systems
	ISO standard 7730	Based on adaptive model	This takes into account physiological conditions as well as psychological. Which leads to certain variations in predictions and comfort calculations using the PMV. The ISSO 7730 states these viability intervals clearly, but when values fall outside of them, the results are likely to be unreliable
	ASHRAE Standard 55	Based on PMV model	Based on the PMV model.
	ADAPTIVE MODEL	Givoni B. (1976)	People, who live in naturally ventilated buildings, usually accept a wider range of temperatures and air speeds as normal. People have a natural tendency to adapt to changing conditions in their environment. This natural tendency is expressed in the Adaptive approach to thermal comfort.
	PMVe-expectancy factor	Fanger and Toftum (2002)	An improvement on the PMV model called the expectancy factor (e), usually 0.5- 1.0 and it is determined by location and frequency of warm periods. This improvement is to cover for discrepancies in the model with respect to non-air-conditioned spaces and warmer climates.
Comfort preference opposed to that of adults.	Humphreys Model	Humphreys and Nicol, 2007	This takes into consideration the variability of the PMV model with respect to children and their responses
Addendum to ASHRAE standards	ASHRAE Standard 55; 1992-2013		-1992-measuremnt protocols -PMV/PDD model and adaptive model included -Evaluating general thermal comfort in an occupied space with current POE practices.

There is no precise temperature at which everyone can be comfortable. As the ASHRAE definition of thermal comfort states, the mind is responsible for the thermal sensation experienced by an individual; therefore, there can be behavioral, cultural, or psychological adaptations to thermal comfort standards. However, a range of values at which a maximum number of people can be comfortable, say 80%, can be established to aid design considerations (Fanger, 1970). Similarly, the percentage of people dissatisfied, PDD.

Fanger (1970), in characterizing the thermal conditions of an indoor space, developed a model to express the relationship between the human body and its environment by using subjective and objective means. He derived a 7-point scale as shown in Figure 24 ranging from cold (-3) to hot (+3). This was based on the PMV (Predicted Mean Vote, developed from the ASHRAE sensation scale as shown in Table 7) and the PPD indicators (Predicted Percentage of Dissatisfied). At least 5% of people dissatisfied are a standard for measuring thermal comfort also shown in Figure 25.

Table 7: ASHRAE Thermal Sensation Scale

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

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

Figure 24: 7 Point PMV Thermal Sensation Scale

Source: Mors, Hensen, Loomans and Boestra (2011**)**

In comparing the two models, there is an obvious similarity in them, in expressing the thermal sensations of respondents. As the sensation measured moves from hot to cold, the values change from (+3) to neutral (0) and then (-3). This is used to measure the comfort votes of the respondents.

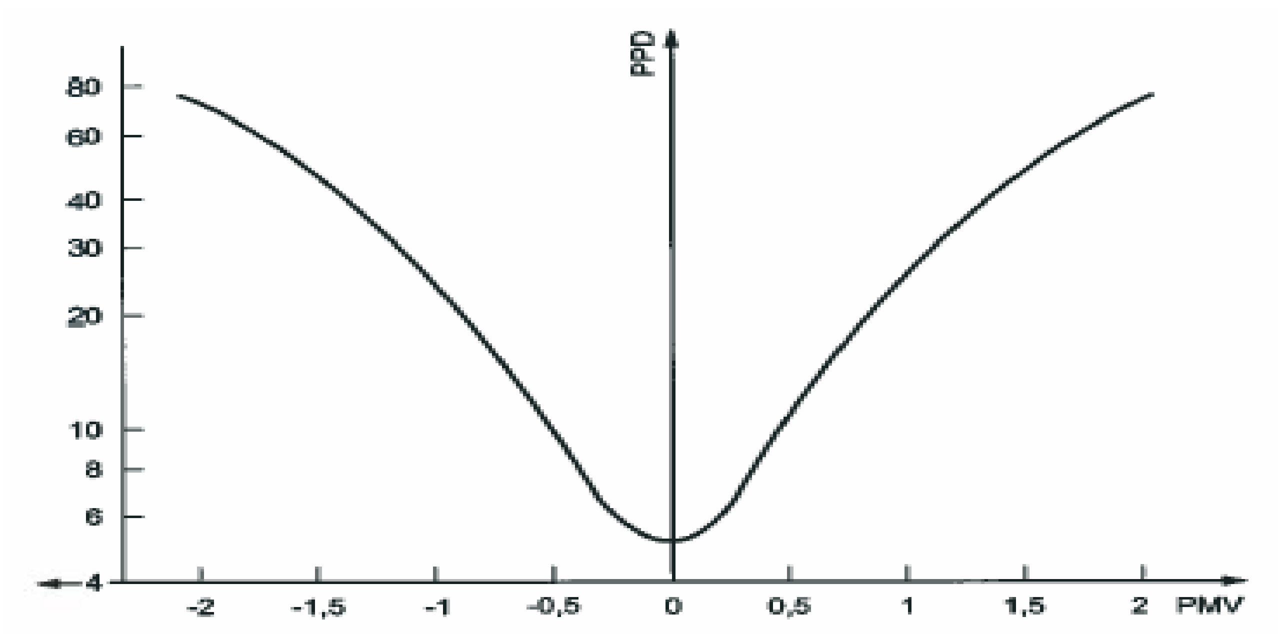


Figure 25: Predicted percentage dissatisfied (PPD) as a function of PMV
Source: Mors, Hensen *et al* (2011)

The ASHRAE standard 55 2010 combines both 2004 and 2010 guide all in one consolidated outline and this is for environmental/thermal acceptability in buildings. It establishes a range of environmental comfort standards acceptable for human occupancy in buildings. It provides guidelines on the time, position and accuracy of measuring tools to be used for carrying out the field survey. Measurement should be taken at 0.1m, 0.6m and 1.1m, and clothing levels between 0.5 - 1.0clo, and activity levels 1.0-1.3 met. The established standard for comfort in classrooms is at 24-26^{0}C, 0.2m/s, and 50% humidity.

The limitations of the PMV model carried out by Fanger to establish the thermal comfort calculations (though used as basis for most thermal comfort field studies) necessitated the use of the adaptive thermal comfort model (AMV) which was more suited for naturally ventilated buildings. PMV model was intended for the design of HVAC systems, which is a controlled environment. It, therefore, did not reflect physiological or psychological adaptations, which exist in the use of free running buildings. People in naturally ventilated buildings can adapt to a wider range of wind speeds.

A different approach to determine thermal comfort for people with reduced surface area to volume ratio was deduced by Parsons (2001), although, its application was not well substantiated. Most field surveys use the PMV model as a basis for thermal comfort calculations, though, recent studies in adaptive thermal comfort evolved, which do not require it. The AMV is the current model being used, although the discrepancies with the PMV model have been catered for in the use of the expectancy factor, ‘e’. The PMVe model is used for the study.

The ‘habitability’ model is a model used to represent environmental comfort, which is a state at which people can perform maximally in their work spaces. The model is based on the theory that physical factors are the foundation or the necessity (safety, hygiene, and accessibility); the functional factors (temperature, noise, lighting, color, ergonomics) come next and then the psychological factors (control, adaptability, ownership) in a hierarchical format. Physical comfort is at the threshold level, below which there would be discomfort. Above this are the functional and psychological comforts. When there is discomfort, the individual uses up active energy to overcome discomfort which distracts and draws away energy, focus and attention from achieving tasks optimally. This theory is suited for a wide range of spaces as shown in Figure 26.

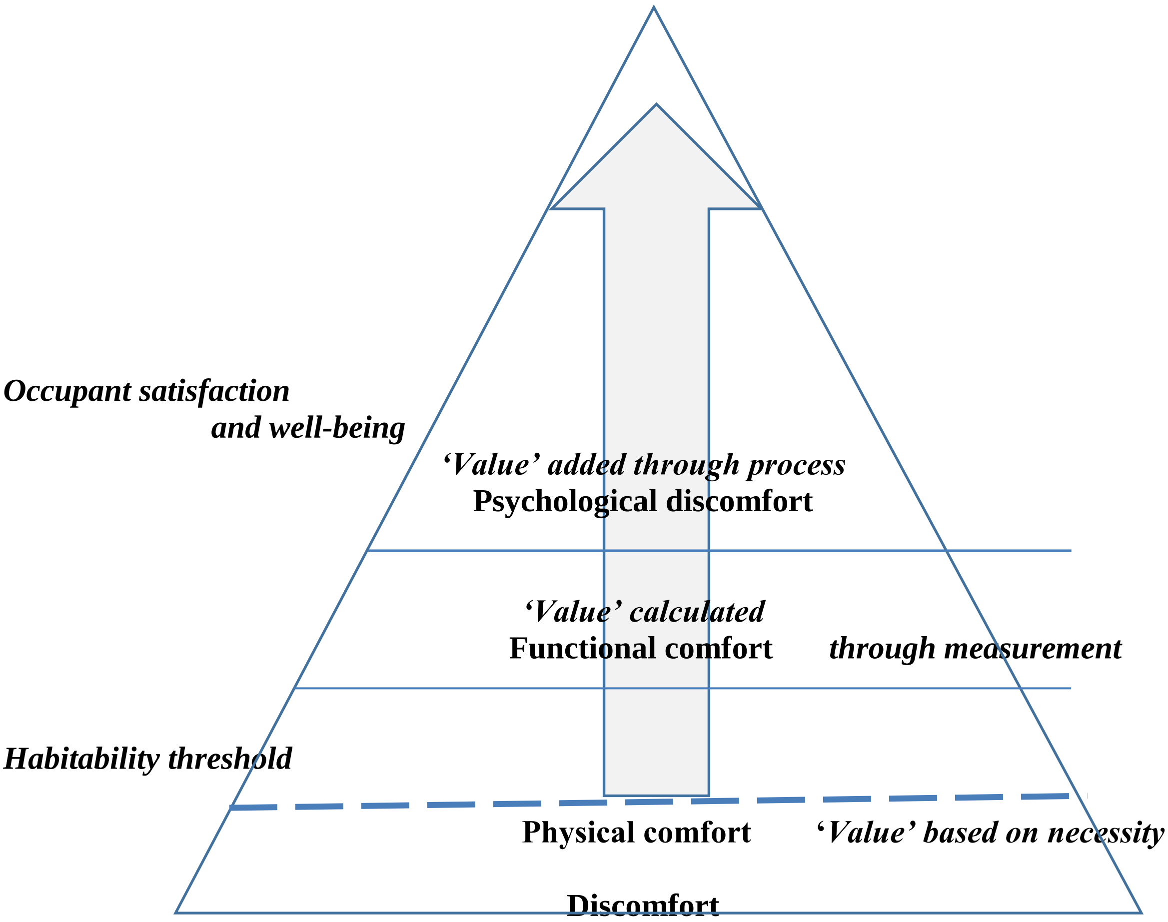


Figure 26: The 'Habitability' pyramid.
Source Vischer, (2005)

The habitability model has been adapted to suit the current research in this hierarchical format: the foundation or necessity for a building structure to achieve thermal comfort is the characteristics of the elements of the building envelope (materials, form, orientation). This influences the measure of environmental factors (the physical factors: air temperature, humidity, mean radiant temperature, air velocity. The resultant is the highest point of the pyramid, which is the thermal performance of the building envelope, from which inferences can be drawn about the thermal comfort level experienced within the building. This is shown in the conceptual model in Figure 27.

2.4.4.1 CONCEPTUAL FRAMEWORK

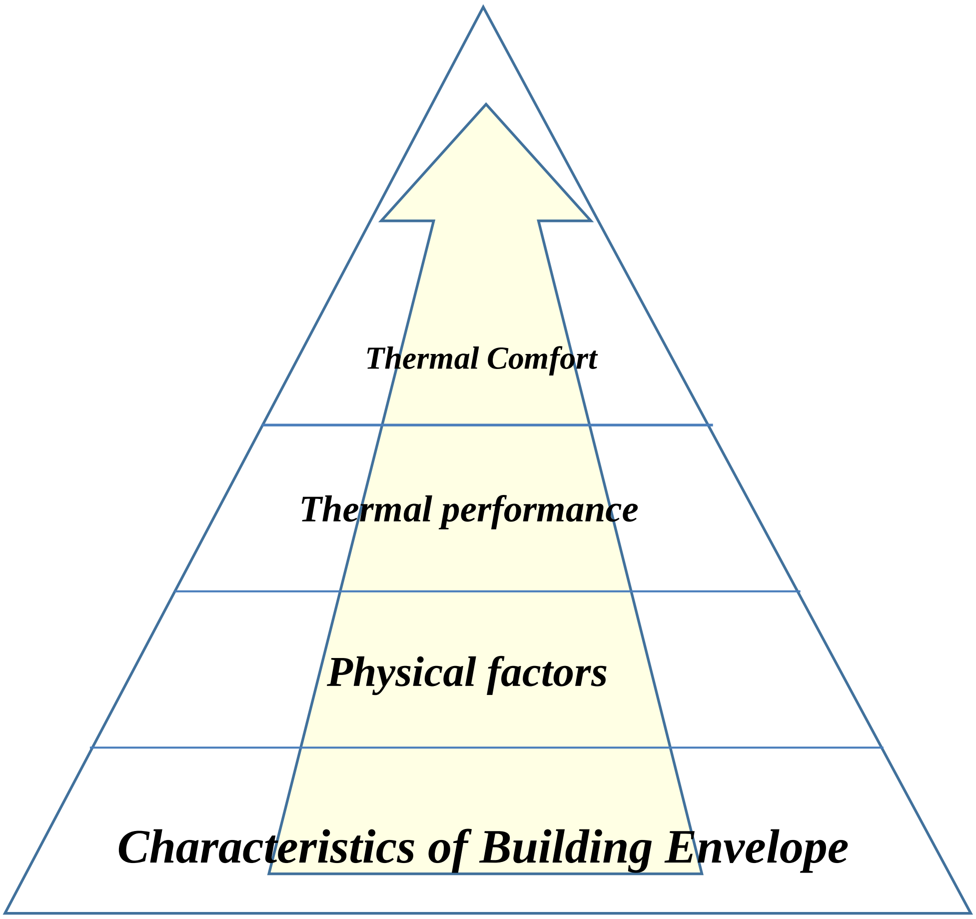


Figure 27: Thermal Comfort Pyramid

The building envelope is therefore at the base and thus reinforcing its position at the underpinning of deliberations towards thermal performance. The next level shows the physical parameters from which the thermal performance of the building envelope and its constituent elements can be extracted. The thermal performance of the building is a pointer indicating whether the building is offering a conducive environment for the tasks to be performed, thus the indoor thermal comfort.

CHAPTER THREE

MATERIALS & METHODS

This section introduces the research design, pilot study, sample size and techniques, characteristics of the study population, type of data and the method of data analysis. The basis of this thesis is survey research. The research purpose is descriptive. It is also quantitative in nature, because it seeks to address the knowledge of the unknown via measurements and testing with the use of surveys and instrumentation.

This section is concerned with the presentation and analysis of the findings of the research. This is a descriptive survey research of the thermal performance of public classroom building envelopes in Lagos Metropolis. Research presents both qualitative and quantitative analysis of the data. Data analysis is a thorough explanation of the data collected from the field survey to draw inferences which could serve as deductions, feedback which could be useful for design decisions. These data have been represented in frequencies, means (averages), and percentages to show the distribution of the data. Also, diagrammatically in bar charts, pie charts, tables and figures to clearly express the relationship between variables. The SPSS analytical tool was used to present the data. Various tests were carried out thereafter such as the linear regression analysis, T test, WilchLamda's test, Logistic regression, Analysis of Variance- ANOVA, Nagerlkele test. The data presented in the previous section will undergo the following analysis in the various sections:

3.1 RESEARCH DESIGN

The international standard for conducting thermal comfort field surveys, the class II field experiment which was stated by ASHRAE standard 55 was adopted in this study. It is based on the heat balance model of the human body, which predicts that thermal sensation is exclusively influenced by environmental factors (temperature, thermal radiation humidity and air speed), and personal factors (activity and clothing).

It involves both objective and subjective measurements. This resulted in the 'quasi experimental' design adopted in this study which includes the following;

1. Physical survey and analysis of the existing buildings
2. Interviews, recording and administration of questionnaires
3. Onsite measurements using weather instruments
4. Computer software with REVIT (BIM- Building Information Modeling) software
5. Data analysis using SPSS software

The research adopted a positivist approach; a research from the known to the unknown (to determine what variables are responsible for a certain condition) done in a natural setting whereby the investigator has little or no influence on the outcome of the experiment. Unlike the laboratory experiment, the results here are realistic as they have not been subjected to any manipulations, and do not have the restricted setting of the laboratory experiments.

The preceding sections comprise of the following subdivisions; thermal comfort factors for field survey, pilot survey, sampling technique, sample size calculations, measuring tools, structured questionnaire presentation, and analysis of the data.

3.2 THERMAL COMFORT FACTORS FOR FIELD SURVEY

AIR TEMPERATURE (AT^{0}C)

Air temperature is usually taken as one of the most significant factor while designing for thermal comfort, James and Koranteng, (2012). It is the degree of coldness or hotness of a space. It is measured using dry bulb thermometer. At high air temperatures, especially that approaching normal body temperature (34^{0}C), the body will require evaporative cooling, through moving or forced air velocity. According to Humphreys (1973), the temperature above a space is usually higher towards the ceiling, than at the seating levels of children within a space.

Therefore, the measurement of the variable will be taken at the sitting level of the pupils in the classrooms. Hourly measurements of 1hr interval for 6hrs were taken at different points within the classroom since school resumes class activities by 9 and ends by 2:00pm. ASHRAE standards for summer comfort ranges between 26-28^{0}C.

HUMIDITY (RH%)

Relative humidity is the moisture content of the air at a time and a given temperature. It is expressed in percentages. Relative humidity (RH) of a space affects the rate at which heat is released from the skin's surface through evaporation. RH is the ratio of partial pressure (or density) of water vapour in the air to the saturation pressure (or density) of water vapour at the same temperature and same total pressure. ASHRAE standards for humidity levels in summer is 70% for European countries.

MEAN RADIANT TEMPERATURE

It is the weighted average temperature of surfaces within a space. It is also, the radiant heat from the surrounding exposed surfaces (view factor) and is depends on the objects emissivity (ability to absorb or emit heat). MRT is stating the effect surface temperatures has on occupant comfort. MRT can be measured using a black globe thermometer. This consists of a black globe with a thermometer suspended in it. The surface is coated with electromagnetic coating, or black matte paint. MRT can also be measured using two-sphere radiometer and the constant-air-temperature sensor. The acceptable standards for adaptive thermal comfort range for naturally ventilated buildings has occupants' met rates at 1.0-1.3 met when clothing levels are 0.5-1.0 clo

AIR VELOCITY

Air velocity or movement is measured in m/s. It is responsible for the evaporation of moisture from the skins surface, speeding up of the evaporative cooling of the body.

CLOTHING

This depends on what type it is, or how many layers an individual is putting on. Thermal comfort is entirely dependent on the insulating effect of the wearer's clothing, which is measured as $0.155m^2K/W$ = 1clo (unit of measurement for internal resistance).

For this study, the students put on standard uniform characterized as light summer cotton clothing, which by the ASHRAE clothing standards is 0.5 clo (unit for clothing levels). The list of clo values is shown in Appendix G.

3.3 PILOT STUDY.

Pilot study was carried out to validate and calibrate the instruments in a Physics laboratory for error readings as shown in Appendix B. The validity of the questionnaire was established by carrying out a pilot study of schools within and around the University of Lagos Campus during dry season from March till April 2016. The University of Lagos staff school and Women Society School and Yaba

College of Technology Staff School were used as case studies. Discussions and training sessions were held with field assistants and interviews with school teachers to determine if the language and information required would be easily understood by the respondents prior to implementing the survey. Teachers of each classroom were also interviewed as well.

The field survey was conducted based on the class 2 field study method which requires both objective and subjective measurements. The field survey was carried out in mixed mode ventilated classrooms during dry season and onset of the rainy season from March till April and then, July till September 2016. Temperature and humidity readings for both indoor and outdoor were taken at intervals of 1hour (for 6 hourly readings) from the floor level at the center of the classrooms, at the seating and standing height of the pupils (corresponding with 0.1m,0.6m,1.1m). Pupils were to assume sitting or sedentary position for at least fifteen minutes, while the survey was being taken by the interviewer, (Adebamowo & Oginni, 2016). The orientation of the classroom and the external contexts of the building were noted. Clothing levels (a standard uniform) was 0.5clo corresponding with light summer clothing, according to ASHRAE clothing standards. Structured questionnaires recording the details of the buildings' components were filled out. Also, field survey method employed the use of online applications which were calibrated against portable measuring tools for easy implementation, and because of the limited time frame. The surveying instruments required portable devices, as opposed to fixed instrumentation because of limited occupancy periods of schools (only day time use) and security reasons.

The questionnaire was adopted from Humphreys and Hancock (2007) research carried out on primary school pupils using simple worded questions and emoticons (cartoons) to convey emotions or sensations. This was also based on the PMV's 7-point scale ranging from +3 to 0 and -3. 0 was for neutral temperature, +3 for hot and -3 for cold.

The questionnaire was tested for the appropriateness of the language used in the questionnaire and a check was carried out also using older pupils within the same school locations as well as their teachers. A preparatory training was carried out for two weeks with the skilled field examiners, prior to the commencement of the field survey.

The 2013 Government statistics tables for public primary schools were used for determining the sample size. School buildings were then stratified according to their form, type of structure-bungalow, low - rise, one-story or two-story buildings and above and materials.

For the pilot study, from the tables a percentage (0.25%) samples of schools was taken from each of the 6-educational district

3.4 DATA COLLECTION

3.4.1 DATA TYPES AND SOURCES

There are two types of data presented in this research. Primary and secondary data

Primary Data

The primary data for analysis towards achieving the objectives of this research were in groups and are broadly identified as follows;

- **Primary Data of Building Characteristics**-by trained field assistants with tertiary level qualification (objective measurement).
- **Primary Data from Respondents**- both teachers and students (subjective measurement). Primary data of objective measurements were taken with the use of measuring instruments. The indices measured are; Air temperature (^{o}C), Humidity levels (%), Air velocity (m/s), Mean radiant temperature (^{0}C).

Secondary data

Secondary data includes data from weather reports and Nigerian Meteorological agency, Oshodi (NIMET), online climatic data from weather station, as well as data from Education Boards statistics (SUBEB) on the population of pupils and numbers of classrooms per local government in Lagos State.

3.5 POPULATION OF STUDY

The population of study was drawn from each of the 6 educational districts (zonal offices) from each LGA in Lagos Metropolis; Oshodi, Sabo, Maryland, Agboju-Lagos, Victoria Island, and Agege. The total number of schools in each of the 6 local government areas in the districts were extracted from the Lagos State Government statistical tables and summed up. Table 8 shows the sample frame and ratio of spread. All data was analyzed using statistical package for social sciences, SPSS packages**.**

3.5.1 SUBJECTS OF THE STUDY

The Lagos state age groups for education levels are 3-5 for pre-school, 6-11 for primary, 12-14 for junior high and 15-17 for senior high schools (Lagos Private School Census 2010-2011 Report (2011). For the scope of this study, the subjects were mainly pupils of the ages 6-11, that is, those of primary level. The teachers of each unit were also interviewed to ascertain the validity of the survey tests carried out.

3.5.2 SAMPLING

The objective of sampling is to provide means of carrying out the data collection and the processing of data so as to enable one make useful or valid deductions. The sample must be an appropriate representation of the whole, (Fellows & Liu, 1977). Likewise, the borders of the sampling frame must be distinct and defined. The sampling technique can either be probability or non-probability sampling. Whichever choice is based on the nature of research data, reliability, or validity of expected results, (Blaxter, Hughes, & Tight, 2001).

3.5.3 SAMPLING FRAME.

The sampling frame was the six educational districts in Lagos namely: Education District 1-Agege, Education District II- Ikeja, Education District III- Ikoyi –Yaba, Education District IV- Agboju, Education District VI, Oshodi. (See appendix D)

Table 8: The 6 educational districts in Lagos and the respective Local Government areas

S/N	EDUCTIONAL DISTRICTS	LGA	NO of SCHOOLS	30%	SAMPLE SIZE
1	**DISTRICTS 1-**	Alimosho, Agege, Ifako-Ijaye.	149	44.4	44
2	**DISTRICTS 2-**	Ikorodu, Somolu, Kosofe.	47	14.1	14
3	**DISTRICTS 3-**	Epe, Ibeju Lekki, Eti-Osa, V/Island.	182	54.6	55
4	**DISTRICTS 4-**	Surulere, Lagos Mainland, Apapa.	144	43.2	43
5	**DISTRICTS 5-**	Badagry, Ojo, Amuwo-Odofin, Ajeromi / Ife- Lodun.	211	63.3	63
6	**DISTRICTS 6-**	Ikeja, Mushin, Oshodi-Isolo.	158	47.4	47
			TOTAL		**266**

A sample size, 266 schools, was extracted from the sample frame - the six educational districts, at 30% from each district, Kothari and Garg (2014). An online sample size generator was also used to compute the sample size as 282 (as shown in appendix B). 210 samples were recovered from field as fit for analysis. The acceptance rate is 74%.

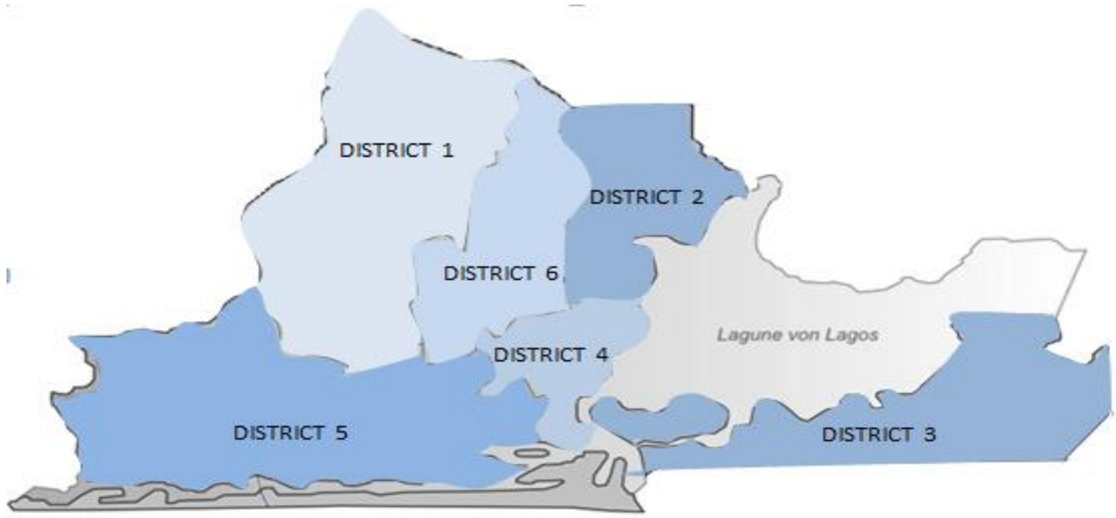


Figure 28: Map of Lagos showing the six educational districts in Lagos state

3.5.4 CHOICE OF SAMPLING TECHNIQUE

Probability sampling is a sample method whereby each element has the opportunity of being included in the sample. The sample design of choice here is the proportionate stratified random sampling technique. A multistage sampling method was required for this research. Random sampling technique was used so that every sample has a probability of being chosen to eliminate bias or control by the researcher, thereby increasing the validity of the results. Each sample is not homogenous; therefore this type of random sampling technique ensured a variety of samples.

3.6 RESEARCH INSTRUMENTS FOR DATA ANALYSIS

In Table 9 is a summary of methods and instruments to be used to achieve each of the objectives.

Table 9: Summary of method and instruments used to achieve the objectives.

	OBJECTIVES	METHOD	INSTRUMENT
Objective 1	To identify the characteristics of primary school building envelopes in Lagos	Observation, data gathering, sketches, and pictures. Grouping classrooms under similar forms, & elements- roof types, wall, fenestrations and floors	Questionnaire & Cameras. Descriptive analysis
Objective 2	To examine thermal performances of the primary school classrooms in Lagos.	Field survey; measuring the air temperature, humidity, mean radiant temperature and air velocity via instruments and correspond with ASHRAE Standards -U/G values of elements	Portable instruments& Online apps. Pearson Product Moments Correlation analysis, T- test.
Objective 3	To determine the relationship between the building envelopes and the thermal performance of the classrooms	Statistical analysis of thermal comfort - PMV votes from respondents versus the thermal performance of classrooms	Pearson Product Moments Correlation analysis
Objective 4	To evaluate the impact of indoor thermal conditions on users of the classrooms	Discuss findings of Statistical analysis	Logistic regressions
Objective 5	To develop a model explaining the relationship between building envelopes and the pupils' satisfaction.	Results versus control experiment of standard model classroom with building characteristics i.e, L, W, H, A, V, k, U	Wilch Lambdas test, Logistic regression

3.6.1 INSTRUMENTS FOR DATA COLLECTION

Several options are available for use by the researcher, but choices were made based on various parameters such as viability, accuracy, cost, and ease of use or technicality.

3.6.2 INSTRUMENTS FOR PRIMARY DATA

Table 10: Instruments for Primary Data

	INSTRUMENTS	**DATA COLLECTION**	**DATA ANALYSIS**
Primary data Physical measurements	Measuring tapes Digital Cameras Compass	Length, breadth, height Orientation Building Elevations	Form analysis REVIT BIM
Environmental variables;	Digital Thermometers Multi-use meters Online applications	Temperature Humidity Mean radiant Air velocity	SSPSS Statistical tools
	Oral interviews	**Personal factors** Metabolic activity Clothing levels	SSPSS Statistical tools
Secondary data	Archival data	**Weather data**	

The following instruments were used in the collection of primary data

1. Portable measuring instruments for Relative humidity, air temperature and air velocity meters, shown in Figure 29.

2. Online measuring applications installed on phones and electronic gadgets. Online applications were downloaded (Figure 30) and used on electronic gadgets such as phones, iPads, after calibration with live measuring instruments for error readings.

   ‘Switch off’ time was observed for about 30mins to cool devices before it allowed carrying out temperature readings as shown in the Appendix B for calibration. Many android applications were used such as Galaxy Sensors- temperature and humidity apps, Compass Pro, Zephyrus air velocity app, and Compass for Android. These applications were readily accessible online and when calibrated with the field instruments were found to be accurate.

Figure 29: RH and air velocity meters

Figure 30: Online Phone Applications

3.6.3 INSTRUMENTS FOR SECONDARY DATA

Structured questionnaires were used with sections 1A -Characteristics of classrooms, B- Sketches of the building structures, Section 2 - Measurement of the environmental variables, and B- the perception of the pupils and activities. Discussions and training sessions were carried out with field assistants and interviews with primary school teachers to determine if the language used and information required would be easily understood by the respondents before implementing the survey. Sketches and diagrams as well as pictures of the plan, location and orientation of the sampled classrooms were taken by the trained assistants. Structured questionnaire from which all parameters of the classrooms have been detailed as shown in the Appendix A.

CHAPTER 4

DATA PRESENTATION, ANALYSIS AND DISCUSSION OF FINDINGS

4.1 DATA PRESENTATION

This section deals with the presentation of the raw data received from the field study for further analysis. The time frame for the field study was March till July, then August till October, the hottest part of the dry season through till the rainy season in 2016 and 2017. Field surveys carried out by Corgnati, Ansaldi, and Filippi (2009); Mishra and Ramgopal (2015); and Zomorodian *et al* (2016) spanned between September and October 2006 till May 2007; autumn 2013 to Spring 2014 and from a thermal comfort review, a minimum of a week to maximum of a year respectively.

4.2 THE THERMAL PERFORMANCE OF IDENTIFIED CLASSROOMS

TABLE 11: Summary of Data of Variables from the Field Survey

Thermal Performance	Range	Minimum	Maximum	Mean	Standard Deviation	Variance
Outdoor Air	14.30^0	19.40^0	33.70^0	28.94^0	2.76^0	7.61^0
Indoor Air	13.30^0	20.60^0	33.90^0	27.75^0	2.29^0	5.25^0
Humidity	99.31%	0.69%	100.00%	62.92%	24.93%	621.67%
MRT	10.60^0	21.08^0	31.68^0	28.27^0	2.30^0	5.31^0

The mean outdoor temperature in Table 16 is 28.9°C, indoor 27.75°C, humidity 62.92% and Mean radiant temperature 28.27°C for all the primary school classrooms surveyed in the educational districts in Lagos state.

Table 12: Test for Hypothesis 1: One-Sample T Test for indoor air temperature

	Test Value = 26.94					
	T	**Df**	**P-value**	**Mean Difference**	**95% Confidence Interval of the Difference**	
					Lower	Upper
Indoor Air Temperature	2.172	37	.036	.8074	.054	1.561

The test of Hypothesis 1 is as follows:

The test statistics shows that at α, the level of significance is equal to 0.05. When P-value is greater than the α-value, the research rejects the null hypothesis and concludes that there is no sufficient evidence to say that there is a difference in the mean indoor temperature and the ASHRAE's standard. When the P-value is less than the α-value the research rejects the null hypothesis, and concludes that there is a significant difference in the mean temperature and the ASHRAE's standard. Thus, from the Table 12, our P-value is 0.036 which is less than our α-value, the level of significance given as 0.05. Thus, the decision rule is to reject the null hypothesis and conclude that that there is a significant difference in the indoor temperature of primary schools in Lagos state.

Table 13: Test for Hypothesis 2: One-Sample Test for Humidity

	Test Value = 40					
	T	**Df**	**Sig. (2-tailed)**	**Mean Difference**	**95% Confidence Interval of the Difference**	
					Lower	Upper
Humidity	5.666	37	.000	22.9157895	14.720435	31.111144

The following inferences can therefore be deduced from the table 13; when P-value is greater than the α-value, the research fails to reject the null hypothesis and concludes that there is no enough evidence to say that there is a significant difference in the mean humidity to that of the ASHRAE's standard of 50%. When the P-value is less than the α-value, the research rejects the null hypothesis and concludes that there is a significant difference in the mean humidity and the ASHRAE's standard. Thus, from the above table, our P-value is 0.000 which is less than the α-value, the level of significance given as 0.05. Thus, the research rejects the null hypothesis and concludes that there is a significant difference in the mean humidity of primary schools in Lagos state to that of the ASHRAE's standard.

Table 14: Test for Hypothesis 3: One-Sample Test for air velocity

	Test Value = 0.5					
	t	**Df**	**Sig. (2-tailed)**	**Mean Difference**	**95% Confidence Interval of the Difference**	
					Lower	Upper
Air Velocity	5.108	38	.000	.42462	.2563	.5929

For the Table 14;

H_0: The air velocity of primary schools in Lagos state is not significantly different from that of the ASHRAE standard which is 0.05m/s versus H_1: The air velocity of primary schools in Lagos state is significantly different from that of the ASHRAE standard which is 0.05m/s. When P-value is greater than the α-value, the research fails to reject the null hypothesis and concludes that there is no enough evidence to say that there is significant difference in the mean air velocity and the ASHRAE standard. When the P-value is less than the α-value the research rejects the null hypothesis, and concludes that there is a significant difference in the mean air velocity and the ASHRAE's standard. Thus, from the above table, our P-value is 0.000 which is less than the α-value, the level of significance given as 0.05. Thus, the research rejects the null hypothesis and concludes that there is a significant difference in the mean air velocity of primary schools in Lagos state which is opposed to that of ASHRAE's standard.

The calculated thermal performance per classroom material variants are shown in Table 15.

Table 15: Thermal Performance per Envelope Type

Building Type	**Thermal Performance (watts /s)**	**(per unit/time)**
A	658.1	1.40
B	456.3	0.98
C	633.0	1.35
D	569.6	1.21
E	713.1	1.52
F	357.4	0.76
G	709.0	1.51
H	408.3	0.87
I	744.9	1.59
J	858.4	1.83
K	873.7	1.87
L	1320.1	2.82

A modified Thermal Performance equation was developed;

$$\varphi = O_{A.O} \sum_{i=1}^{n} U_i$$

Using the Unit per time and values of thermal performances in Table 20,

Where $O_{A.O}$= A ×ΔT (multiplier factor), i value; 1= roof, 2=wall, 3=window, 4= floor transmittances.

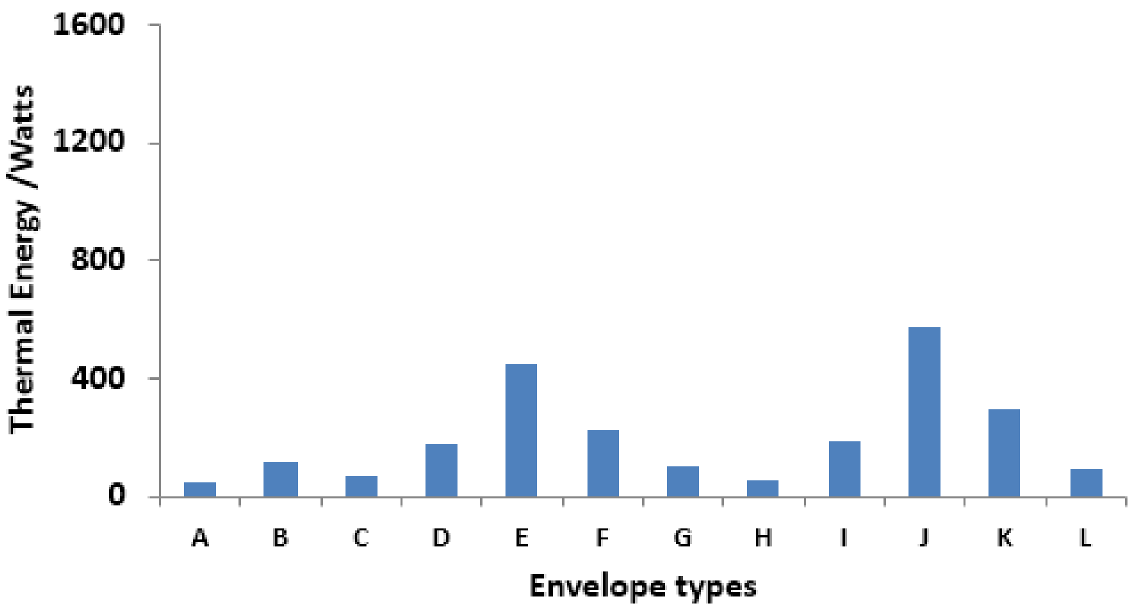


Figure 31: Bar chart showing the Thermal performance at measured temperature

Figure 31 shows the relationship between the various envelope types and their thermal performance at measured temperature. Envelope type A (asbestos/Block wall/Metal/Cement Screed), has a thermal performance of 50.63/watts. Envelope type B (Aluminium/Block wall/Wooden/Tiles) has a thermal performance of 119.67/watts. Envelope type C (Aluminium/Block wall/Metal/Cement Screed) has a thermal performance of 66.40/watts. Envelope D (Concrete/Block wall/Metal/Cement Screed) has a thermal performance of 182.42/watts. Envelope E (Aluminium/Block wall/Glass/Cement Screed) has a thermal performance of 448.80/watts. Envelope F (Aluminium/Wood Partition/Glass/Cement Screed) has a thermal performance of 224.96/watts. Envelope G (Asbestos/Block wall/Concrete Fins/Cement Screed) has a thermal performance of 99.17/watts. Envelope H (Aluminium/Block Wall/Wood/Cement Screed) has a thermal performance of 55.39/watts. Envelope I (Asbestos/Block Wall/Metal/Terrazzo) has a thermal performance of 184.92/watts. Envelope J (Aluminium/Block Wall/Glass/Terrazzo) has a thermal performance of 576.26/watts. Envelope K (Aluminium/Block Wall/Glass/Tiles) has a thermal performance of 296.31/watts. Envelope L (Aluminium/Brick Wall/Glass/Tiles) has a thermal performance of 92.31/watts.

It was discovered that the building's thermal performance was expressed as a composite of the different characteristic elements of the building. Therefore, the heat absorbing and heat retarding materials worked in consonance together, thereby creating a different thermal expression than what was expected. For instance, the highest performance was calculated for the Envelope L (Aluminium/Brick Wall/Glass/Tiles). The aluminium roof and glass windows conducted heat inwards while the brick walls and tiles, retained them as they have a lower thermal conductance, making the envelope hotter than expected

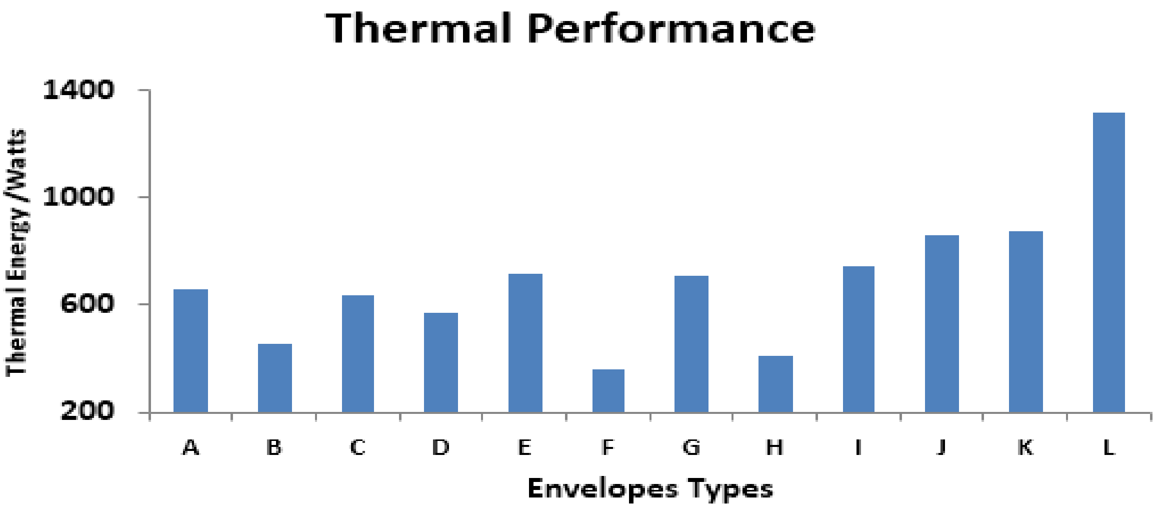


Figure 32: Bar chart showing the Thermal performance at range Temperature (14.3°C)

Figure 32 shows the relationship between the various envelope types and their thermal performance at 14.3^{0}C temperature. Envelope type A (Asbestos/Block wall/Metal/Cement Screed), has a thermal performance of 658.14/watts. Envelope type B (Aluminium/Block wall/Wooden/Tiles) has a thermal performance of 456.33/watts. Envelope type C (Aluminium/Block wall/Metal/Cement Screed) has a thermal performance of 632.97/watts. Envelope type D (Concrete/Block wall/Metal/Cement Screed) has a thermal performance of 569.56/watts. Envelope type E (Aluminium/Block wall/Glass/Cement Screed) has a thermal performance of 713.09/watt. Envelope type F (Aluminium/Wood Partition/Glass/Cement Screed) has a thermal performance of 357.43/watts. Envelope type G (Asbestos/Block wall/Concrete Fins/Cement Screed) has a thermal performance of 709.04/watts. Envelope type H (Aluminium/Block Wall/Wood/Cement Screed) has a thermal performance of 408.30/watts. Envelope type I (Asbestos/Block Wall/Metal/Terrazzo) has a thermal performance of 744.90/watts. Envelope type J (Aluminium/Block Wall/Glass/Terrazzo) has a thermal performance of 858.38/watts. Envelope type K (Aluminium/Block Wall/Glass/Tiles) has a thermal performance of 873.66/watts. Envelope type L (Aluminium/Brick Wall/Glass/Tiles) has a thermal performance of 1320.08/watts. Envelope type F (Aluminium/Wood

Partition/Glass/Cement Screed) and Envelope H (Aluminium/Block Wall/Wood/Cement Screed) type have thermal performance of close proximity.

4.3 THE CHARACTERISTICS OF PRIMARY SCHOOL BUILDING ENVELOPES IN LAGOS

The characteristics of the classroom building envelopes are stated below;

- The form types and frequency of occurrence
- The material specification and distribution across samples.

4.3.1 TYPES OF LAYOUT AND FREQUENCY OF THE DIFFERENT CLASSROOM TYPES IN LAGOS

The total number of classroom blocks surveyed was in the forms of the layouts in Table 16 with Linear Layout having the highest frequency of samples.

Table 16: Characteristics of Classroom Layout

Classroom Layout	**Linear Layout**	**Double Loaded**	**L- shaped Layout**	**U- shaped Layout**
Frequency Of samples	146	16	31	17

The table 17 reveals the various building types in primary schools in Lagos State. The linear form accounted for about 80% of the sample, the double loaded form accounted for about 8%, the L-shape form accounted for about 10% and the U-shape form accounted for about 3%. Amongst the various building forms, the linear form is more popularized among other building forms and the U-shape form was the least popularized among primary schools in Lagos Metropolis. The names of the schools surveyed are listed in Appendix F.

Table 17: Frequency of Occurrences of Classroom Layout Types

Building Types	Percent	Valid Percent	Cumulative Percent
Linear Form	79.5	79.5	79.5
Square shape Form	7.7	7.7	87.2
L-shape Form	10.3	10.3	97.4
U-shape Form	2.6	2.6	100.0
Total	100.0	100.0	

Table 18 reveals various heights of building in primary schools in Lagos state ranging from bungalow to storey buildings. The largest structure is the two-storey building. The group of buildings mostly popularized in primary schools in Lagos state is the bungalow with 69.2% occurrence while both the first floor and the second floor accounted for 15.4% equally.

Table 18: Physical Characteristics of Classroom Envelopes

GROUPS	Percent	Valid Percent	Cumulative Percent
Bungalow	69.2	69.2	69.2
First Floor	15.4	15.4	84.6
Second Floor	15.4	15.4	100.0
Total	100.0	100.0	

4.3.2 MATERIAL OF CLASSROOMS AND FREQUENCY OF DISTRIBUTION

The different types of classroom material specifications are 12 in number, coded with letters A- L in Figure 33.

The Figure 33 shows the frequency of occurrence for each material variant in the survey. Each material is represented by a color code in the legend. From the figure 33, aluminium roof is the highest roof type in occurrence, cement block wall, glazed windows and cement screed floors.

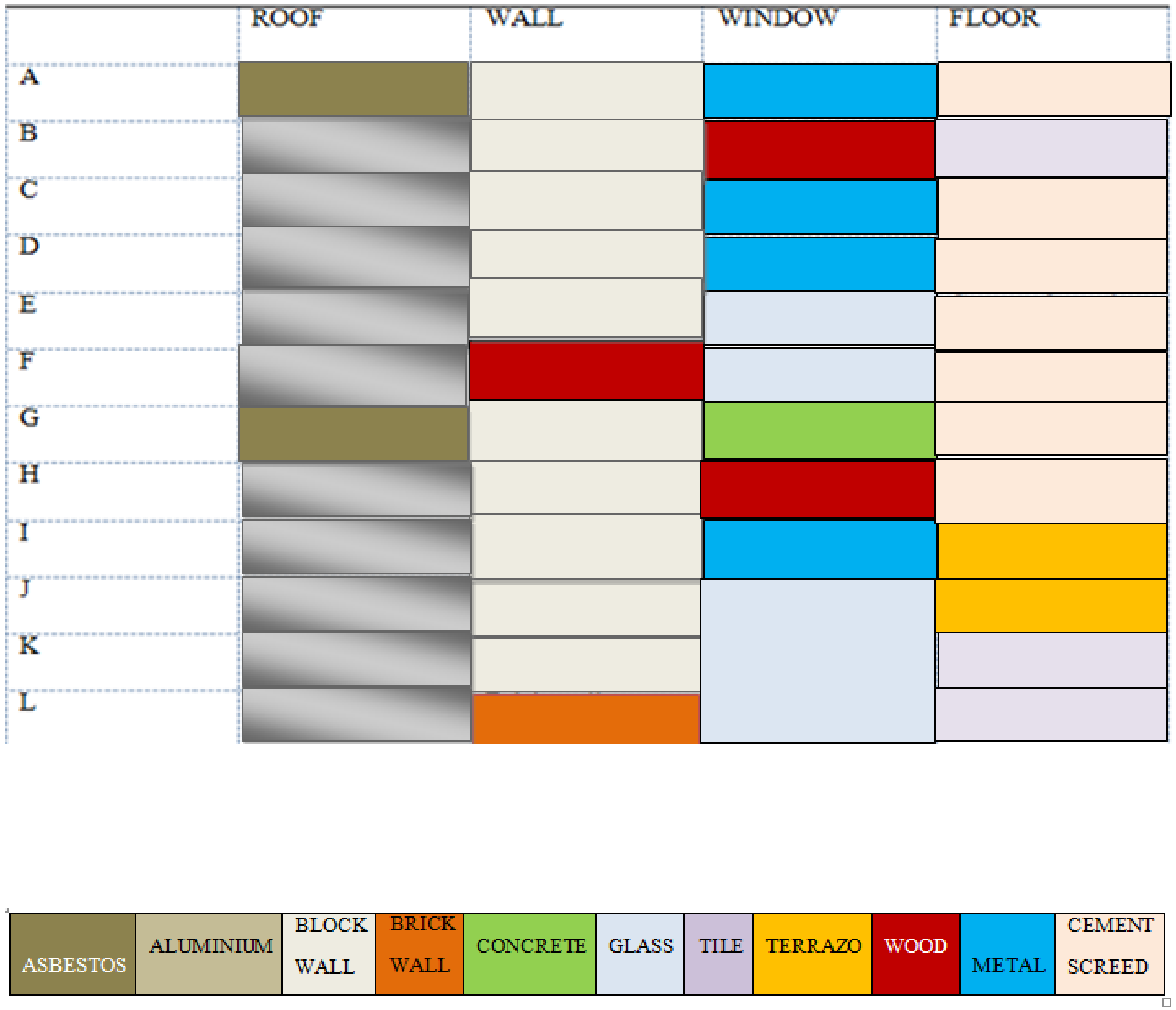


Figure 33: 12 variants A- L with similar characteristics

This is expatiated in the Table 19. It is shown that Aluminium roof/ Cement block wall/ Metal windows/ Cement screed floors have the highest occurrence at thirty percent (30%). This is followed by Aluminium roof/ Cement block wall/ Wooden windows/ Cement screed floors at twenty percent (20%). At fifteen percent (15%) is

Aluminium/ Block wall/ Metal windows/ Terrazzo floor, and all other typologies at 5% and below as shown in Table 19.

Table 19: Percentage of Occurrence of Material Typologies Surveyed

Roof-Wall-Window-Floor	Percent	Valid Percent	Cumulative Percent
Asbestos- Block- Metal- Screed	5.1	5.1	5.1
Aluminium- Block- Glass- Terrazzo	5.1	5.1	10.3
Aluminium- Block- Glass- Tiles	5.1	5.1	15.4
Aluminium- Block- Wood- Tiles	2.6	2.6	17.9
Aluminium- Block- Metal- Screed	30.8	30.8	48.7
Concrete- Block Metal- Screed	5.1	5.1	53.8
Asbestos- Block- Concrete Screen- Screed	2.6	2.6	56.4
Aluminium- Block- Glass- Screed	5.1	5.1	61.5
Aluminium-Block- Wood- Screed	20.5	20.5	82.1
Asbestos- Block- Wood- Screed	5.1	5.1	87.2
Aluminium- Block- Metal- Terrazzo	12.8	12.8	100.0
Total	100.0	100.0	

The summary includes the roof materials, wall materials, window materials and floor finishes. The building envelope mostly popularized in primary schools in Lagos state in this research work is the aluminium/block wall/metallic window/ cement screed floor variant which accounted for about thirty-one (31%) percent. The next in the frequency is the aluminium/block wall/wooden window/cement screed floor variant accounting for about twenty-one (21%) percent. Following in the series is the aluminium/block wall/metal window/terrazzo floor at thirteen (13%) percent occurrence. The remaining 4 typologies had a tie with five (5%) percent occurrence, except the last variant which is the asbestos/ block wall/concrete screen fins/ cement screed floor at two (2%) percent occurrence.

4.4 THE RELATIONSHIP BETWEEN THE THERMAL PERFORMANCE OF THE CLASSROOMS AND THE BUILDING ENVELOPES

Table 20: Relationship between Building Envelopes and Thermal Performance

Correlations		Building Envelopes	Thermal Performance
Building Envelopes	Pearson Correlation	1	.933**
	P-Value		.000
Thermal Performance	Pearson Correlation	.933**	1
	P-Value	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

The study examined the relationship between building envelopes and thermal performance of classrooms. Correlation test was carried out and the Table 20 shows that there is a strong positive correlation between building envelopes and thermal performance of the building materials with a Pearson correlation value of 0.933. The test hypothesis is given as thus:

H_0: There is no correlation between building envelopes and thermal performance, versus,

H_1: There is a positive correlation between building envelopes and thermal performance.

The research rejects the hypothesis H_0 at $\alpha= 0.05$ and 0.01. The research hereby concludes that there is a positive correlation between building envelopes and thermal performance. The result implies that there is a strong relationship between thermal performance and the building envelopes.

4.5 THE RELATIONSHIP BETWEEN THE THERMAL PERFORMANCE AND THE PUPILS' COMFORT

The results of objective four show the relationship between the thermal performance and the pupil's comfort. Logistic regression is used here for a valid result of the relationship between both variables.

Table 21: The Relationship between the Thermal Performance and the Pupils' Comfort

Coefficients[a]

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta		
1	(Constant)	8.273	.983		8.417	.000
	Air temperature (0C)	-.215	.033	-.589	-6.595	.000
	Humidity (%)	-.022	.008	-.260	-2.850	.006
	Class density	-.754	.202	-.331	-3.737	.000

a. Dependent Variable: Thermal Preference Vote; R – sq. = 0.584; Adj. R – sq. = 0.562

The Table 21 shows the three variables significantly responsible for the thermal performance of the classrooms; air temperature, humidity and classroom density, with R -sq. value at 0.584, and 0.562.

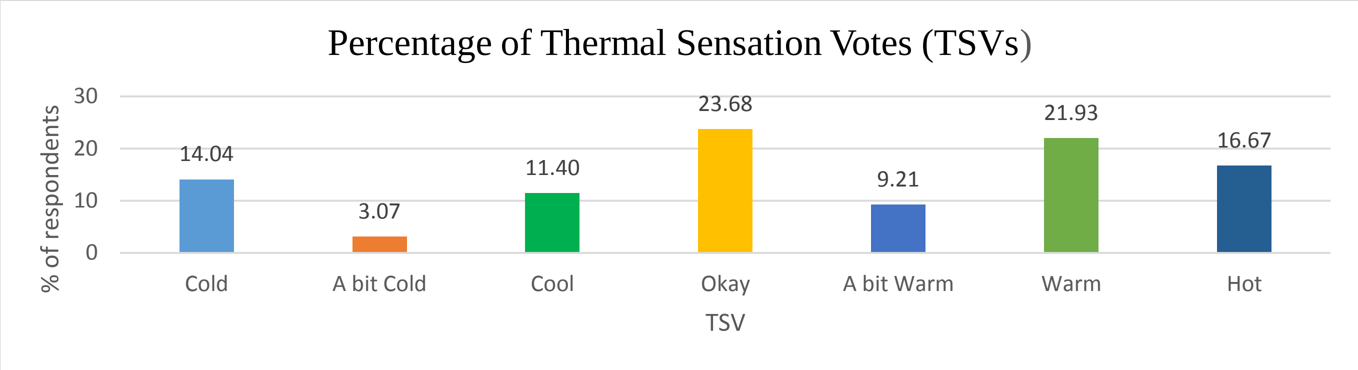


Figure 34: TSV response distribution pattern

In Figure 34, the result reveals that 24% of the pupils rated the TSV as 'okay', 22% rated it as warm, 17% rated it hot while 9% rated it a bit warm. Also, 14% voted 'cold', 11% rated it cool and 3% rated it a bit cold. In total 48% were in the warm range and 28% in the cold range.

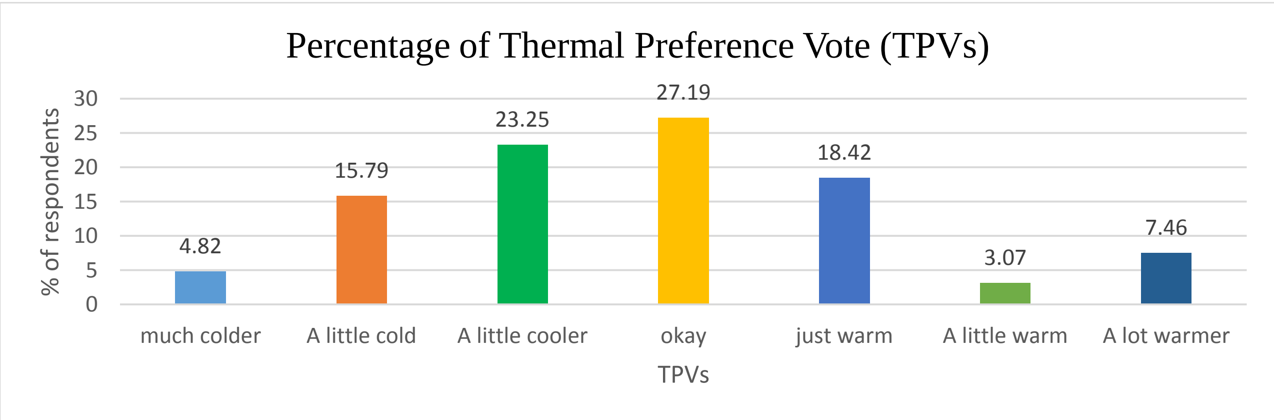


Figure 35: TPV response distribution pattern

Figure 35, the TPV versus TSV showed preference for cooler indoor condition by over 50% of the pupils. Furthermore, TPV shows 'okay' at the highest distribution at twenty seven percent (27%), followed by pupils who wished to be ‘a little cooler’ at twenty three percent (23%), those pupils who were ‘just warm’ at eighteen percent (18%). While in the cold range, pupils who wished to be ‘a little cold’ were at fifteen percent (15%) votes and those who wanted to be ‘much colder’ at four percent 4%.

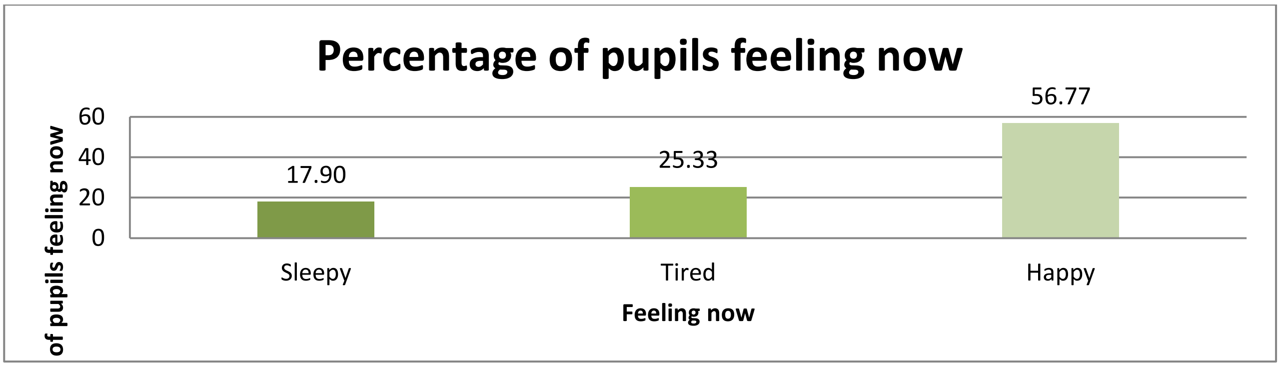


Figure 36: percentage vote for “feeling now”

In Figure 36 Twenty five percent (25%) were tired while seventeen percent (17%) were sleepy. It is worth noting that most of the activities during the period of survey were sedentary, with a few of the pupils returning from their break time. A greater percentage of pupils felt happier (56%) in the hot range of the thermal sensation votes than those in the cold range. This shows a great adaptation for hot periods.

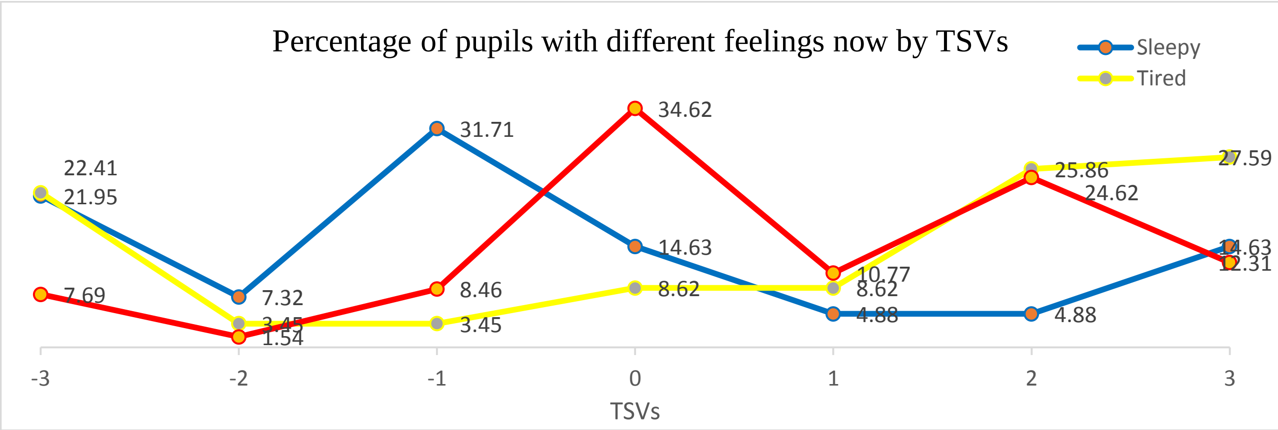
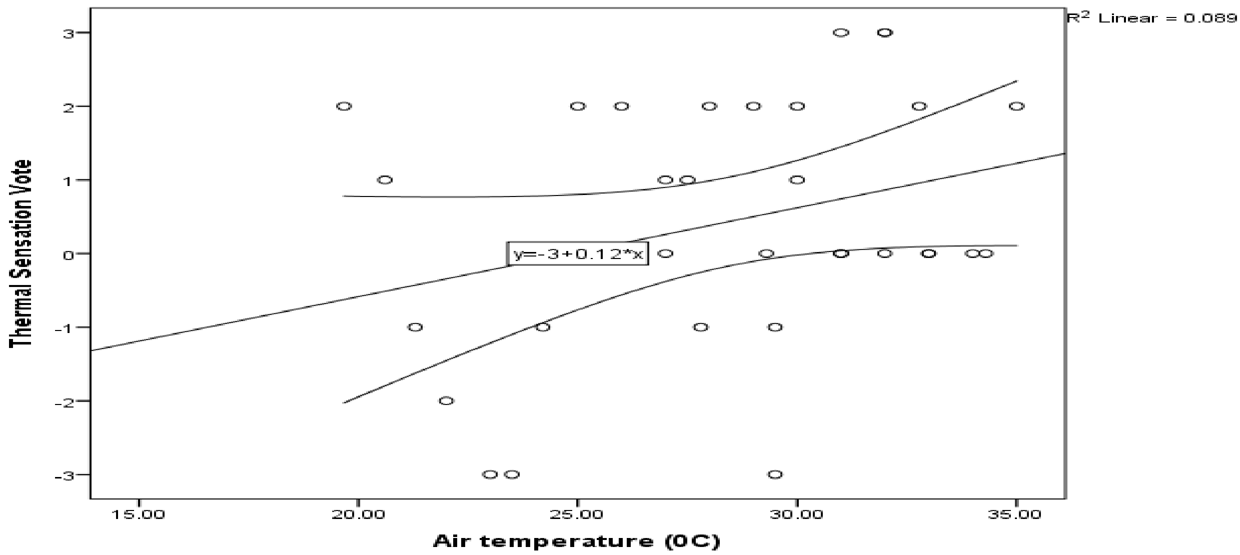


Figure 37: inferential statistics of TSVs

In Figure 37, apart from the respondents in the normal range (okay), the feelings of 'happiness' was higher in the 'warm' to 'hot' range than in the 'cold' range. While feelings of 'sleepiness' were running hand in hand as responses moved towards the cold range, unlike tiredness in the hotter range.

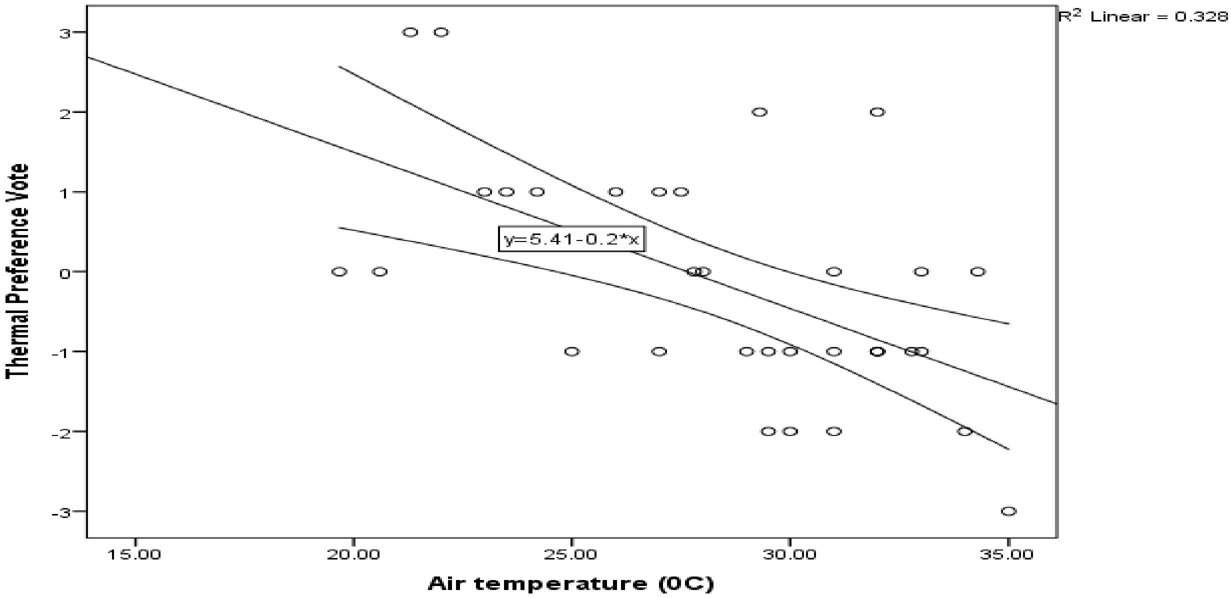


° - scattered plot of the TPV against the air temperature

- shows the positive relationship between the TPV and the air temperature.

Figure 38: relationship between TSV and air temperature

In Figure 38**,** there is significant positive linear relationship between the TSV and Air temperature ($p < 0.05$) in the classroom. It shows that while the air temperature of the classroom increases, the TSV of the respondents rose from the cold region to the hot region.



° - scattered plot of the TPV against the air temperature

- shows the negative relationship between the TPV and the air temperature.

Figure 39: TPV versus air temperature

In Figure 39**,** there is significant negative linear relationship between the TPV and Temperature ($p < 0.05$- level of significance) in the classroom. It shows that while the air temperature of the classroom increases, the TPV of the respondents dropped towards the cold region. This shows correlation.

Table 22: Hypothesis 4: Chi square Tests

	Value	Df	P-Value
Pearson Chi-Square	277.425[a]	222	.007
Likelihood Ratio	271.820	222	.013
Linear-by-Linear Association	3.107	1	.078
N of Valid Cases	182		

a. 266 cells (100.0%) have expected count less than 5. The minimum expected count is 20.

The Table 22 is the result of the chi-square test for independence. The test hypothesis is

H_0: There is no relationship between thermal performance and the pupils' comfort

H_1: There is a relationship between the thermal performances of classrooms and the pupil's comfort.

The research rejects the hypothesis H_0 at $\alpha = 0.05$ and concludes that there is a relationship between the thermal performance of classrooms and pupil's comfort with p-value of 0.007, which is less than 0.05.

4.6 THE MODEL PREDICTING THE RELATIONSHIP BETWEEN THE THERMAL PERFORMANCE AND THE PUPILS' COMFORT

The result of objective five proposes an ideal model showing the relationship between the building envelopes of the classrooms and pupils' comfort.

Table 23: Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	36.824[a]	.118	.178

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

From the Table 23, the Nagelkerke R square value is 0.178 and the Cox & Snell R square value is 0.118 which means that about 18% of the variables that entered into the equation is explained by the response variable and a loglikelihood value of 36.824. It is appropriate to use the Nagelkerke R square since there are more than one variable as predictor variables just like the adjusted R^2.

Table 24: Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	10.726	8	.218

The Hosmer and Lemeshow test in Table 24 shows a goodness of fit test. Thus, from the table, the result shows a non-significant test which means it is a good fit to the model. Thus, the model equation is given by;

$$\boldsymbol{\eta_i = 3.036 + 0.047OAT - 0.013IAT + 0.03Humidity - 0.247MRT - 0.004TP - 0.017Envelope}$$

4.7 DISCUSSION OF FINDINGS

A Cross Section of Some Government- Owned Primary Schools in Lagos

Figure 40: Ajeromi Ifelodun Primary School, with Dwarf Walls and No Ceilings.

Previously, many public schools in Lagos were built with dwarf walls, no fenestrations and ceilings. The floors are either cement screed or unfinished. In recent times, the school building construction has improved with completely built up walls, screen blocks as openings, metal or wooden window materials.

It must be noted that the illumination levels are dependent on how fair the weather is, while unfavourable weather, most of the time, ends the teaching sessions for the day.

Figure 41: Amuwo Odofin Primary School, Mile 2; Poor lighting Primary School Classrooms

Poor illumination levels exist in the built up classrooms, when there is no power supply, and when the metal windows are shut (during rainy seasons), classes are ended abruptly. Overcrowding is a common characteristic of public primary schools in Lagos (Uduku, 2015). In which case, the human bodies emit heat as a by-product of metabolism- food breakdown through metabolic activity. For a highly congested classroom, internal heat gain will be quicker, regardless of exterior temperatures, especially if ventilation is inadequate. As a result of the epileptic supply of power, most government owned facilities, even if designed for both natural and mechanical ventilation (fans), operate as natural ventilated buildings.

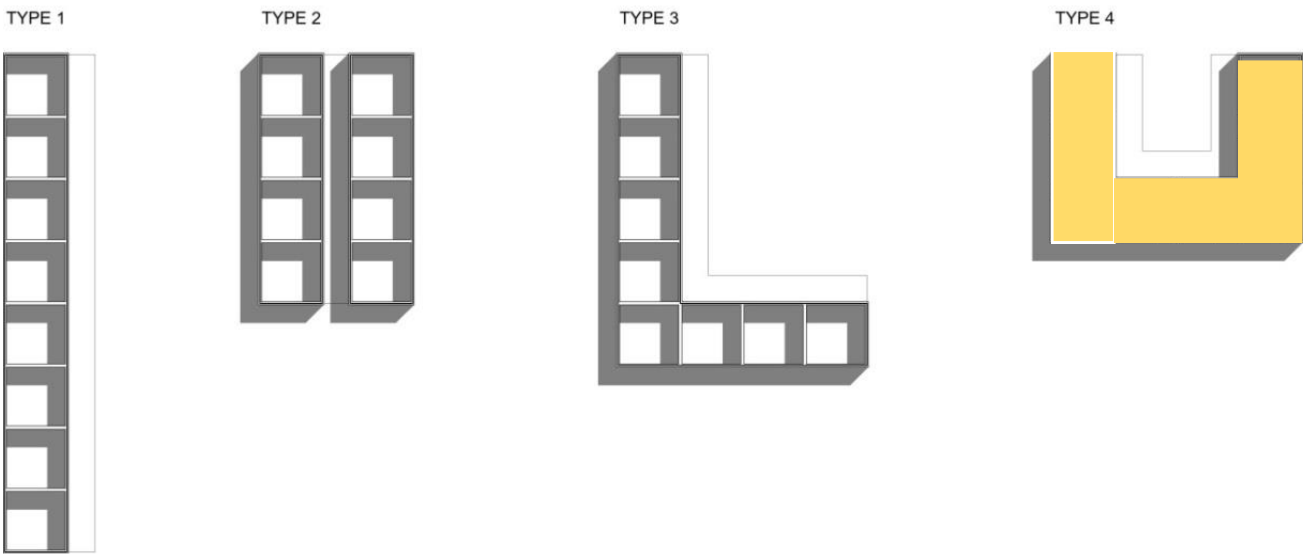
Figure 42: Ken Ade private school, Makoko, Lagos: Light summer clothing as standard uniforms

Clothing levels, according to ASHRAE standards corresponds to light summer clothing. The government owned institutions have a standard uniform provided for all pupils across all levels of both primary and secondary schools. According to ASHRAE 55 standards, the clothing levels of public primary schools correspond with the light summer clothing which is usually accepted as 0.5 clo. Most schools have standard sweaters alongside their uniforms for chilly or rainy weather.

4.7.1 CHARACTERISTICS OF PUBLIC SCHOOL CLASSROOMS IN LAGOS

The results of objective one which sought to examine the characteristics of the public-school classrooms in Lagos were analyzed using descriptive statistics, like knowing frequencies of occurrence and diagrammatic display of the data.

A computer simulation analysis was run on Revit BIM software package. The results observed that the ‘L’ and ‘U’ shaped layout have the least cooling loads compared with the linear and double loaded layout, seen in Appendix C. However, with proper orientation of the linear layout in the East/ West direction (which reduces the surface area exposed to the sun-path) the linear option could be suitable. The ‘U’ layout therefore offers a greater advantage of thermal efficiency, compactness and stability as shown in Figure 43**.**



Linear **Double loaded** **‘L’ shaped** **‘U’ shaped**

Figure 43: different layouts of classrooms

The cooling loads simulated by the REVITBIM software was lowest for the ‘U’ shaped classrooms (Appendix C), followed by the ‘L’ shaped classrooms, then linear and then double loaded layouts. Though each classroom in each layout had a different thermal analysis, the total sum of loads per classroom block was used. A compromise can be reached with the linear shaped classrooms whereby the longer side is in the North/South direction and the use of landscaping, vegetation, reflective glass or sun shading low thermal conductivity materials to reduce cooling loads.

The data presented earlier on forms also showed that classrooms in the linear layout ranked highest in frequency. The least was the ‘U’ shaped layout. The linear shaped layout classroom was least in energy efficiency. Shapes like the L, U, Hare self-shading and will reduce cooling loads as seen by the simulation results. All forms would perform better when constructed with respect to the solar orientation.

This result corresponds with that of Hallquist (2011) which stated that the most energy efficient form is the ‘L’ shaped form. In this case, to cater for the teeming populace two ‘L’ shaped units can be combined together to form one unit of the ‘U’ shaped form for similar results in efficiency. Of all the typologies used in Lagos, the ‘U’ shaped layout is therefore preferred because it is self-shading. However, in cases of site constraints, it can be halved to make the ‘L’ shaped layout which offers similar characteristics of self-shading and volume compared to the linear form as shown in Figure 44.

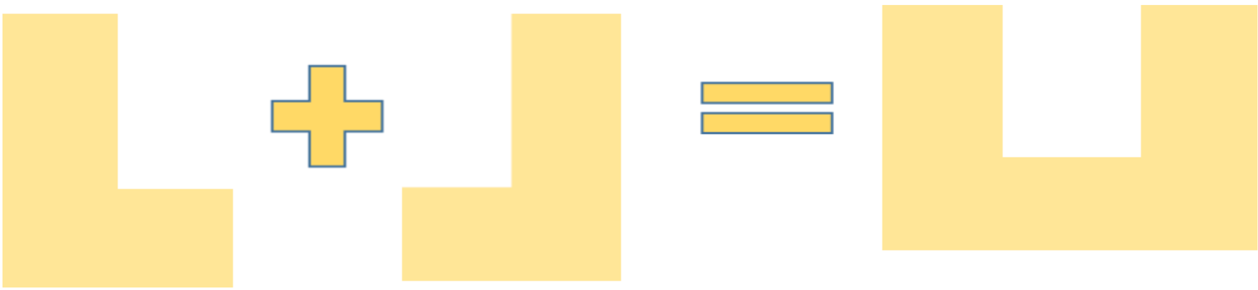


Figure 44: Combination of Classroom Forms

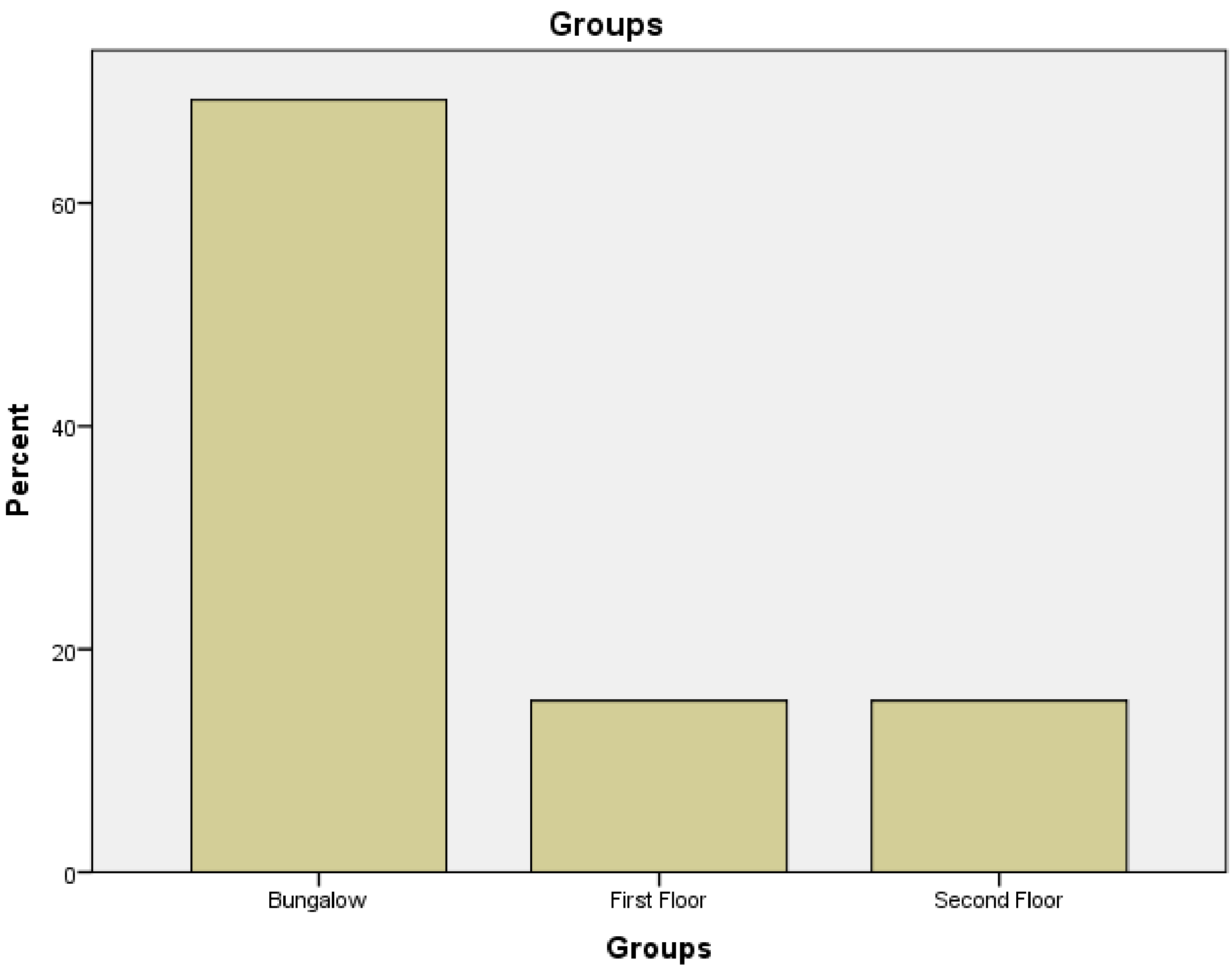


Figure 45: Bar Chart Showing Structural Types of Classroom Buildings

The Figure 45 shows frequency of the structural types of public primary classrooms existing in Lagos. The highest mount is for bungalow units, followed by equal numbers for both first and second floors. Most primary school facilities are low rise, possibilities could be for safety of pupils.

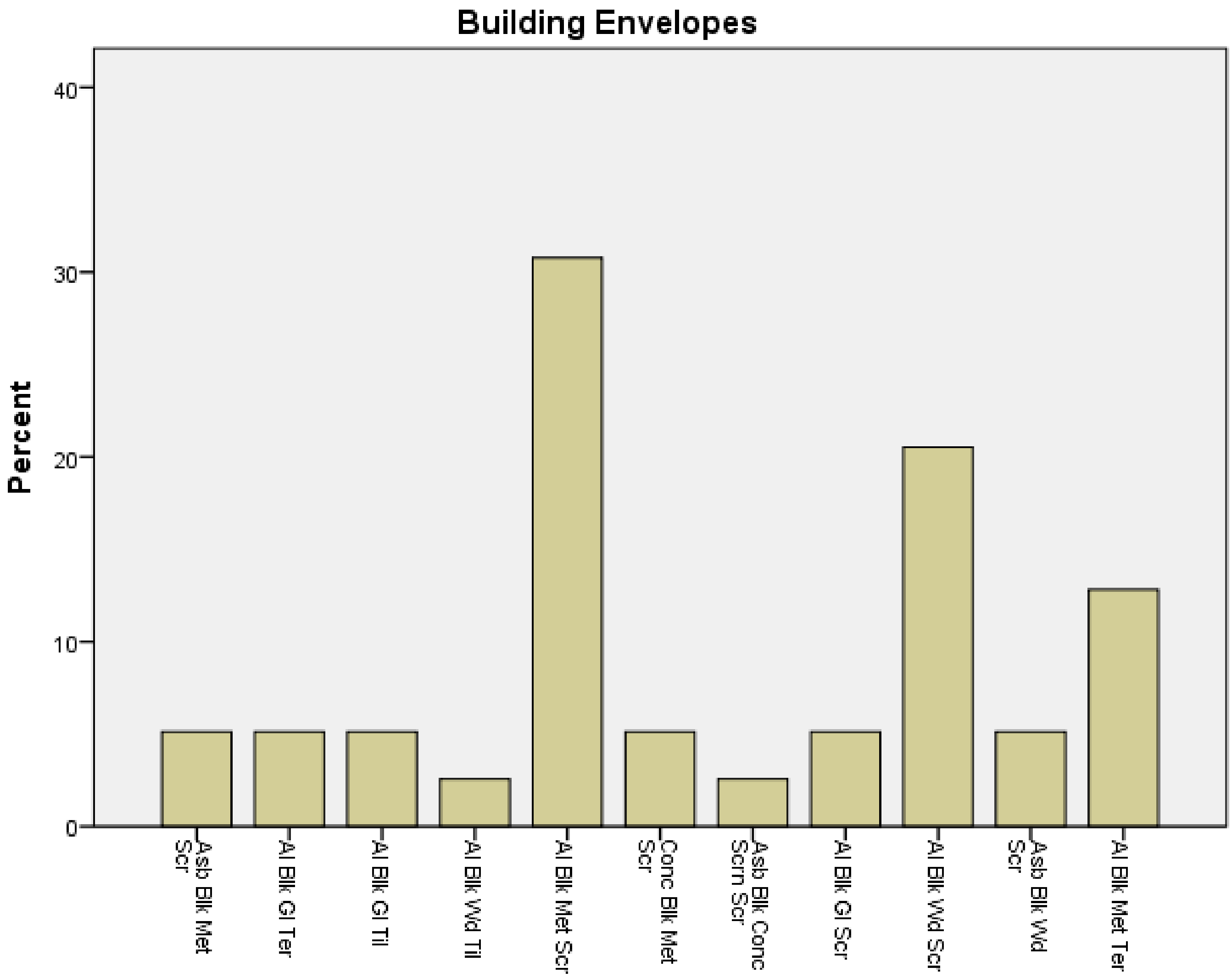


Figure 46: Material Frequency of Classroom Envelope Variants

The Figure 46 shows the frequency of occurrences of material components of the classroom buildings. The highest frequency is of classrooms with aluminium roofs, block walls, metal windows, cement screed floors, aluminium, block walls, wood, cement screed.

The results of material analysis of the highest occurring typology showed that the building envelope materials significantly impacted on the cooling loads of each building typology.

4.7.2 THE FACTORS RESPONSIBLE FOR THERMAL PERFORMANCE OF CLASSROOMS

The results of objective two, which sought to discover the factors responsible for thermal comfort was tested using ANOVA test of difference and T – test. This was used to compare the field survey data with readily established standards. ASHRAE standards (2013) for thermal comfort are 75^0F – 80.5^0F for indoor temperature, humidity 50% and 0.5m/s for air velocity, (Hikmat *et al* 2009).

TABLE 25: Mean and Standard Deviation of Thermal Performance of Roof Material

Roof material	Air temperature (0C)			Humidity (%)		Air Velocity (m/s)	
	N	Mean	SD	Mean	SD	Mean	SD
Aluminium sheets	21	28.22	4.53	57.40	20.27	34.99	89.13
Ceramics/ asbestos	6	31.58	2.50	61.83	14.47	10.98	9.77
Concrete	2	26.00	5.66	42.70	10.89	46.52	-
Corrugated	3	28.43	1.25	57.70	9.02	3.20	1.46
F-statistic		$F_{3, 28} = 1.359$, p = 0.275		$F_{3, 27} = 0.542$, p = 0.658		$F_{3, 22} = 0.284$, p = 0.837	
Remarks		NS		NS		NS	

NB: NS – Not significant at 5%, S – significant at 5%

Table 25 reveals the means and standard deviation of the various thermal conditions measured against the roofing materials used for the classrooms coupled with an ANOVA test of difference of means for the various conditions. It revealed that the highest air temperature was from asbestos roofing materials (mean = 31.58^{0}C, SD = 2.50^{0}C) while others are: Aluminium sheets (mean = 28.22^{0}C, SD = 4.53^{0}C) and Corrugated sheets (mean = 28.43^{0}C, SD = 1.25^{0}C), concrete (mean = 26.000C, SD = 5.660C). Also, the most humid was asbestos roofing materials (mean = 61.83%, SD = 14.47%) while Concrete had the least humidity (mean = 42.70%, SD = 10.89%). Others are: aluminium sheets (mean = 57.40%, SD = 20.27%) and Corrugated sheets (mean = 57.70%, SD = 9.02%).

TABLE 26: Mean and Standard Deviation of Thermal by Roof Type

Roof type	**Air temperature (0C)**			**Humidity (%)**		**Air Velocity (m/s)**	
	N	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Flat roof	9	29.42	3.17	46.50	12.48	90.47	133.85
Gable	15	28.24	4.87	63.48	19.40	3.54	1.54
Pitched	2	27.25	.35	60.50	33.23	9.00	7.07
Hip roof	4	30.07	2.55	62.52	13.24	16.04	25.34
F-statistic		$F_{3, 26}$ = 0.392, p = 0.760		$F_{3, 25}$ = 1.828, p = 0.168		$F_{3, 21}$ = 2.481, p = 0.089	
Remarks		NS		NS		NS	

NB: NS – Not significant at 5%, S – significant at 5%

Table 26 reveals the means and standard deviation of the various thermal conditions measured against the roof types of the studied classrooms coupled with an ANOVA test of difference of mean for the various conditions. It showed that 'hip' roof has the highest air temperature (mean = 30.07^{0}C, SD = 2.55^{0}C) followed by flat (concrete) roofs (mean = 29.42^{0}C, SD = 3.17^{0}C), Gable (mean = 28.24^{0}C, SD = 4,87^{0}C) and the least Pitched roof (mean = 27.25^{0}C, SD = 0.35^{0}C). The least humidity was from flat (concrete) roofs (mean = 46.50%, SD = 12.48%), followed by Pitched roof (mean = 60.50%, SD = 33.23%), Hip roof (mean = 62.52%, SD = 13.24%) while the highest was Gable (mean = 63.48%, SD = 19.40%).

Pitched roofs without insulation conduct heat towards the space below. Most classrooms in Public schools have no ceiling boards and this conducts the heat directly into the classrooms temperature and relative humidity play a significant role in thermal comfort.

4.7.3 THE RELATIONSHIP BETWEEN BUILDING ENVELOPES AND THERMAL PERFORMANCE OF THE PUPILS.

The results of objective three examined the relationship between the building envelopes and thermal performance of the classrooms. The statistical tests used here are correlation and cross tabulation. This test was used to show if there is a significant relationship between the building envelopes and thermal performance of the classrooms. The analysis of this result examined the relationship between the building envelopes and thermal performance of the classrooms. The statistical tests used here are correlation and cross tabulation. This test was used to show if there is a significant relationship between the building envelopes and thermal performance of the classrooms.

TABLE 27: Mean and SD of Thermal by Floor Finish

Floor finish	Air temperature (0C)			Humidity (%)		Air Velocity (m/s)	
	N	Mean	SD	Mean	SD	Mean	SD
Oversite concrete slab	8	29.22	2.66	61.47	17.07	18.47	37.17
Tiled	9	28.48	4.37	57.83	19.48	59.06	120.06
Granolithic	1	31.00	.	63.00	.	28.80	.
Terrazzo	8	27.74	4.64	44.73	13.64	4.19	1.48
Cement Screed	7	28.57	5.85	63.76	19.91	3.12	1.32
F-statistic		$F_{4, 28} = 0.187$, $p = 0.943$		$F_{4, 27} = 1.355$, $p = 0.276$		$F_{4, 22} = 0.706$, $p = 0.597$	
Remarks		NS		NS		NS	

NB: NS – Not significant at 5%, S – significant at 5%

The result in Table 27 shows that while there is no significant difference in the means of the thermal conditions (air temperature ($F_{1,31} = 0.374$), and air velocity ($F_{1, 25} = 0.112$) of the classrooms due to floor types of the classrooms ($p > 0.05$), that of humidity ($F_{1, 30} = 4.996$) was significantly different from each other ($p < 0.05$)

Table 27 reveals the means and standard deviation of the various thermal conditions measured against the floor finish of the studied classrooms coupled with an ANOVA test of difference of means for the various conditions.

4.7.4 THE RELATIONSHIP BETWEEN THE THERMAL PERFORMANCE AND THE RESPONSES OF THE PUPILS

The result of objective four shows the relationship between the thermal performance and the pupil's comfort. Logistic regression is used here for a valid result of the relationship between both variables. The result in Table 29 shows that there is no significant difference in the means of the thermal conditions (air temperature ($F_{4, 28}$ = 0.187), humidity ($F_{4, 27}$ = 1.355) and air velocity ($F_{4, 22}$ = 0.706) of the classrooms due to floor finish of the classrooms ($p > 0.05$). Conduction of heat through the floors is negligible in considerations for thermal comfort except in rare cases.

4.7.4.1 ANALYSIS OF RESULTS

Table 28: Environmental Variables for Field Survey

Thermal Performance^{0}C	Range	Minimum	Maximum	Mean	Standard Deviation	Variance
Outdoor Air Temperature(^{0}C)	14.3	19.40	33.70	28.94	2.76	7.61
	13.3	20.60	33.90	27.75	2.29	5.25
Humidity (%)	99.31	0.69	100.00	62.92	24.93	621.67
Mean Radiant Temperature(^{0}C)	10.60	21.08	31.68	28.27	2.30	5.31
Air Velocity(m/s)	1.90	0.1	2.00	0.92	0.52	0.27

The Table 28 above shows the values of all the variables measured in the public primary school classrooms in Lagos State, ranging from the minimum values of each them to the variances of each variable. For the outdoor air temperature, the minimum outdoor air temperature accounted for about 19.4^{0}C with a maximum value of 33.7^{0}C and a mean value of 28.94^{0}C. This is actually greater than the standard air temperature which is between the range of 22.5^{0}C- 26^{0}C according to ISO standard. The indoor air temperatures are also within the range of the outdoor air temperature with nearly a non-significant value. Humidity on the other hand, had a minimum of 0.69% and a maximum of 100%. The mean value for the humidity is 62.92% and the variance is quite large which may be due to some significant variability in the weather condition as shown in the Table 19**.** The mean radiant temperature had a minimum value of 21.08^{0}C, a maximum value of 31.68^{0}C and a mean temperature of 28.27^{0}C. Lastly, the air velocity accounted for a minimum value of 0.1ms^{-2}, a maximum value of 2ms^{-2} and a mean value of 0.92ms^{-2}.

4.7.5 MODEL PREDICTING THE RELATIONSHIP BETWEEN BUILDING ENVELOPE AND PUPILS' COMFORT

The adjusted coefficient of determination (R^2) of 0.562 shows that the three variables accounted for about 52% of the variability in the TPV of the respondents, which are; temperature, humidity and class density. There is a correlation between the air temperature and humidity levels on the TSV and TPV; therefore, both are very important variables in the determination of thermal comfort;

$$\eta\_i=3.036+0.047OAT-0.013IAT+0.03Humidity-0.247MRT-0.004TP-0.017Envelope$$

Where **η** is Thermal performance votes of the pupils and the negative values of mean radiant temperature, the indoor air temperature, building envelope has an inverse relationship with the outdoor air temperature. The higher the outdoor temperature, the unfavorable the thermal performance and mean radiant temperature of the existing classrooms, thus explaining the relationship between the building envelopes of the classrooms and the responses of the pupils (pupils' comfort).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This section consists of conclusions for the analysis of subjective (thermal comfort field survey) as well as objective analysis (building envelope materials) carried out in the research.

The aim of this study was to assess the building envelopes and thermal performances of public primary school classrooms in Lagos Metropolis. The study was on the responses of a questionnaire based thermal comfort field survey of 200 schools in Metropolitan Lagos. The field survey was carried out in mixed mode ventilated classrooms during dry season and onset of the rainy season from March till April and then, July till September 2016. The results ranged from both subjective and objective measurements. The conclusions are hereby arranged in the following sequence.

Firstly, the comfortable thermal sensation (acceptable) has been observed for the temperature range from 25 to 31°C from the dry to wet seasons. Most of the subjects who recorded cool thermal sensation and preferred a warmer climate in cold or wet seasons, and those of the subjects who were 'slightly warm' and 'hot' preferred a cooler environment in the dry seasons. Also, it was discovered that the pupils' responses were "happy" irrespective of the value of the objective measurements taken.

It can be concluded that the deviation in TPV to that of corresponding TSV especially in the 'neutral or okay' zone is as a result of children's inclination to be playful and happy regardless of the prevailing conditions. This is in line with Humphrey and Hancock (2007) research, where he stated that children probably do not relate discomfort with feelings of happiness or sadness. That is why irrespective of the discomforts, they still signified being happy. However, the effect of discomforts on their concentration and productivity is yet another issue of discuss.

Secondly, the buildings' characteristics impacted on the thermal performance (temperature, humidity variables); these were the two most significant factors. These factors are mostly important for the warm-humid tropics of Lagos. When the air is dry, further evaporation of air through adequate ventilation will cool the surface of the skin and ensure comfort of occupants. But when humidity is high, as well as temperature, evaporation through ventilation alone is insufficient for comfort as the skin remains 'clammy' or 'damp' as a result of oversaturation of the air. Further assistance is then required through mechanical ventilation will be needed.

Thirdly, classroom layouts can be 'shaded' with verandas and galleries on both wings to reduce direct penetration of solar radiation. This can be applied to linear designs to enhance their solar shading potentials. With a depth of 1.5m, regardless of roof insulation, they will still be thermally comfortable. This would mean larger eaves, and circulation spaces which would enhance the designs and create more social outdoor spaces, laced with landscaping to cool the entire structure

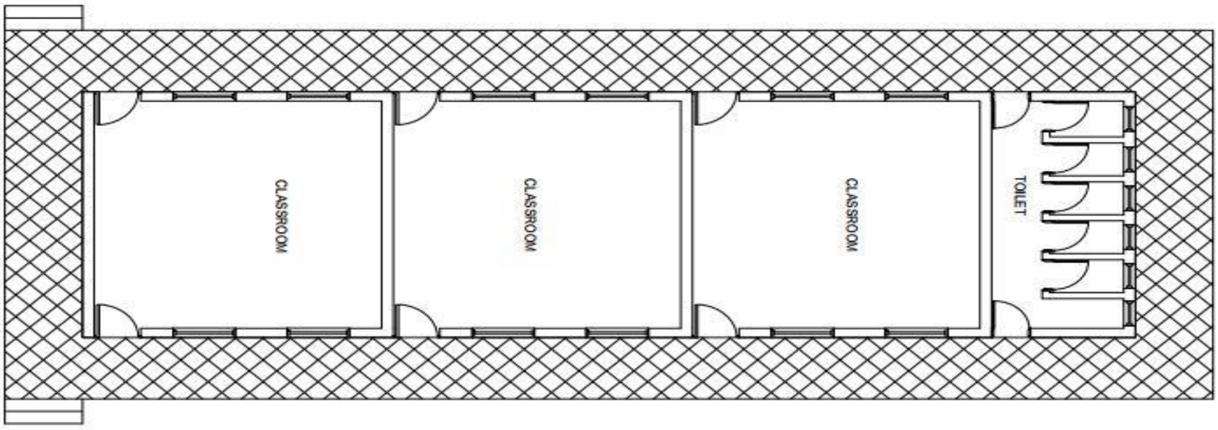


Figure 47: Classroom Plan Layout Showing Galleries on Both Sides

Fourthly, self-shading forms should be used as the constraints of space in Lagos state exists. The luxury of orientation may not be feasible more often than not. But with a self-shading structure, which provides more volume for additional classrooms will be dual advantage.

These units can then be staggered to create courtyard spaces in each set of array of blocks as shown in Figure 48-52.

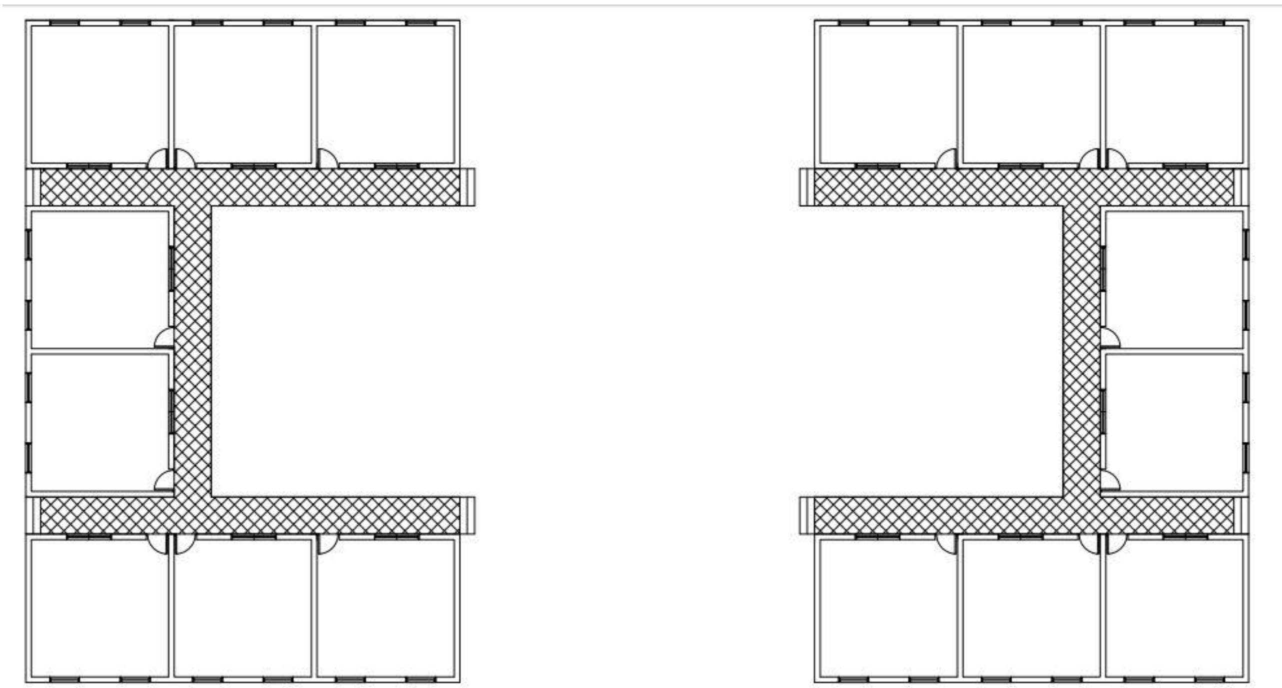


Figure 48: A Module of Classroom Blocks

With a narrow site, two 'U' shaped forms could be combined into one, creating a unit with far more shading on both sides and much more volume in the 'H' form or layout. Two 'U' shaped classrooms equal to one 'H' 'S' or 'E' form classroom. These units can be connected by staircases.

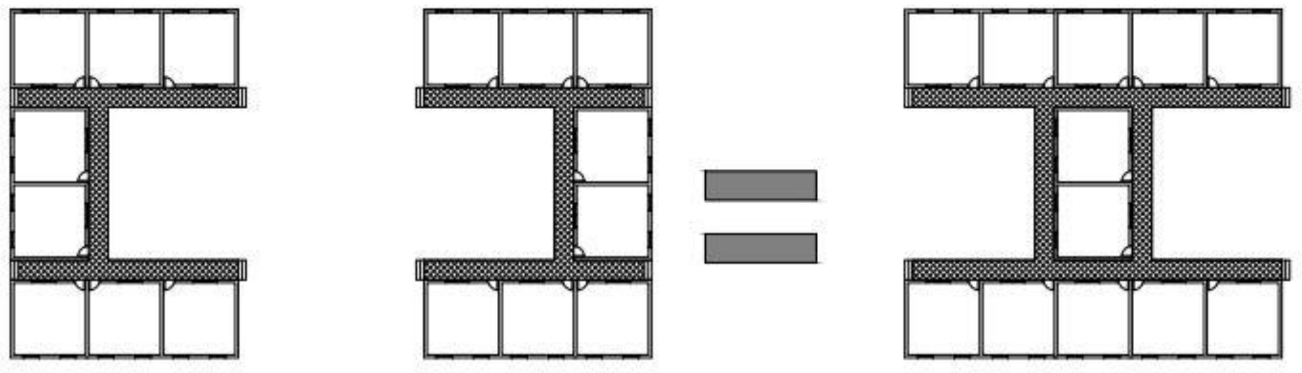


Figure 49: Modules of Classrooms

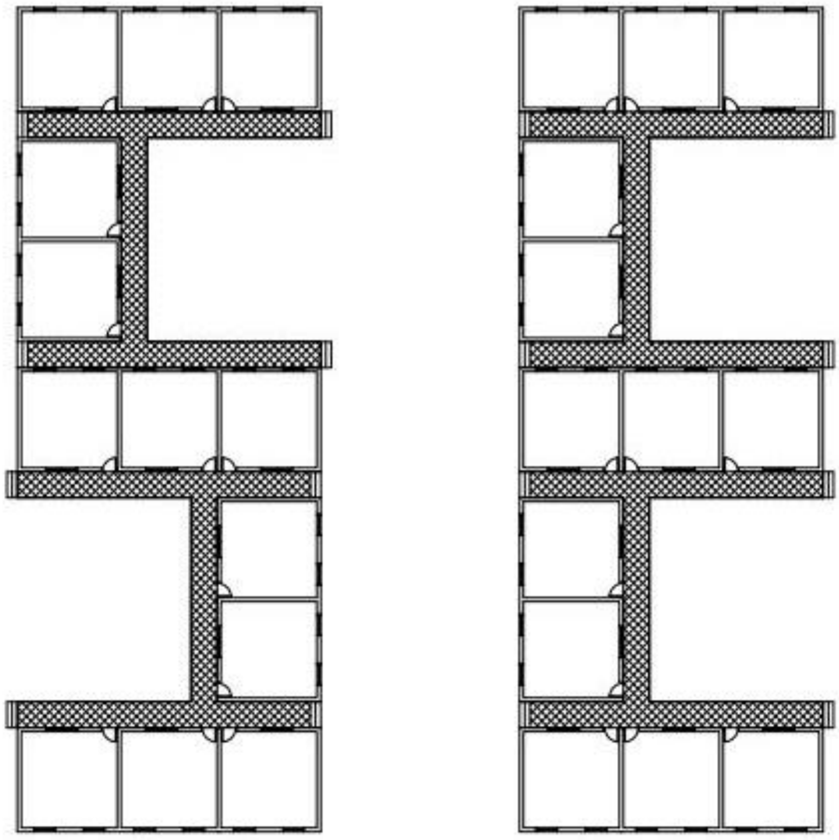


Figure 50: Modules of Classrooms

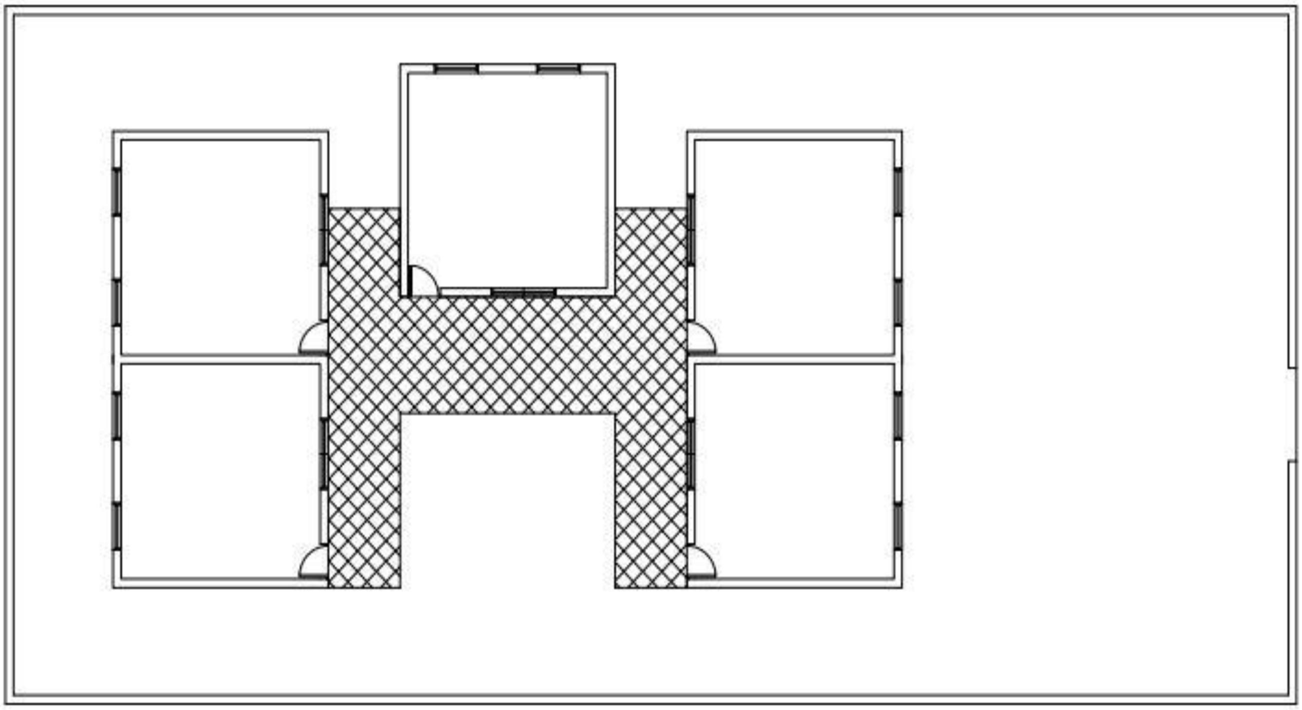


Figure 51: 5 classes in a block on a plot

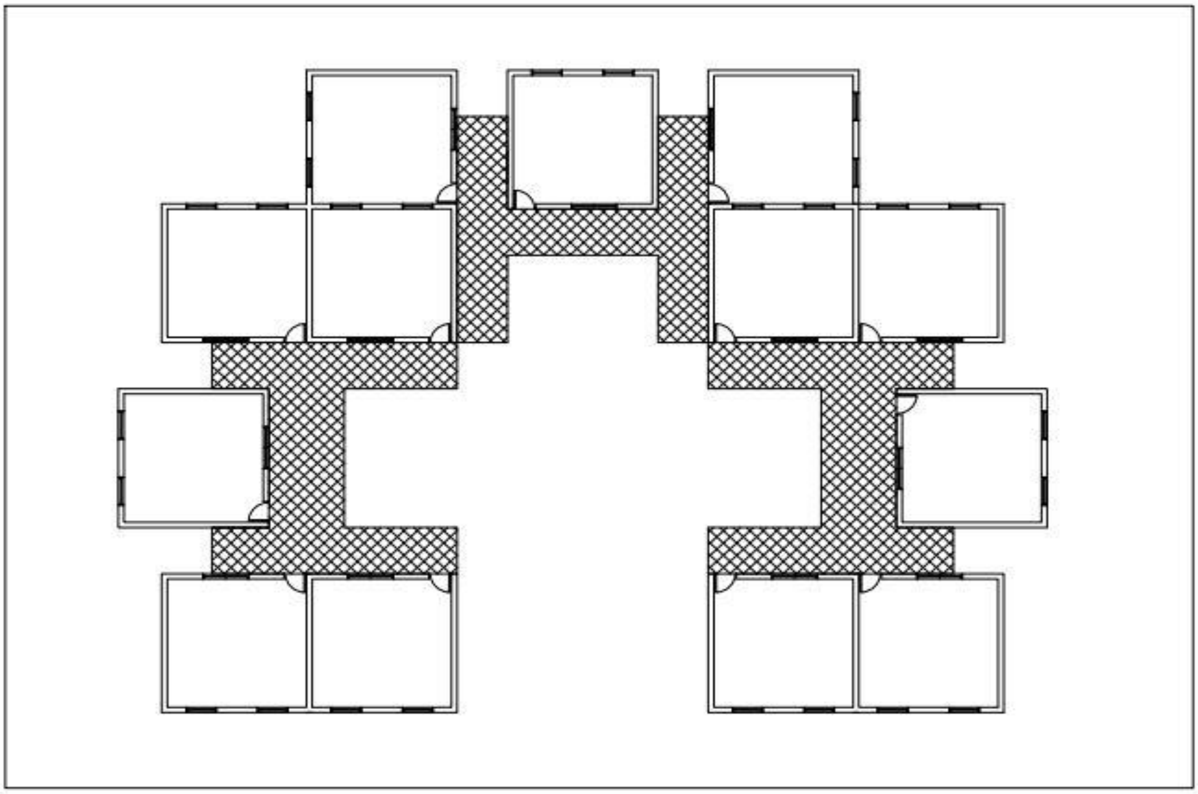


Figure 52: 3 units of “U’ shaped classrooms

Finally, pitched roofs have better surface cooling compared with flat or lean-to roofs. Barrel roof types offer the best advantage of cooler roof surfaces, as the resistance to wind pressure reduces over a curved surface and this encourages higher speeds of winds on this type of roof. The result is a cooler roof surface at the top of such buildings and cuts down the amount of heat that inadvertently would be transmitted through to the interior below. Therefore, higher roof pitches and barrel roofs are advised. Reflective colours and high albedo materials are also inclusive. The common use of metal windows in Lagos state classrooms should be prohibited. Their heavy metal frames and thick projector planes allow for heat infiltration indirectly inwards, especially, when windows are un-shaded from the sun. They also cut down illumination once shut against driving rain on wet days. Fiberglass is preferable as window panes in louvre systems, as they are good insulators, safe and durable. As louvre blades, they can be regulated to suit whatever weather condition or solar penetration angle is prevailing. This is consistent with proposals made by Elaiab (2014), who proposed using fiberglass as roof top insulation on flat roofs.

5.2 CONTRIBUTIONS TO KNOWLEDGE

The need for micro-climatic studies is hereby evident. This research's contributions to knowledge are hereby listed:

1. The study modified a classroom model which can be used in the formulation of educational standards and policies for the provision of climate sensitive and comfortable classroom in Lagos Metropolis.

2. Suitable classroom modules of various sizes and orientations, in conformity with the UNESCO educational standards for Public Primary schools were proposed.

3. The research fills the gap in literature with micro climatic data for thermal comfort in classrooms of public primary schools in Lagos Metropolis. Material specifications for finishes (roof cladding, shape, wall, floor finishes and windows), which will help drop cooling loads in classrooms buildings were also proposed making them less dependent on energy for indoor thermal comfort.

5.3 RECOMMENDATIONS

1. Material specifications are rarely considered in Nigeria - especially with considerations for indoor thermal comfort. Materials that conduct heat inwards can be oriented in the East West direction, shaded or insulated. Roof forms or types also have a significant effect on thermal comfort. Deeper roofs with larger surface areas project heat inwards, especially without appropriate treatment or ceilings. If the building does not require a ceiling, deep verandas of about 1.5m will be necessary for cooler interior spaces.

2. Self-shading forms should be used as the constraints of space exists, inhibiting the appropriate orientation for thermal comfort.

3. The study found that pitched roofs of reasonable height have better surface cooling compared to flat roofs. Thereby offering the best advantage of ventilated roof surfaces.

4. Building envelopes should be designed to enhance activities taking place at uncomfortable periods of the day, midday, when the weather is hot, or provide alternative means of adapting to such conditions.

5. This research recommends the use of computer simulation tools to explore options in the initial design decisions on materials and forms of school classrooms in the tropics to ensure an efficient thermal performance and subsequently, thermal comfort.

6. The results of POE studies should be made available to professionals in the field

5.4 SUGGESTIONS FOR FUTURE RESEARCH

1. The research can be extended to include the impacts on task performance and productivity of pupils in Primary school pupils for deeper enlightenment on the relationship between comfort on productivity of pupils.

2. More rounded research should be carried out throughout the year with more respondents at various climatic zones of the country to establish a more generalized comfort temperature range for Nigeria.

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