EVALUATING THE EFFECTS OF BUILDING FORMS ON THERMAL COMFORT IN OFFICE BUILDINGS IN HOT HUMID AREAS

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DEPARTMENT OF ARCHITECTURE,

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FEBRUARY, 2015

DECLARATION

I hereby declare that the work in this thesis titled "EVALUATING THE EFFECTS OF BUILDING FORMS ON THERMAL COMFORT IN OFFICE BUILDINGS IN HOT HUMID AREAS" was performed by me in the Department of Architecture under the supervision of Dr. M. L. Sagada and Dr. A. M. Stanley.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this work has been presented for another degree or diploma at any institution.

Kyuni Daluku SAMUEL,		
Name of Student	Signature	Date

CERTIFICATION

This thesis titled "EVALUATING THE EFFECTS OF BUILDING FORMS ON THERMAL COMFORT IN OFFICE BUILDINGS IN HOT HUMID AREAS" meets the regulation governing the award of the degree of Master of Science in Architecture of the Ahmadu Bello University, and is approved of its contribution to knowledge and literary presentation.

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ABSTRACT

The problem of thermal comfort has been the major challenge faced by most office buildings. The effect of these could lead to stress, pains and reduction of work efficiency of office workers. Office buildings are considered among the most architectural buildings that consume more energy to provide comfort all year round. One of the major factors affecting the thermal comfort of office buildings is their form. It has a great effect on the heating and cooling loads of a building. Hence, the research seeks to evaluate the thermal performance of different geometrical forms of cone, cube, cuboid, pyramid, and cylinder to see their response to energy loads. The research aims to reach to the best possible form which presents the high thermal performance in order to use it in office buildings in hot humid area of Lafia. The analysis is carried out using the computer program ECOTECT. The results indicate that the cube form receives the least amount of fabric heat gain on the hottest day, while the cone form is best in terms of direct solar heat gains and the cuboid in terms of Sol-Air (opaque Surfaces). In the area of annual cooling loads, the cylinder form performs best followed by the cone. For the amount of solar energy received by the forms, the cone is the least followed by cylinder, cuboid and cube. Energy consumption can be reduced by choosing Double Glazed Low-E material for windows with window to wall ratio (WWR) 40%. The research concluded that different building forms having the same area, volume and envelope materials respond differently to energy loads due to their surface configuration. Ultimately, the cylindrical form is the most suitable form within the context of this research. The research recommends applying thermal comfort design strategies for achieving comfort in hot humid areas, especially with regard to geometric form and envelope material composition in the first stage of the design process.

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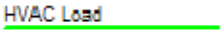
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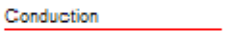
ABBREVIATIONS AND DEFINITIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DBT	Dry Bulb Temperature
ETTV	Envelope Thermal Transfer Value
HVAC	Heating, Ventilation, and Air Conditioning
KWh	Kilowatt Hour
MWh	Megawatt Hour
OTTV	Overall Thermal Transfer Value
PMV	predicted mean vote
PMV	Predicted Mean Vote
RH	Relative Humidity
SHGC	Solar Heat Gain Coefficient
WWR	Window to Walls Ratio

Below are the definitions of the lines and colour codes use as indicators in the simulation analysis.

1. 

The bright green line represents the HVAC load, which is the amount of energy that would be required to maintain the zones at a comfortable internal temperature.

2. 

The solid red line represents conduction - gains/losses that occur through the fabric of the building itself. The materials selected for the construction of the building envelope will affect gains and losses due to conduction.

3. 

The dashed red line represents gains due to indirect solar exposure, otherwise known as the Sol-Air temperature. These heat gains are caused by the molecular excitation within the building materials when exposed to solar radiation.

4. 

The orange line refers to direct solar heat gains. These gains occur through transparent surfaces such as windows and skylights (whereas Sol-Air refers to gains via opaque surfaces, so hence are indirect solar gains).

5. 

The dark green line represents gains and losses that occur due to ventilation and infiltration. In Ecotect, the opening/closing of windows and other ventilation openings can be controlled via an operational schedule, while the rate of infiltration is set under the Zone Management control panel for each zone.

6. 

The blue line represents internal gains due to artificial lighting, occupancy by people and equipment. Internal gains and occupancy rates can be set via the Zone Management control panel for each zone, while objects such as appliances can be assigned heat output values in the material editor.

7. 

Lastly, the cyan line represents gains and losses that occur between adjacent zones.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Creating a thermally comfortable environment is one of the important factors to be considered when designing buildings in hot humid areas. It is very important for architect and engineers to ensure comfort, health and wellbeing of occupants in the building. Thermal comfort can be defined as that condition of the mind, which expresses satisfaction with the environment (Hensen and Centnerova, 2001). The main criteria for thermal comfort as a whole can be divided into environmental parameters: air temperature, radiant temperature, humidity, air velocity and personal parameters: clothing and activity. The above mentioned factors greatly affect the thermal performance of any indoor environment. Wafi *et al,* (2011) pointed out that building occupant's satisfaction of their indoor comfort level depends a lot on the building design and infrastructure. Furthermore, the shape, orientation, fenestration and materials of construction have as much, and perhaps, more effects on the thermal performance than the heating insulation (Conserving Energy in Buildings, 1979). Abed, (2012) shows that, certain design criteria for thermal comfort have affected the designs of buildings which include building shapes, forms, orientation etc.

With growth in demand for building and a resulting demand for energy, energy supply has not been able to meet with the demand. Therefore the building sector could contribute immensely to the sustainable use of energy by adopting sustainable design strategy. Furthermore recommendation on the way forward is to look at sustainable and efficient

means in the design and use of built environment. Energy studies of commercial buildings in Nigeria, shows that office buildings consume about 40% of the energy generated for the country (Batagarawa *et at.,* 2011). It is a challenge for the government agencies, architects and engineers to reduce energy consumption particularly in office buildings.

In order to reduce these energy loads, understanding the overall architectural design features (shapes and forms) of office buildings in hot humid areas is important. Studies by Ling *et al.* (2007) and Catalina *et al.,* (2011), shows that different geometrical forms have the ability to react to thermal comfort differently, due to differences in its geometrical characteristics.

The major problem of thermal comfort in office buildings in hot humid areas is heat gains, due to high air temperature, less air velocity, relative humidity and incident solar radiation. Heat gain is the thermal energy that a room may gain from external and internal sources (Krem, 2012). External sources of heat gain are heat transferred to indoors due to the difference between outside and inside temperature. This gain occurs through the building envelope walls, ceiling, windows, ventilation systems, and air leakage. Internal sources of heat gain are the heat generated by occupants, the heat produced by lighting, and the heat resulting from the equipment.

For this reason, building forms is an important factor that could influence thermal comfort as well as increase/decrease the amount of energy required to heat or cool the building. This thesis therefore, intends to evaluate the effect of building form on thermal comfort in office buildings located in hot humid areas. Also to recommend the most effective form in terms of less energy loads required to produce maximum thermal

comfort and reduction in energy consumption required for cooling (cooling loads) in office building.

1.2 PROBLEM STATEMENT

Studies have shown that buildings consume large amount of energy in order to achieve thermal comfort for their occupants. Batagarawa *et al.* (2011), pointed out that of the 40% of energy consumed by commercial buildings in Nigeria, most of it goes to the cooling aspect of the building. Therefore, we can say that high level of energy is needed because of the increasing demand being placed on Heating Ventilation and Cooling (HVAC) system to provide thermal comfort all year round. And also building designs doesn't give proper consideration to energy saving with regards to environmental factors most especially on building forms and envelope composition. This situation will lead to high energy consumption needed to provide heating or cooling of the building and will affect comfort, health and efficiency of building users. Energy production cannot meet up with the demand as such; there is a need for the creation of building whose internal environments are comfortable (Deen, 2004). Therefore, in order to maximise the energy efficiency of office buildings which is a priority, it is critical to assess the effect of its forms on thermal comfort and energy consumption in these buildings. Furthermore, there is a need to incorporate building forms in the design consideration of office buildings in order to achieve a thermally comfortable environment.

1.3 AIM AND OBJECTIVES

The aim of this research is to evaluate the effect of building forms used in office design in hot humid areas, to see how they affect the thermal comfort of the occupants.

This will be achieved through the following objectives:

i. To identify the factors that affects the thermal performance of buildings.

ii. To study the design considerations for thermal comfort in hot humid areas.

iii. To study the effects of these forms on indoor thermal comfort through computer simulation.

iv. To propose a design of an office building using the form that s thermally comfortable in Lafia.

1.4 RESEARCH QUESTIONS

In line with the above mentioned problem statement, the following research questions have been formulated:

i What is thermal performance of building and the factors affecting it?

ii What are the design considerations of building forms affecting thermal comfort in hot humid areas?

iii How does building form affect thermal performance and indoor comfort?

iv. How will the results from the research be used in the design of an office building in Lafia.

In attempt to answer these questions, some of the issues relating to thermal comfort in office buildings would be clearly understood and addressed properly.

1.5 SIGNIFICANCE OF STUDY

Several researches on methods of energy conservation for different types of buildings were done, focusing on various passive energy saving measures using energy simulation. However, there are no such studies done for hot humid area of Lafia climate. This research therefore, attempts to give a solution for improving office design and enhancing their comfort condition. Furthermore, it will help to give a better understanding about the interactive relationship between the building form and the environment. Finally it will provide a reasonable result since it depends on using simulation program in order to optimize building energy performance.

At the end, this research will serve as a guide to various professionals involved in office buildings as well as government agencies making policies on environmental control.

1.6 SCOPE OF STUDY

This research focuses on office buildings in Lafia, which is located in hot humid area of Nigeria. Geometrical forms of cube, cuboid, cone, cylinder and pyramid will be analyze by computer simulation using climatic and environmental weather file. The forms will be of equal floor area, volume and thermophysical properties of building envelope. The forms will be simulated using ECOTECT program to determine how the various forms react to thermal comfort in terms of energy consumption needed to provide comfort.

Since the research is aimed at evaluating the effects of forms on thermal comfort, the application of the information drawn from the research will be used to design an office building in hot humid area of Lafia.

1.7 JUSTIFICATION

The fundamental reason for creating buildings is to control the immediate environment around people (Deen, 2004). Such control can be manifested by providing shelter from external environment by establishing occupants to live and work comfortably. Therefore, with the 21st century problem of energy conservation, green house effect, global warming, thermal comfort and environmental sustainability being a concern to man. Many efforts have been put in place and are being put to see to the reduction of these problems. Therefore, towards energy efficient office building with less use of energy, simple geometrical form and reduction of running cost is realizable.

To justify the above motive, the following reasons will support:

i. Environmental: creation of a sustainable environment that is friendly and less impacted by human activities will be realized thereby, making buildings in hot humid areas comfortable for use.

ii. Economic: Reduction in the energy consumption of the building will subsequently reduce the running cost of the building.

iii. Improving Quality of life: Health, safety, and wellbeing of occupant of office buildings extend beyond disease control but physical, mental and comfortable environment which enhances the holistic being of an individual and improves his performance.

CHAPTER TWO

LITERATURE REVIEW

2.1 THERMAL COMFORT IN BUILDINGS

According to ASHRAE (2004), thermal comfort can be defined as the condition of mind which expresses satisfaction with the thermal environment. Thermal comfort describe a person's psychological state of the mind and is usually referred to n terms of whether someone ifs feeling too hot or too cold (Health and Safety Executives, 2014). It is always not possible for a group of people exposed to the same climatic conditions of the same room, to feel comfort at the same time due to their physical variance (Çakir, 2006).

The man criteria for thermal comfort for the human body as a whole can be divided to environmental parameters: air temperature, radiant temperature, humidity, air velocity and personal parameters: clothing and activity ((Darby and White, 2005), (Hensen and Centnerova, 2001)). Hensen and Centnerova in addition further stress that there are other environmental parameters that can cause local thermal discomfort such as drought, a high vertical temperature difference between head and ankle or too high radiant temperature asymmetry. Air temperature and air humidity are the most commonly factors addressed in the conventional design process as indicators for thermal comfort (Abed, 2012). However, the most commonly used indicator is thermal comfort is air temperature. Although it is an important indicator to be taken into account, air temperature alone is neither a valid nor an accurate indicator of thermal comfort (Health and Safety Executives, 2014). It is always important to consider it in relation to other environmental and personal factors.

2.1.1. Comfort Zone

According to Çakir (2006), the comfort zone may be defined as a thermal condition in which little or no effort is required by occupants to adjust their bodies to surrounding environmental conditions. The impacts of the above mentioned factors on the thermal balance of the human body irrespective of adaptation to the local climate form the basis on which theoretical comfort models/ standards, such as Fanger's PMV, its derivative ISO 7730 and most versions of ASHRAE Standard 55, were developed (Chenvidyakarn, 2007). Furthermore, these difference leads to the adaptive models predicting comfort zones which vary according to the prevalent local climates, while the theoretical models predict comfort zones which are independent of local thermal conditions (Abed, 2012). Another scale of comfort zone is ASHRAE which has defined a comfort zone for winter and summer season as seen in Figure 2.1, depends on relative humidity and temperature.

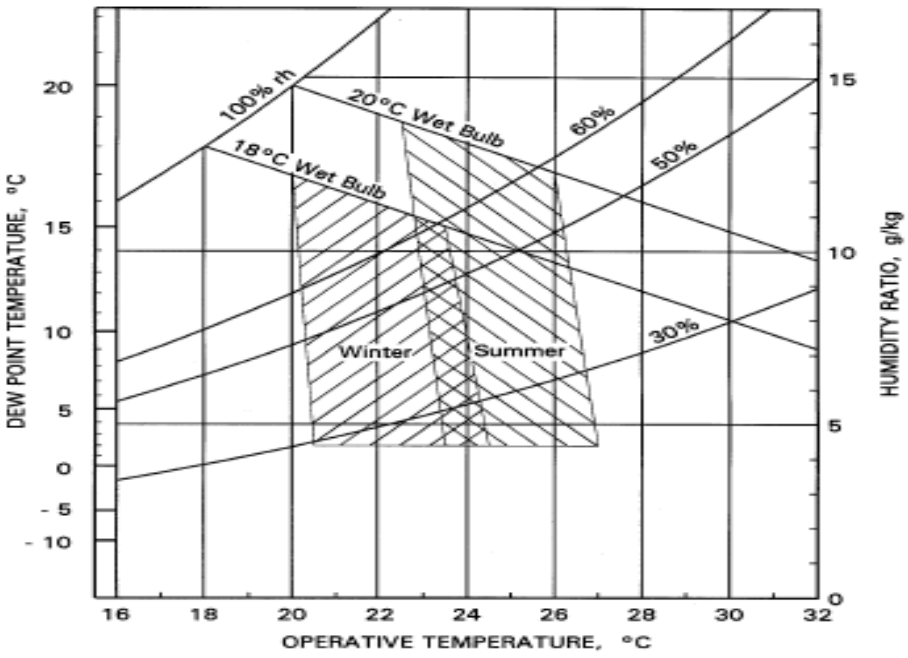


Figure 2.1 ASHRAE Summer and Winter Comfort Zones

Source: ASHRAE, 2001.

Fanger's effort in developing comfort index results in the predicted mean vote 'PMV' which indicates the average comfort vote of a typical population as shown in Table 2.1 below, on a scale from -3, Cold, to +3, Hot, with 0 as thermal neutrality (Evans, 2007).

Table 2.1 Comfort Scale

Comfort scale	Sensation	Bedford's scale
+3	Hot	Hot
+2	Warm	Warm
+1	Slightly warm	Slightly warm
0	Neutral	Comfortable
-1	Slightly cool	Slightly cool
-2	Cool	Cool
-3	Cold	Cold

Source: Evans, (2007).

Charles (2003) found that the PMV model is not always a good predictor of actual thermal sensation, particularly in field study settings due to the difficulties inherent in obtaining accurate measures of clothing insulation and metabolic rate. However, he also suggested that it is easy to predict PMV more accurate in air-conditioned buildings than in naturally ventilated ones. This is due to the influence of outdoor temperature and adaptability tendencies.

2.1.2. Bioclimatic Charts

Bioclimatic charts help the analysis of climate characteristics of a given location in terms of human thermal comfort (Çakir, 2006). They can give an insight concerning building design strategies to maximize indoor comfort conditions when the building is free running. The most commonly used bioclimatic charts are Olgyay and Givoni's Bioclimatic Chart. Olgyay expresses the comfort zone in graphic form taking into consideration two climatic variables which are the dry bulb temperature DBT on the

vertical axis and the relative humidity RH on the horizontal as indicated in Figure 2.2 below.

The comfort zone above is lying in the aerofoil shaped zone at the centre of this graph. The higher lines above this comfort zone indicate the effect of air movement on extending the upper boundary of the comfort zone. The lower lines below the comfort zone indicate various levels of radiation that would compensate for the lower than comfortable temperatures (Auliciems, *et al,* 2007).

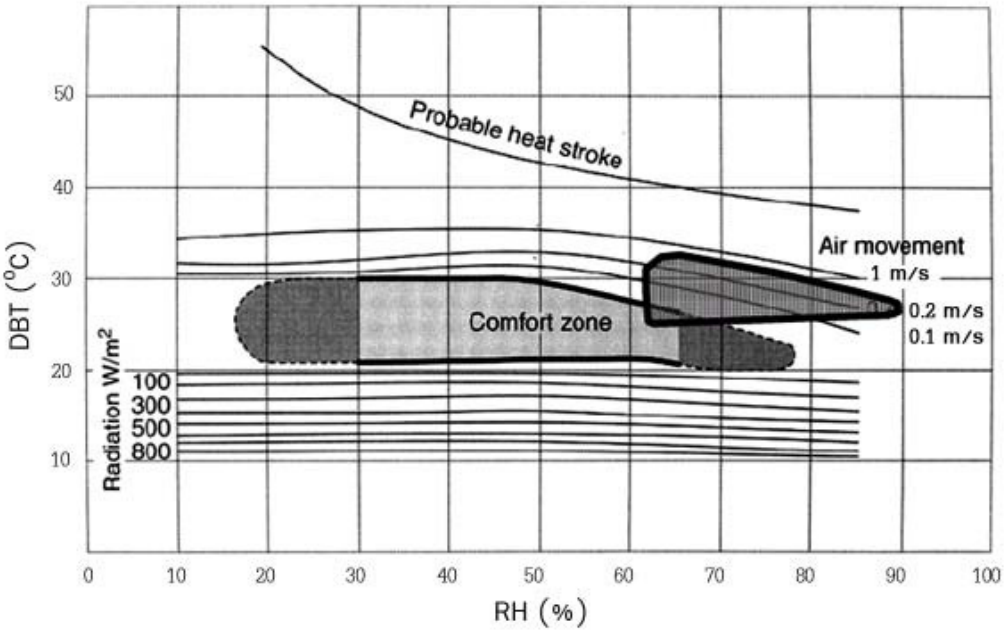


Figure 2.2 Bioclimatic chart modified for hot humid climates.

Source: Olgyay, (1953)

Another chart is presented by Givoni as shown in figure 2.3 below, who used a diagram with dry bulb temperature on the horizontal scale and absolute humidity on the vertical scale. This diagram can contain a number of zones to indicate conditions that require different bioclimatic design resources (Evans, 2007).

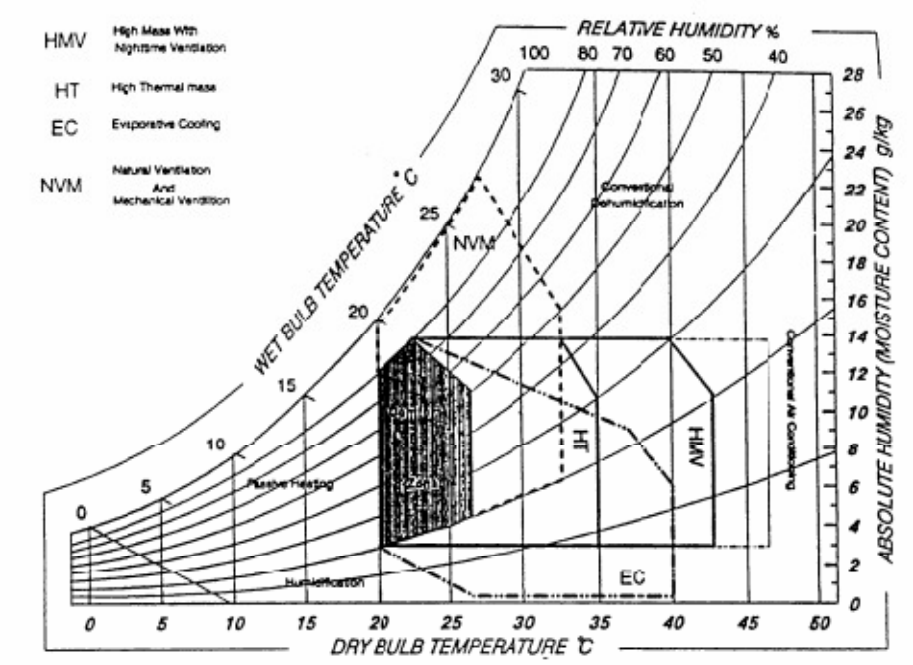


Figure 2.3 Givoni's Bioclimatic chart

Source: (Çakir, 2006)

The chart in Figure 2.3 above assemble temperature amplitude and vapour pressure of the ambient air plotted on the psychometric chart and correlated with specific lines of the passive cooling techniques overlaid on the chart. Givoni focused on the linear relationship between the temperature amplitude and vapour pressure of the outdoor air in several regions (Çakir, 2006). In light of this relationship, appropriate passive cooling strategies are defined in compliance with the prevailing outside climatic conditions.

2.1.3. Thermal Comfort Models In spite of the difficulties of defining acceptable comfort conditions, there are several models for measuring thermal comfort. The most commonly used models according to Mikler *et al.* (2008) are the adaptive models and the heat-balance approach.

i. The Adaptive Approach People have a natural tendency to adapt to changing conditions in their environments. This natural tendency is in the adaptive approach to

thermal comfort, (Nicol and Humpherys, 2002). The fundamental assumption of the adaptive approach is expressed by the adaptive principles: *if a change occurs such as to produce discomfort, people react in ways which tends to restore their comfort*. (Nicol and Humpherys, 2002).

The adaptive approach to thermal comfort starts from the observation that human can take a range of actions in order to maintain they temperature within close limits and thus achieve thermal comfort (LEARN ,2004 in Abed, 2012). The Adaptive Model is the most suitable approach to the passive solar buildings as it defines comfort within a wider range of thermal parameters and correlates variable of outdoor conditions with indoor conditions and, (Mikler *et al.* 2008).

ii. The Heat-Balance Approach This approach combines the theory of heat transfer with the physiology of thermoregulation to determine a narrow range of comfort temperatures which occupants of buildings will find comfortable (Darby and White 2005). The range is determined by a 'PMV' (predicted mean vote) which defines comfort in terms of air temperature and humidity because these parameters are easy to measure and control (Mikler *et al.* 2008). The PMV refers to a thermal scale that runs from cold (-3) to hot (+3) originally developed by fanger and leter adopted as an ISO standard. The recommended PMV range for thermal comfort from ASHRAE 55 is between -0.5 to +0.5 for an interior space (Autodesk Educational Community, 2014).

2.2 THERMAL PERFORMANCE OF BUILDINGS

The most successful criteria of a building design is the thermal performance of building. Thermal performance of a building refers to primarily to how well a building is insulated

from the external weather conditions in order to achieve a comfortable temperature internally (Shomera, 2014). This means keeping the internal temperature higher than the external temperature or lower than the external temperature. It aims to provide the most comfortable environment for occupants and thus minimizing the energy demand for cooling and heating requirements. Nayak and Prajapati (2006) defined the thermal performance of a building as the process of modeling the energy transfer between a building and its surrounding. The difference of temperature between the building indoor and the outdoor environment is the primary consideration for energy flow throughout a building (Abed, 2012). This is also proportional to the thermal quality of the building enclosure (Utzinger and Wasley, 1997). Building thermal performance deals with the heat flow between buildings and outdoor environment, which can be expressed as heat gain and heat loss. Building's components such as walls, windows and roofs and their materials affect these two mechanisms (Abed, 2012).

The thermal performance is considered one of the most important aspects of energy utilization in buildings. The prediction of the buildings thermal performance through heat transfer mechanisms is essential for enhancing the indoor conditions using HVAC and estimation of heating and cooling loads (Abed, 2012).

2.2.1 Factors Affecting Thermal Performance of Buildings

The thermal performance of a building depends on a large number of factors. Nayak and Prajapati (2006) summarized these factors as design variables, material properties, weather and climate data and a building usage data.

2.2.1.1 Design Variables

Buildings are considered the main responsible for indoor thermal conditions because they form the main contact between indoor and outdoor environment (Abed, 2012).

i. The Form of Buildings

The building's form, spacing and configuration in its neighborhood affect both the solar and wind factors. They play a large role in determining the amount of solar radiation received by the building's surface and the airflow around it (Nayak and Prajapati, 2006). As the building surface is the exposed component to the outdoor environment, a small ratio of building surface to the volume which is the main characteristic of compact forms is helpful to maintain thermal balance (LEARN ,2004 in Abed, 2012)

The form of a building can affect the thermal performance as it determines the size and the orientation of the exterior envelope that is exposed to the outdoor environment. Also, cost and aesthetics are affected by the building form (Abed, 2012). Selecting the optimum shape, orientation, and envelope configuration can reduced the energy consumption by about 40% (Wang *et al.* 2006). Another component of the building form is the roof form of the building. The convection heat transfer area and coefficient for the curved roofs such as cylindrical and dome are higher than flat roofs of the same base. Another issue related to roof form is the ceiling height which affects the building's volume (Rosenlund, 2000).

ii. Building Orientation

Building orientation is another critical aspect of passive design. The goal is to orient the building in accordance to sun path and wind direction (Krem, 2012). Orientation helps to

increase or decrease the heat gained from the sun by either maximizing or minimizing the amount of time that the building is exposed to direct sunlight.

The building orientation can affect the building thermal performance by minimizing the direct solar radiation into the buildings envelops either through building openings or opaque walls (Al-Tamimi *et al.* 2010). According to Goulding *et al.* (1992) many factors must be taken into consideration during the selecting of building orientation. They include the expected shading impact and the sun movements according to latitude, time of day and time of year

iii. The Envelope of the Building

Building envelope has a great influence on both indoor and outdoor space condition (Goulding *et al.* 1992). It is one of the main components affects the total heat gain and overall heat transfer coefficient. Al-Tamimi *et al.* (2010), found that the building envelope accounts for 36%, 25% and 43% of the peak cooling load in Hong Kong, Singapore and Saudi Arabia respectively. So it is important for the building envelopes to have a level of thermal resistance and a minimum of thermal bridges in order to avoid the penetration of water vapor inside the buildings (Abed, 2012).

iv. Shading Devices

Shading devices have a useful impact especially in Mediterranean and semi-desert climates (Abed, 2012). The period of the year, the time of the relative transparency of the materials can affect the shading (Goulding *et al.* 1992). A study by Abd El-Monteleb and Ahmed (2012), in the hot arid climate of Egypt showed that the vertical louvers with a protrusion of 38 cm or more result in a decrease of 2^{o}C in indoor temperature. Also, in a

study of Al-Tamimi and Fadzil (2011) in Abed, (2012) concluded that selecting the best shading devices can improve the number of the comfortable hours by about 26% and 4.7% in unventilated and ventilated conditions, respectively in the tropics.

2.2.1.2 Material Properties

Material properties of buildings components play a fundamental role in controlling the process of heat transfer of the building. Abed (2012), pointed out some of the most important thermal properties of heat transfer which are thermal conductivity, thermal resistance, thermal transmittance and density.

i. Thermal Conductivity λ

The thermal conductivity is a property of the material, which represents the quantity of heat per unit time in watts, that flows through a 1m thick even layer of material with an area of 1m2, across a temperature gradient of 1 K (Kelvin) in the direction of the heat flow (ASHRAE, 2001). The lower value thermal conductivity is the less thermal transmission will be.

ii. Thermal Resistance of a Material, R

The thermal resistance of a material is the resistance to heat flow between two surfaces at different temperatures. It can be expressed as the R-value which is a function of the material thickness and the reciprocal of its thermal conductivity (ASHRAE, 2001).

It may be defined as the time required for one unit of heat to pass through unit area of a material of unit thickness when unit temperature difference exists between opposite faces.

iii. Thermal Transmittance, U

The thermal transmittance, U is a direct measure of the thermal insulating ability of a given building component air to air. It is obtained by reciprocating the total thermal resistance of the building component (ASHRAE, 2001). It can be defined as the quantity of heat that flows through a unit area of a building section under steady-state conditions in unit time per unit temperature difference of the air on either side of the section.

iv. Density, Porosity

The density, p (kg/m3), is the mass of a unit volume of the material, comprising the solid itself and the gas- filled pores (Harmathy, 1988). The density plays a great role for the thermal properties: the lighter the material the more insulating and the heavier the more heat storing (Rosenlund, 2000).

2.2.1.3 Climatic Factors

The climatic factors can affect the design operation of buildings envelop in order to achieve comfort and save energy. These climatic factors are the environmental factors affecting thermal comfort which are solar radiation, humidity, wind and air temperature. It's important to understand the general climate of the region and the microclimate (Ridley, 1990).

a. Solar Radiation

Nayak and Prajapati (2006) defined solar radiation as the intensity of sunrays falling per unit time per unit area and is usually expressed in Watts per square meter (W/m2). Solar

radiation, is one of the basic mechanisms for energy transfer between different temperature regions, and it vary from conduction and convection in that it does not depend on an intermediate material as a carrier of energy but rather is impeded by the presence of material between the regions. The temperature of the air also changes according to the amount of the absorbed radiation. Cakir (2006), pointed out that some factors affect the radiation incident on a surface are geographic location (latitude and longitude of the place), orientation, season, time of day and atmospheric conditions. Solar radiation is the most weather variable that influences the air temperatures. It consists of direct radiation and diffuse radiation which vary with the sky conditions (Abed, 2012). Another variables affect the total solar radiation are reflections from the ground and adjacent buildings, shading from adjacent buildings and vegetation (Rosenlund, 2000).

b. Humidity

Air contains a certain amount of vapor, which is called air humidity (Rosenlund, 2000). ASHRAE (2003), defined the relative humidity RH as "the ratio of the partial pressure (or density) of the water vapor in the air to the saturation pressure (or density) of water vapor at the same temperature and the same total pressure. The acceptable rate of humidity differs according to the climate. RH between 40% and 70% does not have a major effect on thermal comfort, and similarly most offices RH is kept between 40%-70% because of computers (HSE, 2014). While a low rate of humidity is preferable in dry climates, it causes discomfort in tropical climate regions (Biket, 2006). However, in work places which are not air conditioned, or where the climatic conditions outdoor may influence the indoor thermal environment, relative humidity may be higher than 70% on worm or hot humid days (HSE, 2014).

There is an inverse relationship between relative humidity and air temperature. It decreases as the air temperature rises. The decrease in the relative humidity towards midday tends to be the largest in summer. Also, high humidity levels reduce the transmission of solar radiation due to the atmospheric absorption. Moreover, high humidity decreases evaporation of water and sweat and thus causes high ambient temperature and discomfort (Nayak and Prajapati, 2006). Humidity affects the rate of perspiration evaporation which affects the ability of the body to dissipate heat at higher ambient temperatures (Ridley, 1990).

c. Wind

Wind has a great influence on buildings design and their thermal performance. This describes the speed of air moving across a body, and may either cool the body in contact or heat the body, depending on if t is cooler or hotter than the environment (HSE, 2014). It affects the convective heat exchanges of a building envelope and the air infiltration (Nayak and Prajapati, 2006). It's necessary to avoid the effect of winter wind which increases the infiltration heat loss and utilizing the summer wind in encouraging ventilation (Ridley, 1990). Many factors affect the wind at the local level such as topography, vegetation and buildings configuration (Rosenlund, 2000). Moving air also increase heat loss through convection without any change in temperature (HSE, 2014). Also, it is important to take wind factor into consideration during the urban planning and architectural design. Buildings height and distances between them can affect the formation of pressure zones which is inevitable in the direction of the wind. Various climate regions require different wind requirement (Biket, 2006).

c. Temperature

Air temperature is the most important environmental factor, measured by the dry bulb temperature (DBT). Air temperature is a measure of the heat or air temperature surrounding a body, and it is usually measured in degree Celsius (^{o}C) or degree Fahrenheit (^{o}F) (HSE, 2014). Most thermometers are measuring ambient air heat. However, radiant heat loss or gain is also important. Radiant heat may not be reflected in the air temperature, but is the impact of cold or hot objects in the area. The temperature in a building is based on the outside temperature and sun loading plus whatever heating or cooling is added by the HVAC or other heating and cooling sources. Room occupants also add heat to the room since the normal body temperature is much higher than the room temperature.

The significant question concerning how temperature affect thermal comfort is, is the air temperature less or greater than the skin temperature. The difference between these two temperatures determines in which direction heat transfer will occur. Additionally, if the temperature of the air is less than the temperature of the gases exhaled from the lungs, then heat from respiration will be exchanged to the air. Generally whenever the air temperature exceeds the temperature of the skin and the respired gases, it is difficult to maintain thermal comfort, (Deen, 2004).

2.2.1.4 Building Occupancy and Operations

Buildings usage produces heat from their occupancy, lights and equipments. Occupation densities and types of activities affect the total heat gain and as well affects the amount of energy required to provide comfort within the space (ASHRAE, 2001).

Table 2.2 Heat production rate in a human body.

Activity	Rate of heat production	
	(W)	(W/m^2)
Sleeping	60	35
Resting	80	45
Sitting, Normal office work	100	55
Typing	150	85
Slow walking(3 km/h)	200	110
Fast walking(6 km/h)	250	140
Hard work(filing, cutting, digging, etc.)	more than 300	More than 170

Source: www.mnre.gov.insolar-energy.

Table 2.2 above shows the rate of heat production by people at different activity level. People give off the heat of metabolism to maintain a constant body temperature. Electric lights and equipment give off heat to the building equal to the electrical energy they consume (Utzinger and Wasley, 1997).

2.2.2 Thermal Transfer Mechanism

Heat is considered one of the forms of energy which transferred between objects due to the difference in temperature. Heat transfer describes the exchange of thermal energy between physical systems depending on the temperature and pressure of the system (Heat Transfer Mechanism, 2014). It always moves from the hotter object to the cooler one (Roos, 2008). Three heat mechanisms which are conduction, convection, and radiation are utilized in the passive solar buildings in such away to control the process of distributing heat throughout the living space (Abed, 2012).

i. Conduction

Conduction heat transfer is energy transported due to molecular motion in interaction, which in solid is due to molecular vibration (Heat Transfer Mechanism, 2014). Conduction is the way heat moves between molecules through materials. Thermal energy transfer occurs in the direction of decreasing temperature, a consequence of the second law of thermodynamics (ASHRAE, 2001). In solid opaque bodies, thermal conduction is the significant heat transfer mechanism because it is achieved through molecular vibration.

Conduction requires the physical contact of two objects. It occurs through the different component of building envelop where heat is conducted from the warmer side to the cooler one (Roos, 2008). The quantity of heat transferred through a material is proportions with its thermal conductivity.

ii. Convection

Roos (2008) defined convection as "heat transfer due to fluid (gas or liquid) or airflow". That explains why warm air rises or cool air falls on a wall’s inside surface. It can be divided into natural convection which occurs due to a temperature difference between zones, and forced convection which occur due to the movement of air by mechanical means (ASHRAE, 2001 & Abed, 2012). In these two cases convection is responsible for the distribution of heat within the occupied space and between zones (Barakat, 1985) in Abed, (2012). Building's materials have an important role in convective. Therefore the choice of building materials for design should be done with consideration to its convective properties in mind in order to control the effects of heating.

iii. Radiation

Radiation is heat transfer between two surfaces as a mean of electromagnetic waves, such as light, infrared radiation, UV radiation or microwaves with nothing between them. Radiation takes place in the sun-exposed surfaces of buildings and its value increases where there are large temperature differences (Roos, 2008). In thermal radiation, there is a change in energy form from internal energy at the source to electromagnetic energy for transmission, then back to internal energy at the receiver (ASHRAE, 2001). Materials properties such as transparency and colors play a significant role in determining the percentage of solar radiation absorbed, reflected, or transmitted, depending on certain properties of that object.

2.2.3 Thermal Balance in Buildings

This term can be expressed as the overall thermal transfer value (OTTV), which is considered as a measure of the heat transfer from outside to the indoor environment through the external envelope of a building (Abed, 2012). The main principle in term of buildings thermal balance is the heat transfer between buildings and environment. It take into consideration three components of the heat gain as shown in Figure 2.4 which are conduction through an opaque surface, conduction through glass window and solar radiation through glass window (Nikpour *et al.* 2011).

Another two sources of heat gain as mentioned by Utzinger and Wasley (1997) are the internal heat gains and the air exchange via ventilation or infiltration. Heat gain by the occupants depends on the number of people in the room and the rate of heat released by each person, which depends on the degree of activity.

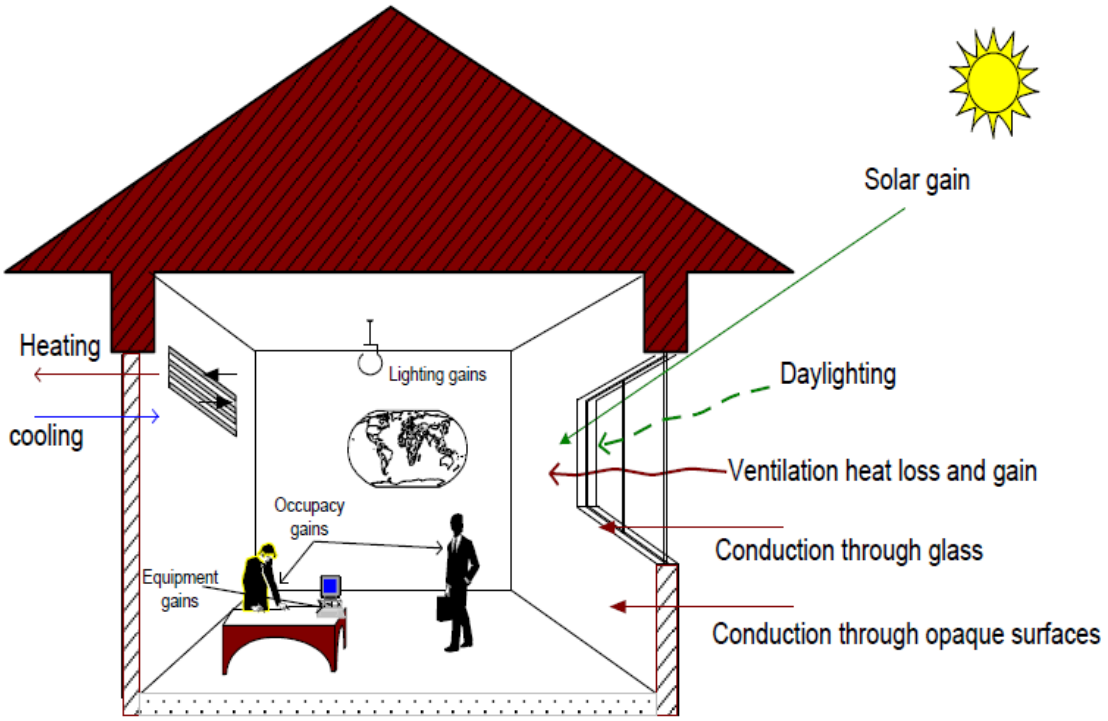


Figure 2.4 Sources of heat gain and heat loss in buildings

Source: Krem, (2012).

Heat gain from lighting depends on light equipment efficiency and lighting level. Heat gain from equipment depends on number of machines and their efficiency (Krem, 2012).

2.2.3.1 Heat Transfer through Building

One of the most important components affecting the total heat gain and the overall heat transfer coefficient is the building envelope (Al-Tamimi *et al.* 2010). The Envelope Thermal Transfer Value represents the thermal performance of the whole envelope. It takes into consideration the three basic components of heat gain through the external walls and windows of a building which are: heat conduction through opaque walls, heat conduction through glass windows, and solar radiation through glass windows (Abed,

2012). Also heat transfer through the building envelope is affected by the area of its components and the thermal conductance of their materials.

Heat Transfer Rate through the Building Walls

Ling *et. al.,* (2007) estimated that vertical wall in high rise buildings received 86.6% of the annual solar insulation. Figure 2.5 shows, that of the total solar radiation incident on the outer surface of the wall, a part of it is reflected to the environment. The remaining part is absorbed by the wall and converted into heat energy. A part of the heat is again lost to the environment through convection and radiation from the wall's outer surface. The remaining part is conducted into the wall; where it is partly stored thereby raising the wall temperature – while the rest reaches the room's interior surface.

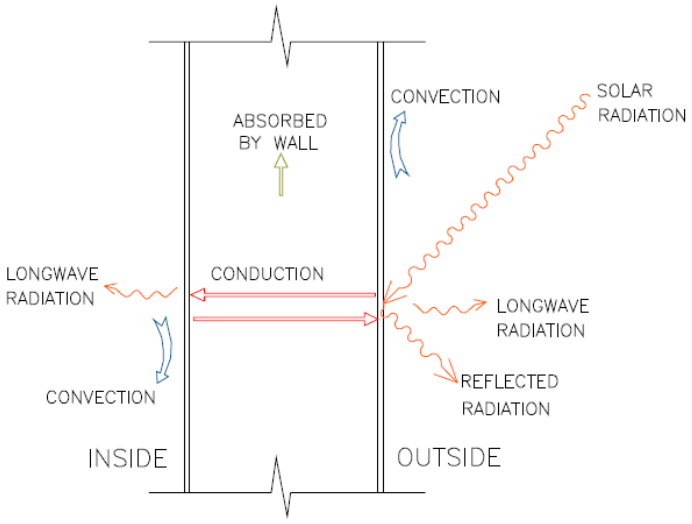


Figure 2.5 Heat transfer processes occurring in a wall

Source: www.mnre.gov.insolar-energy.

The key here is to recognize that at a steady state, the convective heat transfer rate into the wall must be equal to the rate at which heat is conducted through the wall and must be equal to the rate at which heat is removed from the wall by convection (Learn Thermo, 2014). Heat loss or gains through walls can be reduced using cavity walls insulation. The

material prevents air circulating inside the cavity therefore reducing heat gain/loss by convection (BBC-GCSE Bitesize, 2014).

Heat Transfer Rate through the Building Glazing

Glazing have a large influence on the building thermal balance, as it affects the rate of heat gain and loss in the building envelope. A study conducted by Al-Tamimi *et al.* (2010), found out that heat gain through the exterior window accounts for 25-28% of the total heat gain, adding to the infiltration. This is up to 40 % in hot summer and cold winter zone. Therefore, glazing material, orientation and its ratio to the wall help to cause cooling effects and avoid the increasing in the indoor air temperature.

2.2.3.2 Building Internal Heat Gains

This term represents all the sources of heat inside the building, namely the occupants, lights, appliances and other equipment. The heat gain as a result of occupants in a building is a combination of sensible and latent heat. Sensible heat gains from occupants results from the difference between the human body temperature and the temperature of the air inside the room (ASHRAE, 2001). Heat gain by the occupants depends on the number of people in the room and the rate of heat released by each person, which depends on the degree of activity.

Another source of internal heat gains is heat gain from lighting which depends on light equipment efficiency and lighting level. Heat gain from equipment depends on number of machines, their efficiency and their duration of operation (ASHRAE, 2001).

2.2.4 Method of Calculating Thermal Performance of Building Using Computer Simulation.

Building thermal simulation is the dynamic analysis of the energy performance of buildings using computer modeling and simulation techniques (Bahar *et.al*. 2013). In simulation, a calculation of building thermal loads and thermal consumption are involved in determining the thermal characteristics of the building and its building systems. Furthermore, Bahar *et.al*. (2013), pointed out the importance of building thermal simulation as a powerful method for studying the thermal performance of buildings and to evaluate architectural design. Evaluation of thermal comfort involves assessment of at least six factors: human activity levels, thermal resistance of clothing, air temperature, mean radiant temperature, air velocity and vapor pressure in ambient air (Fanger, (1970). Thermal analysis basically means using a manual calculation or computer program to mathematically model the interplay of thermal processes within a building. One way to analyze thermal performance in buildings is by using thermal simulation programs that are capable of calculating all of those values accurately (Bahar *et.al*. 2013). The accuracy of a thermal simulation result is determined by the input data. This input data as shown in Figure 2.6 mainly consists of the building geometry, internal loads, HVAC systems and components, weather data, operating strategies and schedules, and simulation specific parameters. There are two commonly used approaches for energy thermal simulation as pointed out which are: simplified methods and detailed methods. The simplified methods use integrated weather representations, like degree days or degree hours, to predict the building's response to the exterior environment. The second method of energy modeling,

the detailed method, literally performs a whole-building heat loss/heat gain calculation every hour of the year.

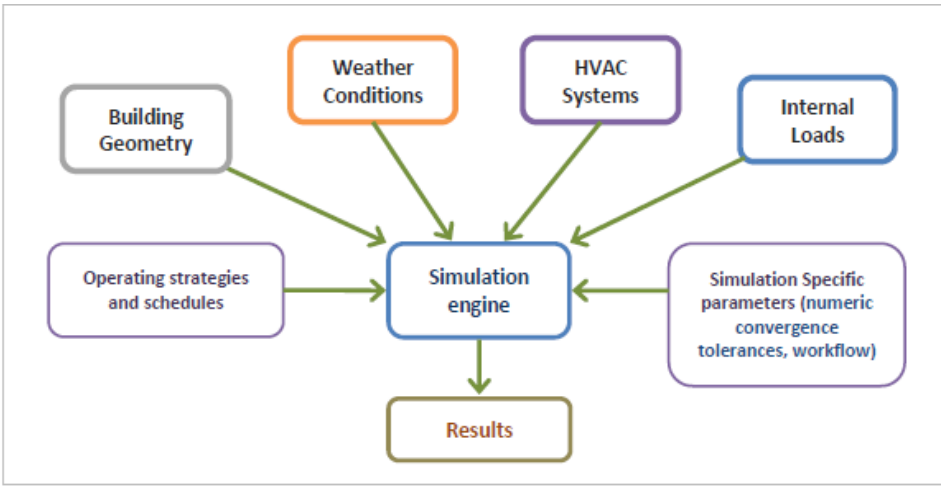


Figure 2.6 General input data of thermal simulation engines.

Source: Bahar *et al*. (2013)

Using these detailed calculations, one can study the effects of internal thermal mass, solar shading devices, computerized thermostatic controls, daylighting dimmers, occupancy sensors, and any other parameter that responds to hourly stimuli.

2.2.4.1 Building Thermal Simulation Tools.

There exist today a large number of simulation tools as Building Information Modeling (BIM) applications concerning thermal simulation in buildings. Based on the analysis of recent trends in thermal tools, this report reviewed certain selected tools that are most applicable to the BIM application (Bahar *et.al*. 2013).

Bahar *et.al*. (2013) further noted that the most applicable tool by professional users in the Architecture-Engineering Construction (AEC) community (whether they focus on the BIM platform or not). These applications are Ecotect, DPV (Design Performance Viewer), Design Builder, EnergyPlus, eQUEST, EcoDesigner, ESP-r, Green Building

Studio, Lesosai, IDA ICE, IES VE, TRACE700, TRNSYS and Riuska. The choice of using ECOTECT for this analysis is based on the following reasons pointed out by Huda, (2012). ECOTECT is a software package with a unique approach to conceptual building design. It couples an intuitive 3-D design interface with a comprehensive set of performance analysis functions and interactive information displays. ECOTECT offers a wide range of internal analysis functions which can be used at any time while modeling.

2.2.4.2 Ecotect Simulation Software.

Ecotect was developed by Dr. Andrew Marsh and Square One Research Ltd. that was acquired by Autodesk. Ecotect analysis offers a wide range of simulation and building energy analysis functionalities to visualize and simulate a building's performance within the context of its environment (Ecotect, 2011). The following steps show how Ecotect is use for thermal performance calculation/analysis:

Thermal Computer Model Preparation: It is important to construct a thermal model of the proposed design using ECOTECT. Each model constructed is defined using zones and properties to help in achieving the purpose of the study. This model will be used to study the various performance aspects of the thermal design. At this stage it is advisable to simplify the model in order to get quicker results.

ECOTECT Thermal Analysis: As for analysis, it is expected to investigate the climate responsiveness and overall thermal performance of a building. ECOTECT calculates internal temperatures, spatial comfort and heating and cooling loads for models with any number of zones or type of geometry. There is need to assign material choices to all objects. There is also need to assign HVAC mode and operational schedules for occupancy.

i. Temperature Profile Study: This study is carried out in order to calculate the hourly temperatures for all the zones for the hottest and coldest days of the year.

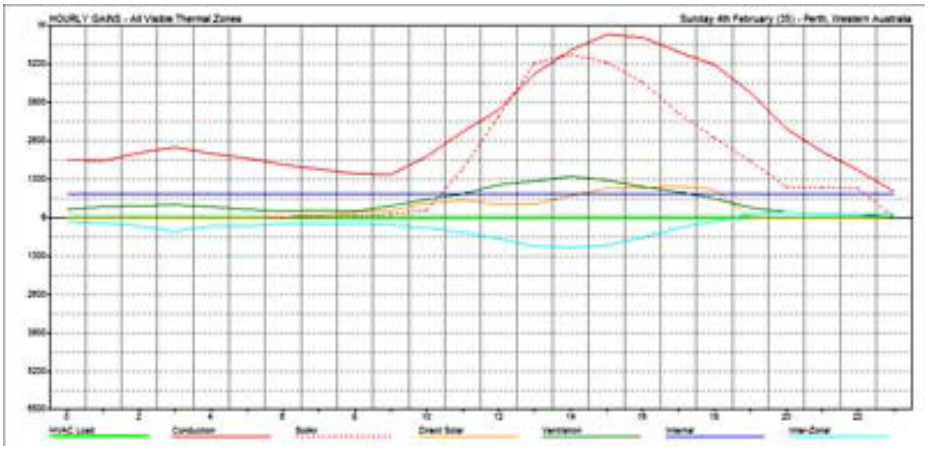


Figure 2.7 Hourly Temperature Gains and Losses Graph.

Source: Ecotect, (2011).

Figure 2.7 above shows the temperature profile study of a building for the whole day. This show how temperature increase hourly within the day and how it affects HVAC loads and other indicators like conduction, solar, solAir, ventilation and inter-zonal.

ii. Heating and Cooling Loads Studies: This aspect calculates the average monthly heating and cooling loads of the project and creates a graph showing the monthly heating and cooling loads of the building for a typical year.

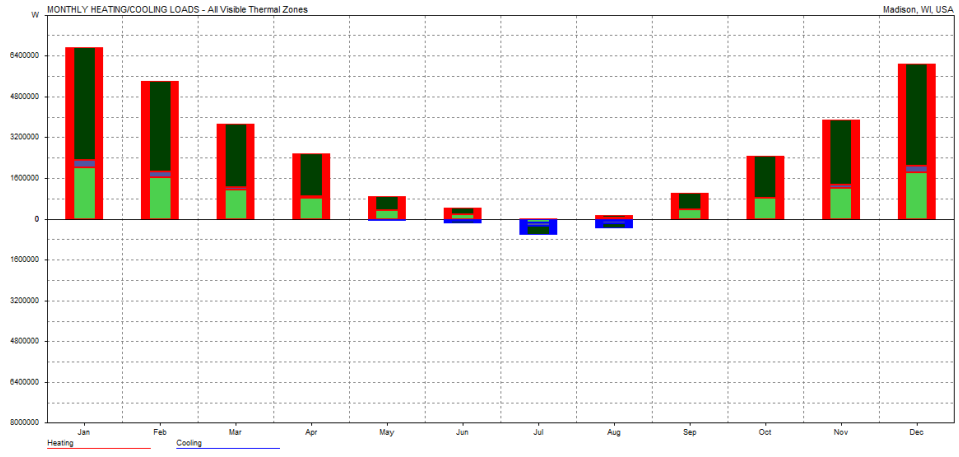


Figure 2.8 Average Monthly Heating and Cooling loads.

Source: Ecotect, (2011).

Figure 2.8 shows the graph which indicates the heating loads above and cooling loads. Each bar contains all the various contributors to the heating or cooling loads of the zone. Variation in colors shows the various zones and their contribution. Here the shades of green inside each bar represent the individual contributions from spaces like living area, kitchen/restroom, and bedroom areas of the building.

iii. Passive Solar Study: The passive solar analysis shows the overall effect of solar radiation on the building envelope. Figure 2.9 below shows the different percentage of heat gain/loss through conduction, solair, direct solar, ventilation, internal and inter-zonal on the building.

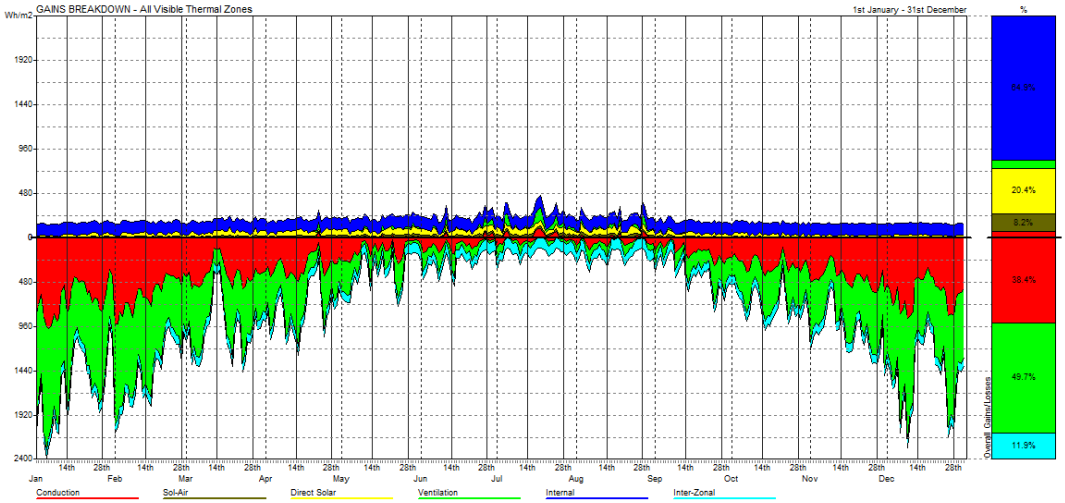


Figure 2.9 Passive Gains/Loss analysis.

Source: Ecotect, (2011)

As seen in Figure 2.9 above, the heat losses through the building envelope due to conduction and infiltration (shown in red and green, respectively) dominate the internal heat gains contributed by appliances, lighting, and occupants (shown in blue).

iv. Thermal Mass Study: Varying the thermal mass of some element(s) of the model helps in evaluating their impacts on the calculated building loads. This has to do with the

analysis of their thermophysical properties and material types. This helps in making right choice of materials.

2.3. CLIMATE

Weather and climate have a profound influence on life on Earth. They are part of the daily experience of human beings and are essential for health, food production and well-being. Many consider the prospect of human-induced climate change as a matter of concern. According to National Air Space Agency (NASA) “weather”, as we experience it, is the fluctuating state of the atmosphere around us, characterized by the temperature, wind, precipitation, clouds and other weather elements over a short period of time. While “Climate” refers to the average weather in terms of the mean and its variability over a certain time-span and a certain area (NASA, 2014).

2.3.1 Climate Classification

One of most commonly used classification system for describing the climate is Köppen’s. The Köppen system recognizes five major climate types based on the annual and monthly averages of temperature and precipitation. Each type is designated by a capital letter. A second letter in the classification considers the precipitation and a third letter the air temperature (Abed, 2012). The major climate classifications are: Warm-Humid Climate (Moist Tropical), Hot-Arid Climate, Temperate Climates (Humid Middle Latitude), Cold Climates (Snow) and Polar Climates as shown in Figure 2.10.

Warm-Humid Climate (Moist Tropical)

The most important characteristic of this climate is the high temperatures and the heavy rain. Minimum average monthly temperature is above 18°C. Humidity and cloudiness increase the importance of diffuse solar radiation while they decrease the potential for radiative sky cooling. Rainfall and winds are the main determinant of seasons (Rosenlund, 2000). Köppen specifies three A climates which S seen in Figure 2.10 which are Wet equatorial climate (Af), Tropical monsoon and trade-wind littoral climate (Am) and Tropical wet-dry climate (Aw) (Huda, 2012).

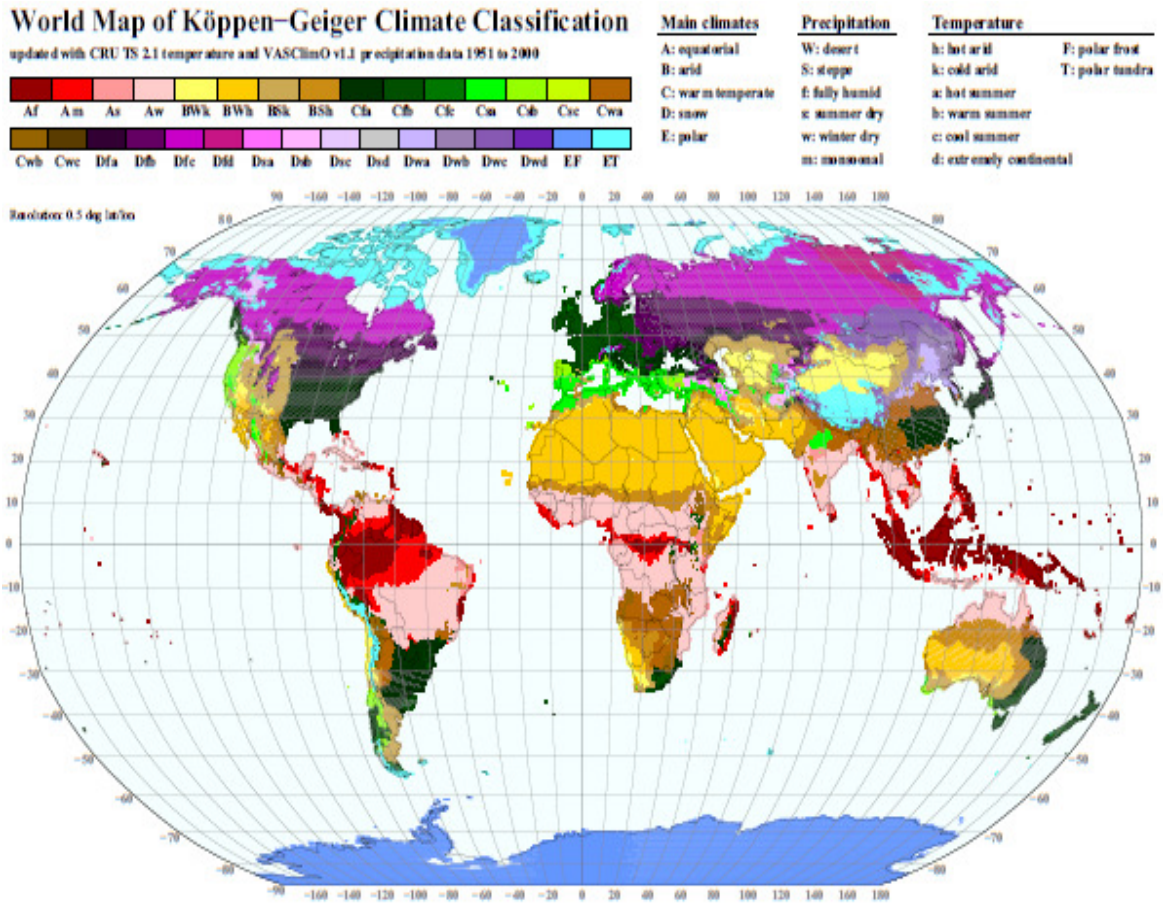


Figure 2.10 Koppens World Climate Classifications

Source: Huda, (2012)

2.3.2 Climate Design Strategies for Hot Humid Areas

In hot humid climates, a significant amount of energy can be saved if cooling needs can be minimized. In general, to achieve this, solar and conductive heat gains should be contained, and natural ventilation promoted for cooling and humidity removal (Chenvidyakarn, 2007). The climatic design strategies depend on utilizing the opportunities and capabilities of the local climate. Some of the key strategies for minimizing cooling needs involve appropriate form, orientation and spatial organization (layout), shading, and appropriate use of materials, colors, textures and vegetation (Chenvidyakarn, 2007 and Abed, 2012). Some of these strategies remain the same in different climates. However, Abed (2012) stressed that form; orientation and layout, of the buildings in addition to spacing between them are the most important strategies affecting indoor thermal comfort. Also, building envelope has a great influence as it separates the outdoor and indoor environment (Leylian *et al.* 2010).

i. Building Form

Previous works has shown that when the form of a building is considered, architectural design can significantly improve the energy consumption of a building. Similarly, studies by Mark, (1997) and Depecker *et al.* (2007 have shown that building shape can have a significant impact on the cost of heating and cooling. However, Adnan *et al.,* (2009), have noticed that no general guidelines are available to architects and designers on the impact of the form on the energy efficiency of buildings. The main determinant factor for choice and selection of building form is the ability to maximize ventilation and to minimize solar collection through the envelope, where the most important requirement is

cooling. This can be achieved through increasing the area available for air movement and decreasing the remaining external surface areas. The most suitable form in this climate is the open elongated shape in order to provide air movement which considered the only way of achieving thermal comfort (Chenvidyakarn, 2007). The height of the buildings should, in general, not exceed 3-storys. Since the higher buildings receive too much radiant heat and give wind obstruction to neighboring buildings, building's height shouldn't exceed 3-storys (Gut et al. 1993). Pitched roofs with wide overhangs or verandas create shade and rain protection (Rosenlund, 2000).

ii. Orientation

Orientation and spatial organization affect the ability of a building to ventilate and receive solar radiation. To minimize solar gain and maximize ventilation, buildings in hot humid climates usually employ spread-out plans and permeable internal organization (Chenvidyakarn, 2007). Also, Givoni, (1969) pointed out that the amount of radiation received by the building is determined by orientation. Orientation has a significant influence on the cooling load. In areas where comfort is acquired mainly by air movement, it is important to orient the building according to prevailing winds. By orientating the longer sides of the buildings to intercept prevailing winds and the shorter sides to face the direction of the strongest solar radiation as in Figure 2.11, effective ventilation can be achieved, while thermal impact from solar radiation is minimized (Chenvidyakarn, 2007).

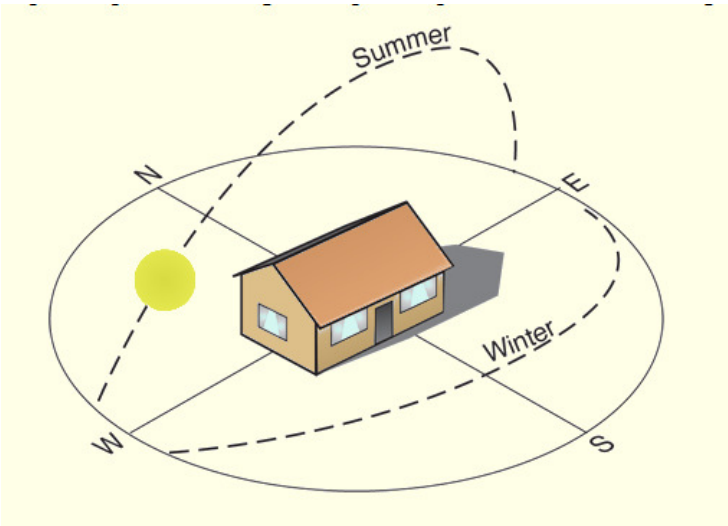


Figure 2.11 Building Orientation

Source: www.ecowho.com

In regions where ambient temperature has greater influence on comfort than ventilation, orientation with respect to the sun is important.

iii. Shading

The main principle in shading strategy is to avoid the penetration of direct solar radiation into the building through its opening and heat absorbing materials (Abed, 2012). Well-designed shading devices can significantly reduce building peak cooling load and corresponding energy consumption and enhance daylight utilization in buildings. Shading devices can also avoid glare by reducing contrast ratios of building interior (HK Green Building Technology, 2014). Also, solar shading devices such as overhangs, awnings and blinds which are lightweight ventilated shading panels attached to walls and roofs can be utilized in order to avoid unwanted solar radiation in summer and allowing it in winter (Abed, 2012). Solar gain through windows is often a major component of the heat gains of a building. Some of the external shading strategies for windows are illustrated in Figure 2.12.

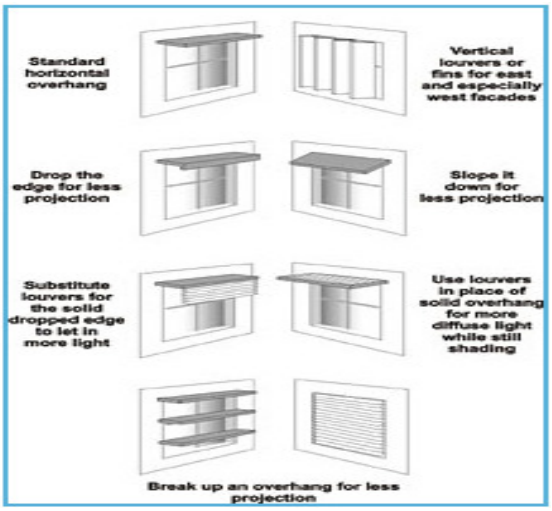


Figure 2.12 Different Shading Strategies
Source: www.ecowho.com

Also, solar radiation on the opaque parts of the building envelope raises the surface temperature of the envelope and contributes to the heating of the interior environment (Chenvidyakarn, 2007). Effective shading can be provided by various means, including dedicated shading devices, nearby structures, vegetation and special glasses. However, external shading devices are considered the most effective, since they intercept solar radiation before it passes through the building envelope into the interior space.

iv. Glazing and Fenestration

The glazed system is an important strategy in passive solar design as it can cause the large portion of building's heat gain. Glass and glazing selection play a key role in determining the overall building's thermal performance. Fenestration thermal performance requirements must be integrated with the design of the building's heating and cooling systems (Nik Vigener and Brown 2009). The heat gain through the exterior window as observed by Yu et al (2008) accounts for 25–28% of the total heat gain, and when added to the infiltration, it makes 40% of the total while exterior wall heat gain

represents 23–24%. Window's material, orientation and its area ratio to the wall WWR are the main factors affect the performance of the glazed system. The effective utilization of these factors with applying natural ventilation can enhance the thermal comfort by decreasing the negative effect of solar radiation (Al-Tamimi *et al.* 2010). The main influencing factor of the previous factors is the overall window to wall area ratio. On east, south, and west exposures, greater window areas will admit more solar gain during winter (Mikler *et al.* 2008).

2.4. OFFICE BUILDINGS

Office buildings are buildings that fall under the category of institutional building type. The way an office building works is based on an organized defined role that affects the requirement of the office space. These defined roles are office structure, customer management and office technology (Neufert, 2006). The major organization in office works focuses on human relationship and communication. Office design influences all aspect of the working environment which has strong influence on job satisfaction.

2.4.1 Spaces in Office Buildings

The space provided to a person/people to accommodate his/their individual furniture and equipment and allow them to perform their job functions is referred to as a workstation. Workstation space may be enclosed or open depending on the confidentiality, security, visual and acoustical privacy requirements of the job. A large office building will consist of several different spaces depending on its organizational structures and function. But the primary spaces needed as shown by Neufert, (2006), are listed below.

i. Office areas have separate offices being defined by cooperate or individual workstations. It can be a unit room or an open space for multiple users. Some examples of office areas include: Standard separate office, deluxe separate office, open plan office, grouped offices and combined offices.

ii. Records areas are for storage of files, drawings micro-film and electronic media, filling and recording equipments, documents reproduction, and play-back and shredding.

iii. Central clerical service areas contain dictating, duplicating, printing and photocopying equipment and personal computers.

iv. Post room handles all mails both incoming and outgoing posts.

v. cooperate display area contains board rooms, meeting rooms, conference rooms as well as exhibition areas, mostly such areas have dismountable walls for ease of modification.

vi. Social display facilities mostly include cloakrooms, preparatory areas (kitchen), refreshments area, toilets and rest areas for employees.

vii. Circulation Spaces include corridors, stairways, and lifts, internal and external emergency exits.

viii. Central service areas are responsible for technical equipments, air conditioning, ventilation, heating, electric power, water supply, data processing, computer and telecommunication centre, cleaning and maintenance.

ix. Additional Spaces covers all other extensions like parking, drop off and entrance.

2.4.2 Design requirements for thermal comfort in Office Buildings

Man is affected greatly by the environmental parameters of thermal comfort which are lighting, heat (temperature), ventilation, sound etc. Therefore this consideration is to provide the steps that should be taken to improve the individual effect of those things that

impairs the efficiency of production in the senate building. Although these considerations apply to all projects in general terms, but for every specific project, the degree of importance attached to each consideration varies. This design requirements include; ventilation (natural and artificial), lighting (natural and artificial), thermal insulation and proper landscaping (Krem, 2012).

2.4.3 Office Buildings Heat Gains

The major problem of thermal comfort in office buildings in hot humid areas is heat gains, due to high air temperature, less air velocity, relative humidity and incident solar radiation. Heat gain is the thermal energy that a room may gain from external and internal sources (Krem, 2012). External sources of heat gain are heat transferred to indoors due to the difference between outside and inside temperature. This gain occurs through the building envelope walls, ceiling, windows, ventilation systems, and air leakage. Internal sources of heat gain are the heat generated by occupants, the heat produced by lighting, and the heat resulting from the equipment.

2.4.4 The University System

A university is a symbol of excellence. According to Oxford dictionary, university can be defined as a high-level educational institution in which students study for degrees and academic research is done, therefore there is need for effective management of the university to achieve meaningful results or goals. The major responsibilities assigned to the University are teaching and research (Ajibade, nd). The administration of most Universities in the country is centered around the Council, Senate, faculties and departments for academic decisions, and library, registry, catering, bursary and

maintenance sections for supportive activities (Ajibade, nd). The organizational system is somehow rigid as it creates different organizational units and a central need for coordination.

The university organizational hierarchy as pointed out by Shuara (2010), as seen in Figure 2.11 are: a visitor, a chancellor, a pro- chancellor and members of the council, a vice- chancellor, deputy vice- chancellor, provost and members of the senate, a body to be called congregation, a body to be called convocation, students and staff at campuses of the university, staff, students and members of colleges, schools, faculties, institutes and other teaching and research units of the university. Persons who hold the offices constituted by the first schedule to this edict whether or not any such persons have been mentioned in any paragraph of this subsection. All graduates and undergraduates of the university. This is graphically represented below in Figure 2.11.

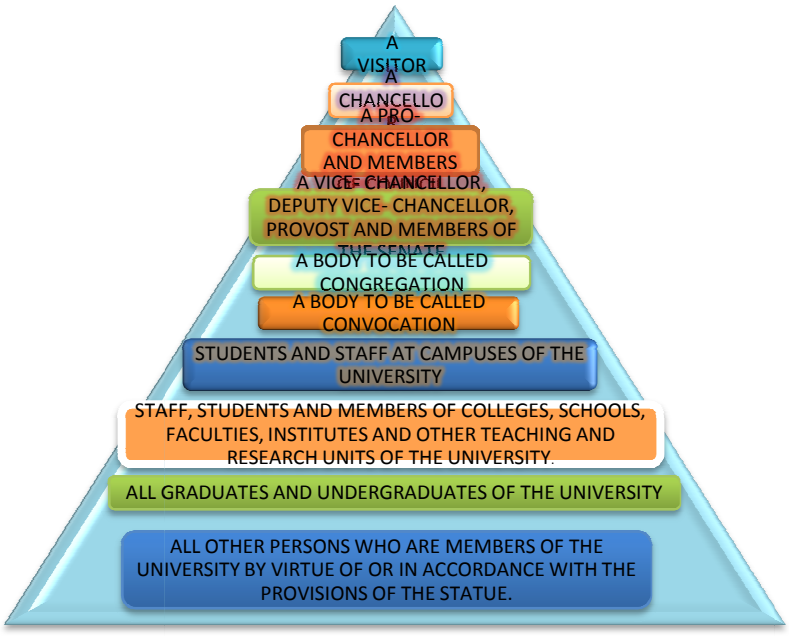


Figure 2.13 University Composition Chart.

Source: Shuara, (2010).

2.4.5 University Senate/Administrative Building

A senate building is basically the administrative sector of the university. It houses the university council and senate chamber and other offices. The governing structure of any institution be it academic or not determines to a great extent whatever happens within the administrative building. There are two main bodies which make up the university administration. These are: the staff and students. The staff can be of the following; senior staff, intermediate and subordinate staff.

The necessity to appreciate what a senate building should be composed of, makes it necessary to compartmentalize the structure in accordance with the different bodies for which the building is intended (Shuara, 2010). The building is expected to house the vice-chancellor's office, the registrar's office, and the bursar's office. Provisions are also made for the university governing council.

2.4.6 Functional relationship within the senate building

The success of this project depends largely on the proper understanding between and within different departments, sections and units. These relationships of this kind can be classified under two major headings

i. Administrative structure

This is paramount in determining the functional relationship expected between and within the different departments. The hierarchical structure and possible directions of work flow are the two basic factors that are involved in the administrative structure. Administrative hierarchy basically contains the different steps and levels that exist in the highest officer

in the unit and subsequently to the office of the chief executive which in this case is the vice-chancellor. This provides the required horizontal and vertical separation in an office complex.

ii. General service

The senate building performs important services to the community. Community here refers to the students, staff and general public. The students are most important because every other person is there because of the availability of the students and most importantly their large numbers as, if there are no students, there will be no university.

As such, sections serving the community service have the tendency of having excess visitors at certain periods. Consequently importance should be attached to direction of pedestrian traffic performing activities like registration, clearance, obtaining accommodation, payment of fees etc. for clarity. All sections performing the above activities should be closely related to avoid rowdy in the building.

2.4.7 Component of a Senate Building

Due to the nature of work performed by each component, the senate building has been divided into seven components. This is to ease the administrative work. The components are: Vice –chancellor's office, Planning unit, Registry, Bursary, Student's affair, General administration and Senate / council chamber (Shuara, 2010).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 RESEARCH APPROACH

The research approach adopted for this study is a quantitative, being an evaluative research. The use of case study and computer simulation for this study will help in achieving the aim and objectives of this research. The evaluative case study type is most relevant in this case as it application establishes that evaluative case studies are used for testing the effectiveness of programs in order to suggest modification and alternatives (Veal, 2006). This method allows for testing of variables measured with numbers, and statistical analysis in order to aid in achieving the set aim of the research.

3.2 MATERIAL AND METHODS

Knowing well, that this research is evaluative in nature, it will employ the case study and simulation as method of data collection. Materials were the case study buildings, checklist, geometric forms, and weather data for Lafia climate. This research makes use of the case study approach as an essential working method. This method is carefully selected in order to help in proper analysis and careful discussion of the results. A checklist is use to check the extent to which the design consideration for achieving thermal comfort in hot humid areas was consider in the selected cases. Using ECOTECT as the simulation tool, the effect of building form on thermal comfort is evaluated based on temperature profile study, heating and cooling loads studies and passive gains analysis. This is done in order to determine the best form in terms of energy performance, heating and cooling loads and passive solar gains/loss.

3.3 POPULATION OF STUDY

The population of study will cover senate buildings located in hot humid areas and other neighboring areas in order to investigate how the design consideration for achieving thermal comfort in hot humid areas is duly considered. Three buildings were selected, two in Nasarawa state (Lafia and Keffi) and one in Kaduna State (Zaria). The selected cases are; Senate Building Federal University Lafia, State University Keffi and Ahamadu Bello University Zaria.

3.4 INSTRUMENTS OF DATA COLLECTION

The instruments employed for the collection of data in this research include visual survey; check list and simulation program indicators.

i. Visual Survey- Has to do with the physical observation of the building in order to note its appearance in terms of the building forms, orientation, envelope properties and physical features/ expressions being put in the design.

ii. Check list – The check list was developed with the aim to check the rate or extent which the design consideration was achieved in the selected case studies. The check list has a ranking of 0-5 (0=None, 1=Poor, 2=Fair, 3=Good, 4=V.Good and 5=Excellent). Each of the consideration will be rated as shown above for each building, and a summation will be done in order to find the building that best apply these considerations.

iii. Computer Simulation Indicators– In order to evaluate the thermal performance of the various building forms and the viability and workability of the method/procedure adopted, indicators are needed. These indicators are energy consumption (total heating

and cooling loads), HVAC loads, conduction, SolAir, Direct solar, ventilation, internal and inter-zonal.

3.5 VARIABLES

The following are the variables to be use in the research.

a. Case Study Variables

i. Building Form

ii. Orientation and Planning

ii. Shading

iv. Glazing and Fenestration

v. Material Properties

b. Simulation Variables

i. Energy performance: temperature profile study, heating and cooling loads, passive gains analysis.

ii. Form: Cube, Cuboid, Cylinder, Cone and Pyramid

iii. Orientation: 0^o, 15^o, 30^o, 45^o, 60^o, 75^o and 90^o

iv. Glazing: 20% WWR, 40%WWR and 60%WWR

3.6 METHOD OF DATA ANALYSIS

The method adopted for data analysis in this study is checklist for case study and ecotect for computer simulation.

Case Study- The checklist is use to analyze the design requirements for achieving thermal comfort in hot humid areas on the three case study conducted. Based on the following major variables; form, orientation, shading, glazing and envelope composition being considered in the buildings. A check list based on site development, building layout, envelope composition and building interior was used to further analyze the extent which the above variables were considered in the three buildings. Each of the case study will be analyzed based on a ranking of 0-5 as mentioned above. The summation of the variable in the checklist will help in deciding the building that best apply the consideration needed for achieving thermal comfort.

Simulation- All the forms will be modeled in ECOTECT software and the envelope thermophysical properties of all the forms will be the same. The occupancy, activity level and appliances of all the forms will be the same. Each form is simulated independently to generate the energy consumption. The simulation will be done in three phases, these are: analysis of the effects of form on energy consumption, the effect of orientation on energy consumption and lastly the effect of glazing on the energy consumption. The indicators used in the test are; total energy consumption, HVAC load, Conduction, SolAir, Solar, Direct solar, Ventilation, Internal, Inter-zonal and Fabric.

i. Effects of form on energy consumption: The variables for this test is the hourly temperature profile study, the annual heating and cooling load study, and the passive gain/loss analysis of the different forms.

ii. Effects of orientation on energy consumption: The square and rectangle form is used in this section with seven different orientations at 15^{o} interval. Each of the form is tested at each orientation and the best orientation with the least energy consumption is selected.

iii. Effects of glazing on energy consumption: The square form is used in his regards with variables of 20%, 40% and 60% WWR. Other variables will include the glazing type amd materials. Here, the effect of WWR and glazing material will be analyzed and the best to this regard will be selected.

Finally, the form with the least amount of energy consumption will be selected as the preferred form. The indicators mentioned above will serve as a guide for discussion of the findings.

3.7 VALIDITY AND RELIABILITY OF INSTRUMENT

For this research, the method of data collection is by desk study (secondary data collection), i.e the data to be used are those stored in either statistical or descriptive format. The most significant advantage of the secondary data is related to time and cost. The format of the secondary data is compactable to be used in most computer simulation software's. This method have been used by researchers on similar field like Ling et al.(2007), Catalina et. al.(2011) and Huda (2012). The data gotten from these centers will come in different statistical mode for use in the experiment. Mean daily, weekly, monthly and annual of air temperature, air velocity, relative humidity and solar radiation of the study area gotten will be use to analyze (simulate) and present the findings in appropriate formats like figures, graphs e.t.c.

CHAPTER FOUR

DATA PRESENTATION AND RESULTS

4.1. CASE STUDIES

In this chapter, the results of the case study conducted and the analysis carried out is presented. The results focused on the variables as described in the methodology of this study. These variables of study were developed from an extensive review of the literature and similar studies. The case study focuses on the factors affecting the thermal performance of the selected buildings as well as the design considerations for achieving thermal comfort in hot humid areas. The possible areas are; building form, orientation, shading, glazing and fenestrations and envelope material properties.

4.2. CASE STUDY ONE: SENATE BUILDING FEDERAL UNIVERSITY LAFIA .



Plate I: Approach View of Administrative Building.

Source: Researcher's Field Survey (2014).

4.2.1 Background Information:

The Federal University of Lafia, is a new University established in Lafia, the capital of Nasarawa State in 2010 by the Goodluck Jonathan administration as one of the nine new federal universities established in the six geo-political zones of Nigeria. The university was formally planned to be established along Jos road in Lafia metropolis and it was ment to begin operation using the facilities of College of Agriculture in Lafia, but the university has been moved to Obi road in Lafia metropolis. The senate building occupied the building that once serves as the Local Government Secretariat, now redesigned by Castle & Cubicles Nigerian Limited and renovated by T-Bag Associates Nigerian Limited. The building is located centrally within the temporary campus of the university. Bearing at longitude 8^{o}28'18.95"N and latitude 8^{o}35'22.21"E.

4.2.2 Architectural Context:

The architecture is modern in style, having an open rectangular plan covered by two large open courtyards which provides the building with ventilation and natural lighting. The building is a single storey structure constructed of concrete, sandcrete block wall with clear glass aluminium windows as in Plater I. The entrance has a projected canopy held up by concrete columns serving as drop off. The administrative building is a one storey mixed used building comprising of offices, library, lecture hall, conference hall, classes and conveniences. The building has a floor area of about 3060.3m2. Having lecture hall, laboratory and lecture classes are located on the ground floor, while lecturer offices and administrative staff offices are located on the first floor. It was constructed as a temporary facility for the start up of the school, which will later be converted to an annex building.

4.2.3 Building form:

The building is a rectangular building having two square courtyards as seen in Figure 4.1 below. The building is a single storey building accommodating both administrative offices and some class rooms. Being a temporary facility, most of the facilities are found within the same building. The central walkways surrounding the courtyards help in shading part of the building interior.

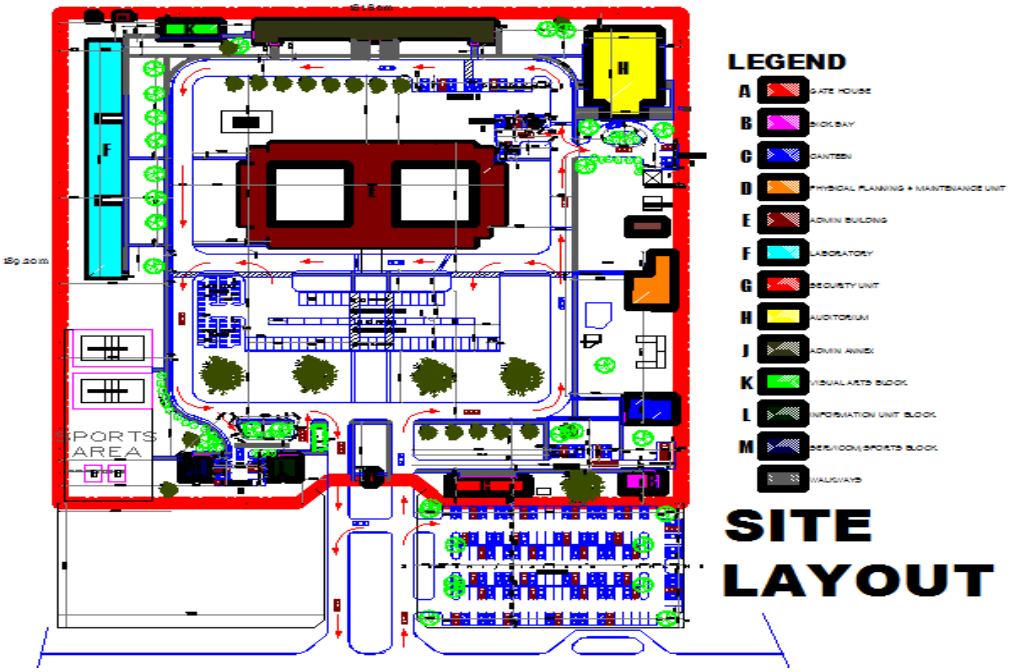


Figure 4.1 Site layout of Administrative Building.

Source: Public Planning Unit Federal University Lafia.

4.2.4 Building Orientation:

The building is oriented along the East-West direction, with the longer side facing the North and South. This is done primarily to reduce the impact of solar radiation reaching the surface of the building. However, due to change in longitude and latitude, the sun path may vary giving less shade to the building as seen in plate II below.



Plate II Ariel View of Administrative Building.

Source: Google earth. (2013).

4.2.5 Building Shading:

The building as in Plate III has no any form of shading provided either to the windows or wall envelope. This therefore leads to direct incident solar radiation reaching the building surface without any form of obstruction.



Plate III. North West Elevation with no shading.

Source: Researcher's Field Survey (2014).

This will lead to high internal temperature and glare effects to occupants of the building as seen in Plate IIV. The only source of shading provided is the roof eaves overhang which is 600mm as in Plate III.

4.2.6 Building Glazing and Fenestration:

The primary material for glazing used in the building is single glazed aluminum window. Windows are found in opposite sides of the building to aid in cross ventilation, from the exterior to the courtyards as in Plate III and IV. Window blinds are introduced at windows along the East-West direction to prevent glare and internal heating as seen in Plate V.





Plate IV: Open Courtyard in Admin Building. Plate V General Library in Admin Building

Source: Researcher's Field Survey (2014).

4.2.7 Building materials and Components:

The dominant building materials used for the building are reinforced concrete, sandcrete block wall, glazed aluminium windows and terrazzo floor on floor. Structural columns are use as supports and central staircase for circulation as seen in Plate VI and VII.





. Plate VI Central Staircase Plate VII Lecture Class/Hall

Source: Researcher's Field Survey (2014).

Table 4.1 Discussion of case study one based on other variables.

Variables	Descriptions
Major facilities and functional spaces.	Drop off, security point, laboratories, library, lecturer and administrative offices, class rooms and lecture halls, courtyards, corridors, walkways.
Building materials	Sandcrete blocks, concrete, steel, aluminum, glass, timber
Structural systems	Reinforce concrete floor slabs, beams and columns, block walls as shown in Plate VII.
Architectural expressions	Well defined entrance/drop off. Two floors linked with staircase, lobby, verandah and walkways for circulation. Two large courtyards for lightning, ventilation and aesthetics. External staircase and doors for fire escape and linkage with other adjoining facilities on the site. Hipped roof with aluminum roofing sheets, aluminum sliding windows.
Architectural form and composition	A rectangular building with two courtyards. One story building as shown in Plate I and Figure 4.1
Circulation system	Staircase, ramp, walkways and corridors as shown in plate VI.

4.3 CASE STUDY TWO: SENATE BUILDING STATE UNIVERSITY KEFFI.



Plate VIII: Approach View of Administrative Building.

Source: Researcher's Field Survey (2014).

4.3.1 Background Information:

The Senate Building State University Keffi, Nasarawa State is located along Abuja-Akwanga Road Keffi, Nasarawa state. On longitude 8°50'31.75"N and latitude 7°54'24.38"E. designed by Ministry of Works and Urban Development, Nasarawa State and then renovated for use as the senate building. The building is situated in the centre of the University to be accessible by other buildings within the campus.

4.3.2 Architectural Context:

The architecture is modern in style, having a rectangular plan covered by three large open courtyards which provides the building with ventilation and natural lighting. The building is a single storey structure constructed of concrete, sandcrete block wall with clear glass

aluminium windows. The approach has three projected canopy that is up by concrete columns serving as drop off as in Plate VIII. The administrative building is a one storey building specially designed for the administrative running of the institution. It is a rectangular form building located in the central area of the university with a floor area of about 1785.42m^2, oriented with the longer side tilted facing the North East direction. It comprises mostly of administrative offices like V. C. office and D. V. C's offices, other top administrative offices each having secretary offices attached to them. The planning and zoning of this building is done base on the relationship between functional spaces, rate of activities and traffic flow within each space and general function base on units. Some of this spaces and units include communication and protocol, staffing, information, bursar and account section on ground floors etc. The top hierarchy offices are located on the first floor having the VC and DVC's office, conference hall, senate chambers, registry, account and Finance etc. The building is coordinated with a one main entrance, with other adjacent entrance for emergency exits. The presence of four courtyards serves as source of lightning, ventilation and aesthetics.

4.3.3 Building Form:

The building is a rectangular building having four courtyards. The building is a single storey building accommodating administrative. The form being rectangle in nature as in Plate IX below has a width to length ratio 1:3, divided by courtyards for ventilation and lighting.

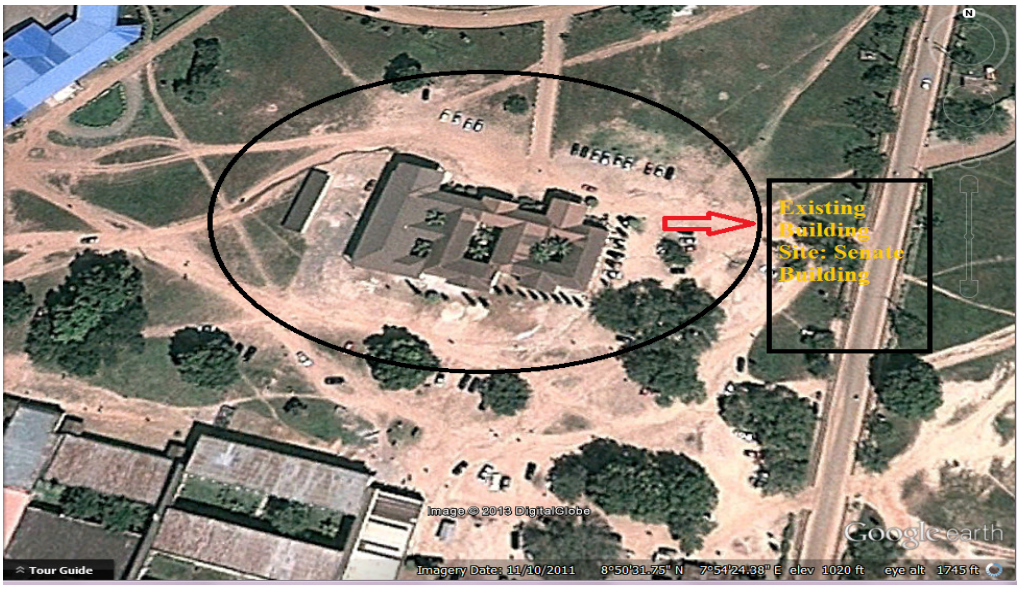


Plate IX Arial of Administrative Building.

Source: Google earth. (2013).

4.3.4 Building Orientation:

The building is oriented along the East-West direction, with the longer side facing the North and South. This is done primarily to reduce the impact of solar radiation reaching the surface of the building. The form is slightly oriented off the true North by 30^{o} to more air movement and reduces solar impact as in plate IX.

4.3.5 Building Shading:

The building has no any form of external shading provided either to the windows or wall envelope along the North-South faces. Along the East-West direction, a recess was provided to shade the windows from direct solar radiation. Trees are provided along the East-West direction in plate X, to reduce solar radiation reaching the wall surface. The only source of shading provided is the roof eaves overhang which is 600mm as shown in plate X. window blinds ar introduce in the west direction to reduce solar radiation and glare effects as seen in Plate XIII.



Plate X: North East Elevation of Admin Building

Source: Researcher's Field Survey (2014).

4.3.6 Building Glazing and Fenestration:

The primary material for glazing used in the building is single glazed aluminum window. Windows are found in opposite sides of the building to aid in cross ventilation, from the exterior to the courtyards. Window blinds are introduced at windows along the East-West direction to prevent glare and internal heating as seen in Plate XIII.

4.3.7 Building Materials and Components:

The dominant building materials used for the building are reinforced concrete, sandcrete block wall, glazed aluminium windows and terrazzo floor on floor. Other materials and components include metal railings on staircase and courtyard, rectangular columns in the courtyard as in Plate XI and XII.



Plate XI: Open Courtyard in Admin Building.



Plate XII: Central Staircase in Admin Building

Source: Researcher's Field Survey (2014).



Plate XIII Senate Chamber.

Source: Researcher's Field Survey (2014).

Table 4.2 Discussion of case study two based on variables.

Variables	Descriptions
Major facilities and functional spaces.	Drop off, security point, administrative offices, conference halls, courtyards, corridors and walkways as seen n the plates above.
Building materials	Sandcrete blocks, concrete, steel, aluminum, glass, timber
Structural systems	Reinforce concrete floor slabs, beams and columns (250x600mm), 225mm block walls, open well staircase as seen in Plate XI and XII.
Architectural expressions	Well defined entrance/drop off. Two floors linked with staircase, lobby, verandah and walkways for circulation. Two large courtyards for lightning, ventilation and aesthetics. External staircase and doors for fire escape and linkage with other adjoining facilities on the site. Hipped roof with aluminum roofing sheets, aluminum sliding windows.
Architectural form and composition	A rectangular building with two courtyards. One story building as shown in Plate IX and X above.
Circulation system	Horizontal circulation consists of elements such as the corridors, walkways and lobbies. Vertical circulation includes staircases, ramps etc. The efficiency of the placement of these stairs is considered based on the number provided.

4.4 CASE STUDY THREE: SENATE BUILDING AHMADU BELLO UNIVERSITY ZARIA.



Plate XIV: Approach View of Administrative Building.

Source: Researcher's Field Survey (2014).

4.4.1 Background Information

The senate building of Ahmadu Bello University, Zaria is located at the Main Campus, Samaru Zaria, Kaduna state. On a bearing of longitude $11^0$9'33"N and latitude $7^0$30'18"E. Designed by Yusuf Mohammed & Associates and constructed in 1980. Being a premier university of the north, the building is seen from the main entrance as people approach the university.

4.4.2 Architectural Context:

The building is an eight storey building situated in the central academic environment if the institution. A building standing three to four floors taller than other s in the vicinity makes it a centre of reference. Design to cater for the administrative function of the

institution; it contains the office of the top personalities in the hem of affairs of the university. It is a square building having a floor area of 2,025m^2, oriented towards the North West. It's a building having the tower podium design concept. Offices and functional spaces are arranged based on functions and organizational hierarchy based on floors. The building is coordinated with three entrances one dedicated to the top ranking personnel, the second for the general staffs as seen in Plate XIV and other users and the third is not in use as at present. There is a presence a void from the ground floor and the first floor, while the senate chamber is located in the second floor. From the third floor to the eight floors there is an open courtyard. This serves as source of lightning, ventilation and aesthetics.

4.4.3 Building Form:

The building has a square form with the tower on the podium. The building is a single storey building accommodating administrative.

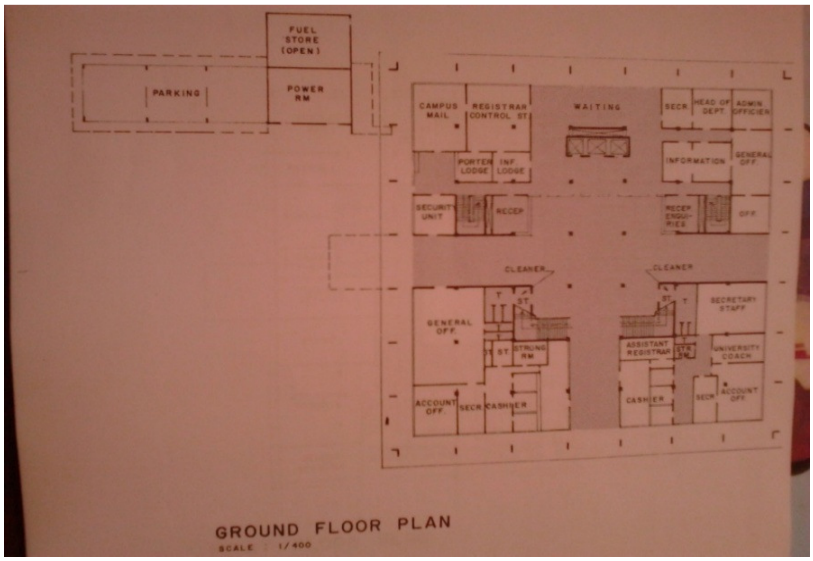


Figure 4.2 Ground Floor Plan of Administrative Building.

Source: Estate Department ABU Zaria (2013).

The form being square in nature as in Figure 4.2 and Plate XV, has a width to length ratio 1:1 with an open courtyard for ventilation and lighting. The square form makes the building more compact with all facilities and spaces fused within the single building.

4.4.4 Building Orientation:

The building is oriented diagonally along the East-West direction. This is done primarily to reduce the impact of solar radiation reaching the surface of the building. The form is slightly oriented off the true North by 45^{o} for more air movement and to reduce solar impact as in Plate XV.



Plate XV Ariel view of Administrative Building.

Source: Google earth. (2013).

4.4.5 Building Shading:

The building has both vertical and horizontal shading device, which helps in preventing direct incident solar radiation reaching the building surface. The egg crate shading device helps in controlling air movements into the building, alongside the vertical wing walls as seen in plate XVI and XVII.





Plate XVI: North Elevation of Admin Building. Plate XVII: North East Elevation of Admin Building

Source: Researcher's Field Survey (2014).

4.4.6 Building Glazing and Fenestration:

The primary material for glazing used in the building is single glazed aluminum window as in plate XVI and XVII. Windows are found in the exterior walls with high level windows in the courtyard. Large openings and fenestrations on the ground floor as shown in figure 4.2 helps in air circulation and enhance stack effect in the building.

4.4.7 Building Materials and Components:

The dominant building materials used for the building are reinforced concrete, sandcrete block wall, glazed aluminium windows and terrazzo floor on floor. The structural system composed of vertical columns, waffle grid and ribbed floors slabs as in Plate XVIII and XX below. The open courtyard in Plate XVIX serves for lighting and ventilation, while the senate chamber on the third floor is supported with the structural columns as seen in Plate XVIII and XXI below.



Plate XVIII: Void from third to eight floors.



Plate XVIX: Open Courtyard from third floors.

Source: Researcher's Field Survey (2014).





Plate XX: Staircase and lifts system in Administrative Building.

Source: Researcher's Field Survey (2014).



Plate XXI: Senate Chambers

Source: Researcher's Field Survey (2014).

Table 4.3 Discussion of case study three based on variables.

Variables	Descriptions
Major facilities and functional spaces.	General and staff entrances, security point, voids, courtyards, senate chambers, waiting areas, corridors, offices, stores, walkways as shown n the plates above.
Building materials	Sandcrete blocks, concrete, steel, aluminum, glass,
Structural systems	Reinforce concrete floor slabs (ribbed floor system), beams and columns (square 450x450mm), 225mm,150mm block walls, parapet walls, staircase as shown in Plate XVIX above.
Architectural expressions	Well defined entrance, eight floors linked with staircase and central lifts system, lobby, corridors and walkways for circulation. Courtyard for lightning, ventilation and aesthetics. Decked roof finished with glazed ceramic floor tiles, horizontal and vertical concrete fins/shading device overhanged, aluminum windows (sliding and casement-top hung).
Architectural form and composition	A square form building with courtyard, Eight stories high as shown in Figure 4.2 above.
Circulation system	Horizontal circulation consists of elements such as the corridors, walkways and lobbies. Vertical circulation includes two staircases and three lifts system. The efficiency of the placement of these stairs is considered based on the number of users.

4.5 DISCUSSION OF CASE STUDY FINDINGS.

Three building were studied based on the variables and design consideration for hot humid areas. Below is the summary of the three case studies (using design consideration for hot humid climates)

Some of the design strategies adopted in achieving comfort in the buildings were also noted and discussed based on their effectiveness. The major strategy noted is the passive design strategy or principle. For the purpose of this research the major areas of concern is the building form, orientation (solar and wind), shading and envelope. From Table 4.4 below, two of the buildings studied used the rectangular form, while the third is a square form. The rectangular forms are oriented along the East-West Direction with the Longer sides facing the North-South. For the wind orientation, case study one and two were oriented to intercept the prevailing wind, while case study three use external fins to trap and channel wind. Case study one and two has no shading device but three has both vertical and horizontal wing walls which serves as shading device from sun. For the building envelope, all use conventional building materials but case study three has more fenestration and openings compare to the first two.

Table 4.4 Summary of case study finding (passive design strategies adopted).

SOME DESIGN STRATEGIES ADOPTED			
	Case Study One	Case Study two	Case Study Three
Building Form	Rectangular courtyard Form having two floors and two square courtyards.	Rectangular courtyard Form of two floors, having two square and one rectangular courtyards	Square Form of nine floors with a void and a courtyard
Solar Orientation	Directly East-West with the longer sides facing the North-South direction	Directly East-West with the longer sides facing the North-South direction	Diagonally facing the north, with the other diagonal sides facing East-West respectively
Wind Orientation	Oriented with the longer side facing North-South, taking advantage of the two predominant wind flow	Oriented with the longer side facing North-South, taking advantage of the two predominant wind flow	Positioned with solar consideration, hence the need to compromise wind consideration, therefore the need to incorporate vertical and horizontal elements to trap wind for usage and adopting stack effect for cooling.
Shading	No any significant shading mechanism put in place to cover wall openings against incident solar radiation	Small vertical projection at column ends to serve as recess for the East-West walls against incident solar radiation	Use of vertical and horizontal wing walls and shading devices all round the building faces and wall openings.
Envelope	Building envelope made up of mostly conventional building materials. Walls having up to 40% openings for allowance of air movements into the building envelope	Building envelope made up of mostly conventional building materials. Walls having up to 30% openings for allowance of air movements into the building envelope	Building envelope made up of mostly conventional building materials. Walls having up to 45-50% openings for allowance of air movements into the building envelope, also wing walls available.

(Source: Research, 2014.)

The check list used to access the extent of the design strategies used in achieving thermal comfort in hot humid areas is given below. From the result of the checklist in table 4.5 below, it was found that the Senate building of Ahmadu Bello Unversity considers and applies the design strategies required for achieving thermal comfort more than the other two cases.

Table 4.5 Checklist of case study findings.

PARAMETER	**CASE STUDY ONE: FEDERAL UNIVERSITY LAFIA.**	**CASE STUDY TWO: STATE UNIVERSITY KEFFI.**	**CASE STUDY THREE: AHMADU BELLO UNIVERSITY ZARIA.**
For Site Development			
Site planning and layout	Good	Good	V. Good
Use of vegetation for shading	Poor	Good	Good
Ground cover type	Good	Fair	V. Good
Site drainage	Good	Poor	V. Good
For Building Layout			
Building orientation	V. Good	V. Good	Excellent
Plan organization	V. Good	V. Good	V. Good
Functional and Activities planning	Good	V. Good	V. Good
For Building Envelope And Composition			
Building envelope	Fair	Good	V. Good
Wing walls	Good	V. Good	Excellent
Shading device	Poor	Poor	V. Good
Color and finishes	V. Good	V. Good	V. Good
Overhang and Projections	Fair	Good	V. Good
Stack Ventilation	Fair	Fair	Excellent
Roofing materials	Good	Good	V. Good
For Building Interiors			
Planning interior	Good	Good	Good
Floor to floor height	Good	Good	V. Good
TOTAL	**44**	**47**	**65**
KEY: 5=Excellent, 4=V. Good, 3=Good, 2=Fair, 1=Poor, 0=None/Nill			

Table 4.5 above shows the assessing of the three case studies conducted, with consideration to the design requirements needed to provide comfort in hot humid areas. The design requirements/considerations were greatly considered in the senate building of ABU Zaria, followed by State university Keffi and lastly that of Lafia. Most of the consideration by case study three is in orientation, wing walls, shading device and stack effect for ventilation.

4.6. FORM ANALYSIS.

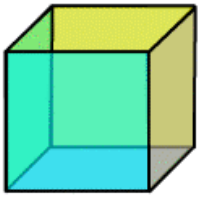
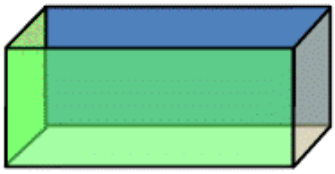
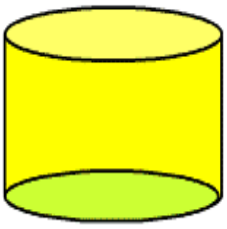
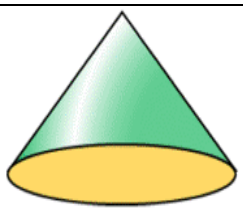
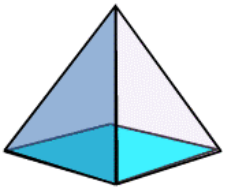
Building form is one of the major parameter that determines the relationship between the building envelope and its environment. This can affect the rate of thermal parameters reacting on the building, thereby affecting the thermal condition. The impact of different geometry with the same floor area, floor to floor height, and envelope thermophysical properties will be analyzed and discussed. In order to understand the effect of geometrical forms, a parametric investigation will be carried out. This will be carried out in three phase. The first phase will be to analyze five geometric forms having the same floor area and volume to determine their heating, cooling and total loads (that is the amount of energy needed to provide comfort all year). Secondly, the form above will be further analyzed based on differences in orientation. And lastly, the effect of glazing size (window to wall ratio) and materials will be looked upon.

The following are assumptions adopted in the modeling of the forms:

i. The buildings form in this analysis is assumed to be in a region without slope, and the buildings are not shaded (stand alone).

ii. Each building form as in Table 4.6 is composed of 81m^2 floor area, 729m^2 volume and total façade exposed area vary due to the difference in the plan shape.

Table 4.6 Forms and parameters.

Shape	3D VIEW	BASIC PARAMETERS	AREA PARAMETERS
CUBE		Floor Area=81m^2 Surface Area=486m^2 Exposed Area=405m^2 Volume=729m^3	L=9m B=9m H=9m
CUBOID		Floor Area=81m^2 Surface Area=513m^2 Exposed Area=432m^2 Volume=729m^3	L=13.5m B=6m H=9m
CYLINDER		Floor Area=81m^2 Surface Area=449m^2 Exposed Area=369m^2 Volume=729m^3	R=5.7m H=9m
CONE		Floor Area=81m^2 Surface Area=520m^2 Exposed Area=440m^2 Volume=729m^3	R=5.07m H=27m
PYRAMID		Floor Area=81m^2 Surface Area=538m^2 Exposed Area=492m^2 Volume=729m^3	L=9m B=9m H=27m

(Source: Research, 2014.)

iii. The occupancy hour of the building used is considered to be from 7:00am-18:00pm on week days and 00:00 during weekends. Occupant's activity rate is 70w and $12m^2$ per occupant in a typical office plan.

The simulation program also takes into account not only the internal heat gain of the occupants, but also from the electronic appliances. The operative standards and simulations settings on ecotect were stet based on ASHRAE Standard 55, for buildings in hot humid areas.

The office appliances are simple office equipments like computer, printer, scanner and fax machines are set at $10.8m^2$ for a typical office.

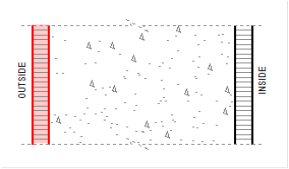
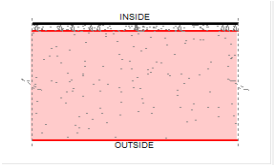
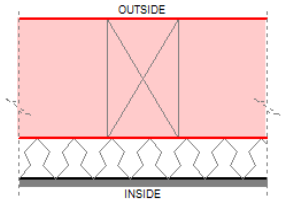
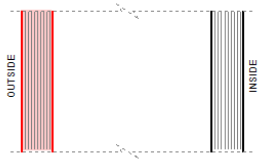
Operative temperature range for building occupants in typical winter clothing (0.8-1.2clo) is specified at (20^oC – 23.5^oC) and for summer clothing (0.35-0.6clo) is (22.5^oC-26^oC). The comfort band taken for the office interior is set at 20^oC for heating and 26^oC for cooling.

Also the relative humidity for 80% occupant satisfaction is 60%RH, the activity level of 1.2met is recommended and air speed low enough to avoid drift is acceptable. Using 60%RH, 0.5m/s air speed, 400lux lighting level for office desk/workshop and other primary standards needed for comfort were used for the simulation process which is shown in details at the appendix sheet.

iv. The building envelope thermophysical properties of the building envelope is given in the 4.7 below. This helps in determining the rate of conduction, convection and radiation of solar heat between the environment and the building interior. It shows the material description (graphical representations, thickness and placements of materials),

components constituents and thickness, and finally the thermal properties of the envelope material (U-value, admittance, time lag, absorption, transmittance etc).

Table 4.7 Form Thermophysical Properties.

Form envelope component	**Thermal conductivity**
Wall: 110mm concrete block with 10mm plaster either side. 	U-value = 1.8W/m2K Admittance =3.36W/m2K Solar absorption =0.565 Visible transmittance =0 Thermal decreament =0.78 Thermal lag = 5hrs
Floor: ConcSlab_Tiles_OnGround: 100mm thick concrete slab on ground plus ceramic tiles. 	U-value = 0.880W/m2K Admittance =6.100 W/m2K Solar absorption =0. 47520 Visible transmittance =0 Thermal decreament =0.31 Thermal lag = 4.6hrs
Ceiling: Plaster_Insulation_Suspended: 10mm suspended plaster board ceiling, plus 50mm insulation, with remainder (150mm) joists as air gap. 	U-value = 0.500W/m2K Admittance =0.900W/m2K Solar absorption =0.368 Visible transmittance =0 Thermal decreament =0.32 Thermal lag =0.7hrs
Window: DoubleGlazed_LowE_AlumFrame: Double glazed with aluminium frame (no thermal break), emissivity of 0.10. 	U-value = 2.410W/m2K Admittance =2.380W/m2K Solar heat gain coeff. =0.75 Visible transmittance =0.611 Reflective index of glass =1.74

(Source: Research, 2014.)

4.6.1 Effects of Geometric Forms on Energy Consumption.

The simulation of the five geometric forms (cube, cuboid, cone, cylinder and pyramid) is presented below. The results will be presented based on their energy consumpton from the best to the least based on the indicators mentioned in chapter three.

4.6.1.1 Temperature Profile Study: The hourly temperatures profile for all thermal zones of cube, cuboid, cone, cylinder and pyramid for the hottest day as shown in the figures 4.3-7 below. The profile shows on a daily bases the amount of energy that will be required to maintain the form zone at a comfortable internal temperature.

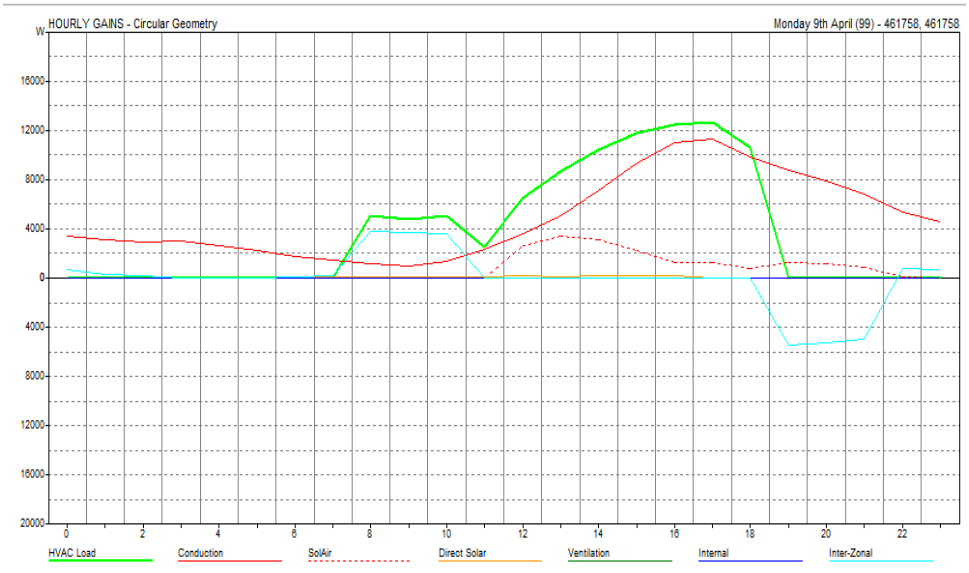


Figure 4.3 Analysis Hourly Temperature profile for hottest day Cone.

Source: Researcher's Work (2014).

From Figure 4.3 above, the cone form is the best needing 90564Wh of load for HVAC, heat gain through fabric is 135304Wh, solar is 1467Wh and gives off -1393Wh to inter-zonal agencies.

Second best is the pyramid form as seen in Figure 4.4 below with HVAC 93892Wh, 171222Wh gains through fabric, and gives off -452Wh to inter zonal agencies.

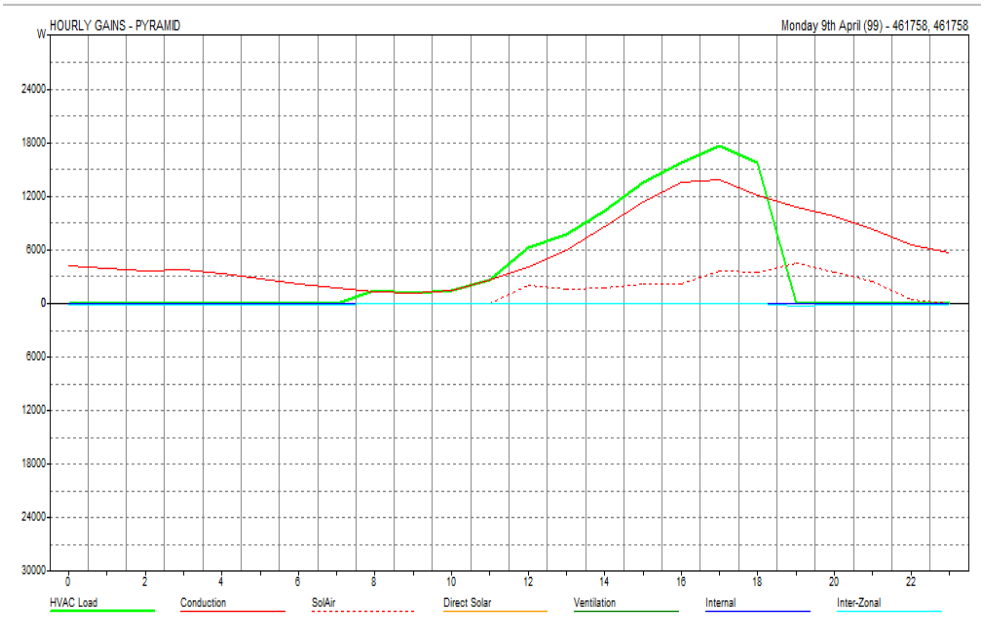


Figure 4.4 Analysis Hourly Temperature profile for hottest day Pyramid.

Source: Researcher's Work (2014).

The cylinder form is the third as seen in figure 4.5 below with 171272Wh for HVAC, gains of 172400Wh on fabric, 63253Wh on solar and -849Wh to inter zonal agencies.

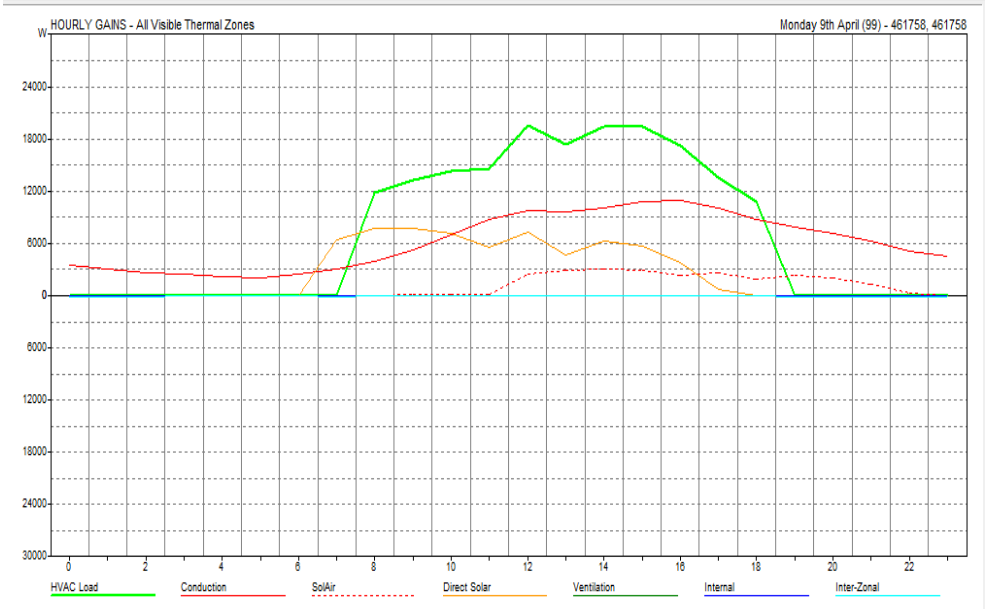


Figure 4.5 Analysis Hourly Temperature profile for hottest day Cylinder.

Source: Researcher's Work (2014).

Fourth is the cube in Figure 4.6 below with 273800Wh for HVAC, and gains of 242198Wh on fabric, 118911Wh on solar and gives off -371Wh to inter zonal agencies.

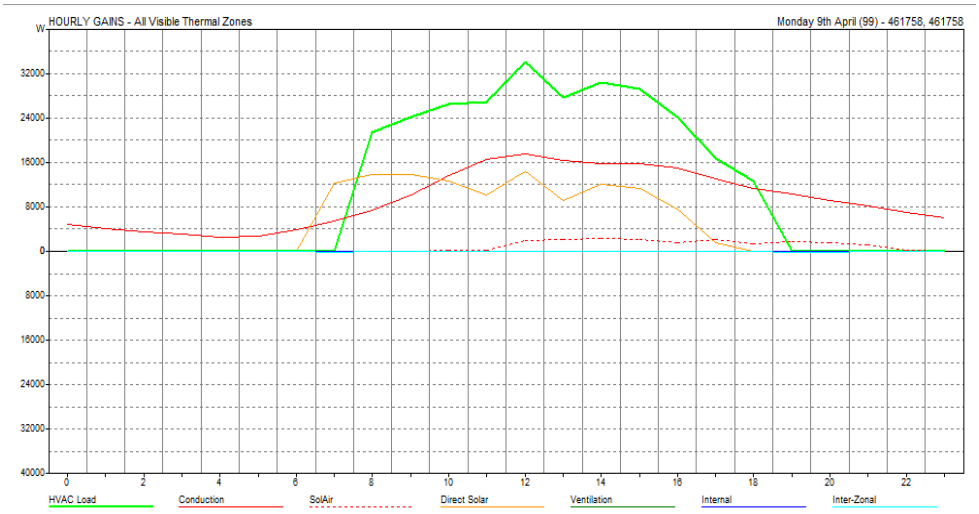


Figure 4.6. Analysis of Hourly Temperature profile for hottest day Cube.

Source: Researcher's Work (2014).

The least efficient form is the cuboid Figure 4.7 with the highest amount of energy for HVAC 284946Wh, and gains of 263292Wh on fabric, 114678Wh from solar and gives off -383 to inter zonal agencies.

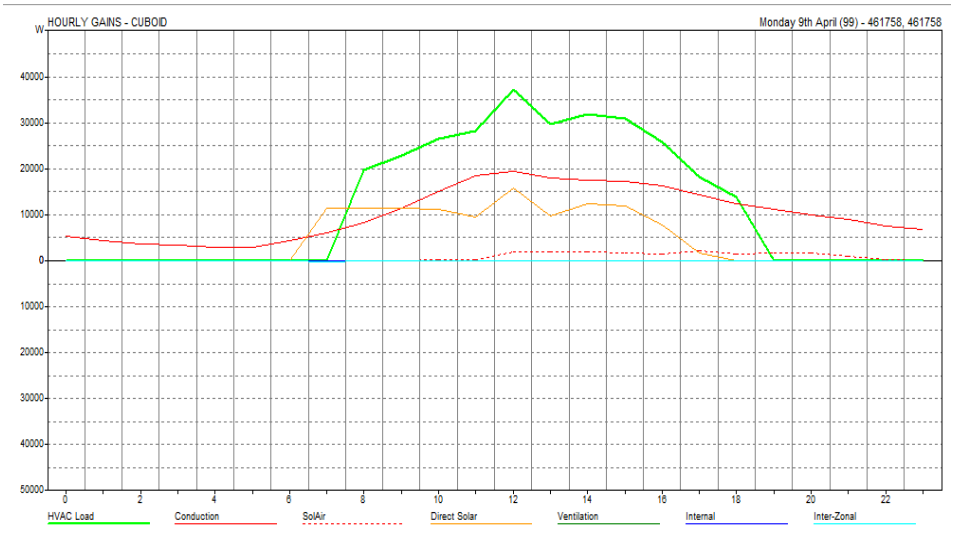


Figure 4.7 Analysis Hourly Temperature profile for hottest day Cuboid.

Source: Researcher's Work (2014).

From the analysis carried out on the hottest day of the year April, the summary of the daily loads is given in the table below.

Table 4.8. Summary table for hottest day cooling loads.

HOUR	HVAC (Wh)	FABRIC (Wh)	SOLAR (Wh)	VENT. (Wh)	INTERN (Wh)	ZONAL (Wh)
CONE	90564	135304	1467	0	0	-1393
PYRAMID	93892	171222	0	0	0	-1452
CYLINDER	171272	172400	63253	0	0	-849
CUBE	273800	242198	118911	0	0	-371
CUBOID	284946	263292	114678	0	0	-383

Source: Researcher's Work (2014).

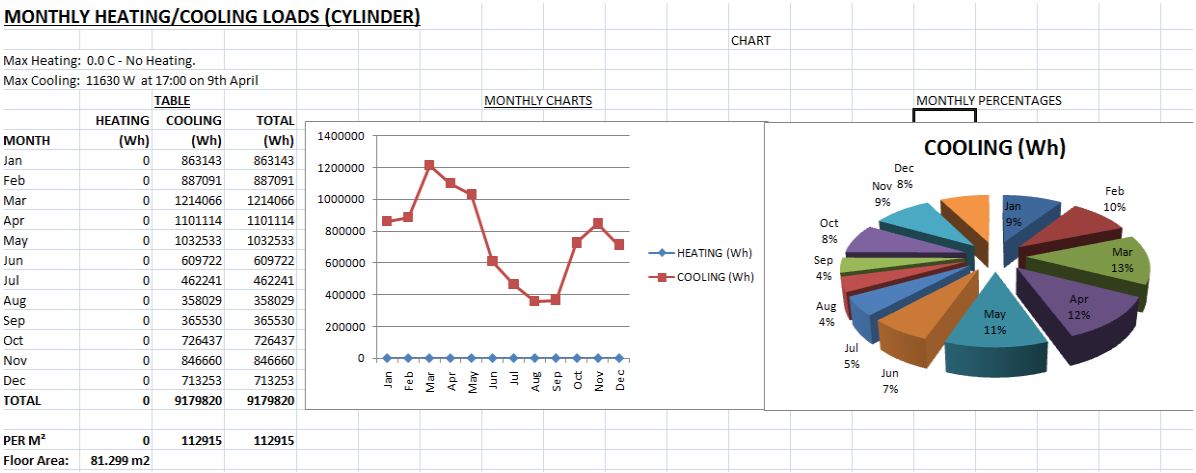
From table 4.8 above, the cone and the pyramid forms require less loads (HVAC) to provide comfort within the space for the hottest day 90564Wh and 93892Wh. Also, they are the highest to give off energy to adjacent zones or spaces of over -1393Wh and -1452Wh respectively. The cylinder is the third with 171272Wh load and gives off -849Wh load to other zones. On the other hand, the cube and cuboid need higher loads of 273800Wh and 284946Wh daily loads and releases the least of -371Wh and -383Wh to other zones.

For the amount of solar heating loads received, the cone is the least followed by the cylinder, cuboid and cube. No heat load was noticed due to ventilation and infiltration as well as internal heat gains in the forms. Building form heat gain is usually noticed between 7:00am and 6:00pm for all the forms and is usually high at noon time.

4.6.1.2 Heating and Cooling Loads Study: The monthly and annual energy consumption of the five forms is expressed in the figures below. Calculations and results

are deduced from monthly energy consumption and presented based on their performance, from the least load (best) to the highest load (worst).

From Figure 4.8 below, the cylinder form performs best with 9179820Wh of cooling load requirement. Most of the cooling loads in between March to May with the highest in March (1214066Wh) and the lowest in August (358029Wh).



MONTHLY HEATING/COOLING LOADS (CYLINDER)

Max Heating: 0.0 C - No Heating.
Max Cooling: 11630 W at 17:00 on 9th April

TABLE

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	0	863143	863143
Feb	0	887091	887091
Mar	0	1214066	1214066
Apr	0	1101114	1101114
May	0	1032533	1032533
Jun	0	609722	609722
Jul	0	462241	462241
Aug	0	358029	358029
Sep	0	365530	365530
Oct	0	726437	726437
Nov	0	846660	846660
Dec	0	713253	713253
TOTAL	0	9179820	9179820
PER M²	0	112915	112915
Floor Area:	81.299 m2		

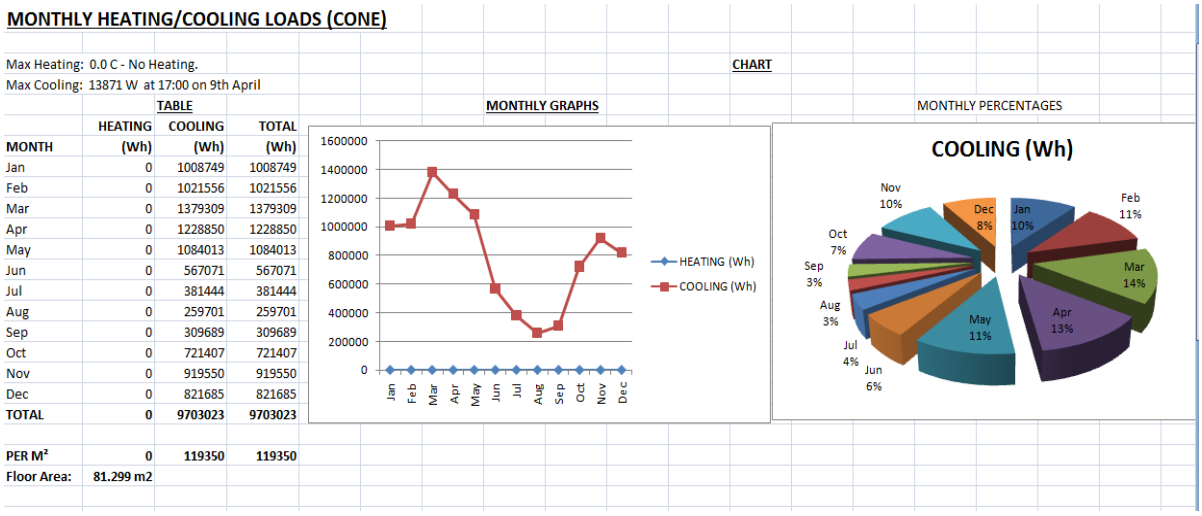
CHART

MONTHLY CHARTS

MONTHLY PERCENTAGES

Figure 4.8 Monthly heating and cooling loads of cylinder form.

Source: Researcher's Work (2014).



MONTHLY HEATING/COOLING LOADS (CONE)

Max Heating: 0.0 C - No Heating.
Max Cooling: 13871 W at 17:00 on 9th April

TABLE

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	0	1008749	1008749
Feb	0	1021556	1021556
Mar	0	1379309	1379309
Apr	0	1228850	1228850
May	0	1084013	1084013
Jun	0	567071	567071
Jul	0	381444	381444
Aug	0	259701	259701
Sep	0	309689	309689
Oct	0	721407	721407
Nov	0	919550	919550
Dec	0	821685	821685
TOTAL	0	9703023	9703023
PER M²	0	119350	119350
Floor Area:	81.299 m2		

CHART

MONTHLY GRAPHS

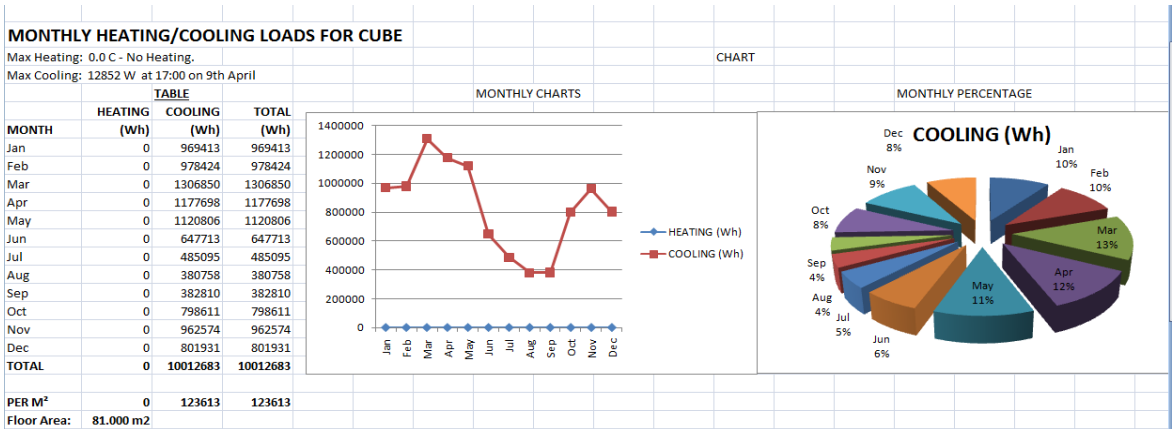
MONTHLY PERCENTAGES

Figure 4.9 Monthly heating and cooling loads cone form.

Source: Researcher's Work (2014).

The second best is the cone form Figure 4.9 above with annual cooling load of 9703023Wh, with the highest cooling load in March (1379309Wh) and the lowest in August (259701Wh).

The third is the cube form Figure 4.10 below with an annual cooling load of 10012683Wh, with the highest cooling load in April (1177698Wh) and lowest in August (380758Wh).



MONTHLY HEATING/COOLING LOADS FOR CUBE

Max Heating: 0.0 C - No Heating.
Max Cooling: 12852 W at 17:00 on 9th April

TABLE

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	0	969413	969413
Feb	0	978424	978424
Mar	0	1306850	1306850
Apr	0	1177698	1177698
May	0	1120806	1120806
Jun	0	647713	647713
Jul	0	485095	485095
Aug	0	380758	380758
Sep	0	382810	382810
Oct	0	798611	798611
Nov	0	962574	962574
Dec	0	801931	801931
TOTAL	**0**	**10012683**	**10012683**
PER M²	**0**	**123613**	**123613**
Floor Area:	**81.000 m2**		

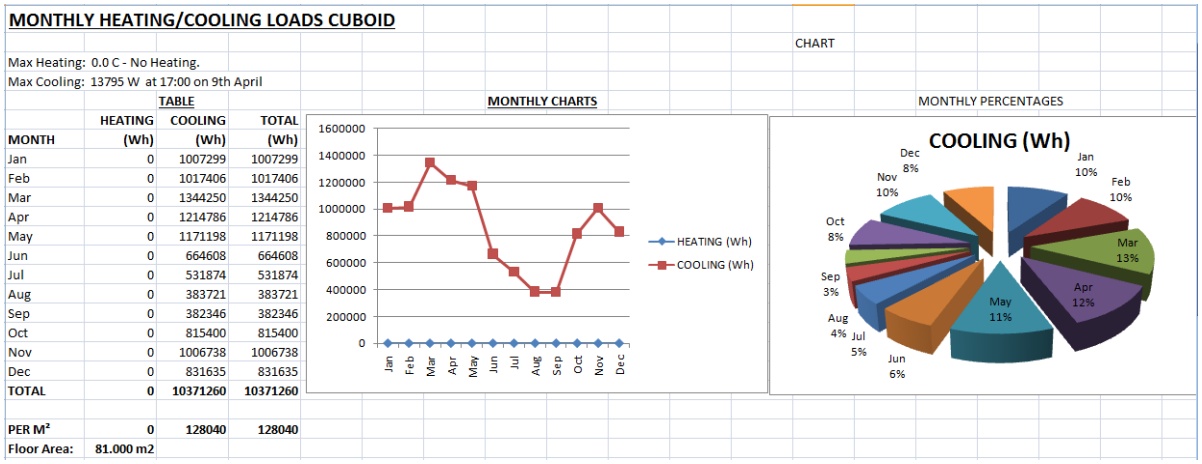
CHART

MONTHLY CHARTS

MONTHLY PERCENTAGE

Figure 4.10 Monthly heating and cooling loads of cube form.

Source: Researcher's Work (2014).



MONTHLY HEATING/COOLING LOADS CUBOID

Max Heating: 0.0 C - No Heating.
Max Cooling: 13795 W at 17:00 on 9th April

TABLE

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	0	1007299	1007299
Feb	0	1017406	1017406
Mar	0	1344250	1344250
Apr	0	1214786	1214786
May	0	1171198	1171198
Jun	0	664608	664608
Jul	0	531874	531874
Aug	0	383721	383721
Sep	0	382346	382346
Oct	0	815400	815400
Nov	0	1006738	1006738
Dec	0	831635	831635
TOTAL	**0**	**10371260**	**10371260**
PER M²	**0**	**128040**	**128040**
Floor Area:	**81.000 m2**		

CHART

MONTHLY CHARTS

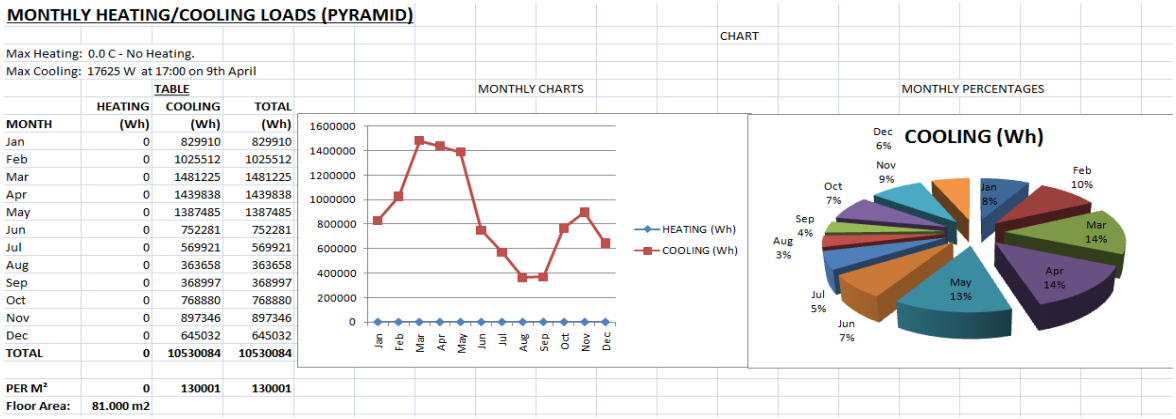
MONTHLY PERCENTAGES

Figure 4.11 Monthly heating and cooling loads of cuboid form.

Source: Researcher's Work (2014).

The fourth is the cuboid form Figure 4.11 with an annual cooling load of 1037126Wh, with the highest cooling load in April (1214786Wh) and the lowest in September (382346Wh).

The least is the pyramid form Figure 4.12 below with the highest cooling load of 10530084Wh, with the highest cooling load of 1481225Wh in March and lowest of 363.658Wh in August.



MONTHLY HEATING/COOLING LOADS (PYRAMID)

Max Heating: 0.0 C - No Heating.
Max Cooling: 17625 W at 17:00 on 9th April

TABLE

MONTH	HEATING (Wh)	COOLING (Wh)	TOTAL (Wh)
Jan	0	829910	829910
Feb	0	1025512	1025512
Mar	0	1481225	1481225
Apr	0	1439838	1439838
May	0	1387485	1387485
Jun	0	752281	752281
Jul	0	569921	569921
Aug	0	363658	363658
Sep	0	368997	368997
Oct	0	768880	768880
Nov	0	897346	897346
Dec	0	645032	645032
TOTAL	0	10530084	10530084
PER M²	0	130001	130001
Floor Area:	81.000 m2		

CHART

MONTHLY CHARTS

MONTHLY PERCENTAGES

Figure 4.12 Monthly heating and cooling loads of pyramid form.

Source: Researcher's Work (2014).

It is seen in Figures 4.8-12 above that all through the year for the five forms there is no need to provide heating at any time of the year. A monthly energy consumption of each form shows that between March –May, the highest consumption rate is noticed with monthly range of between 11%-14% of total consumption. On the other hand, the lowest energy consumption ranges between 3%-5% monthly between July-September.

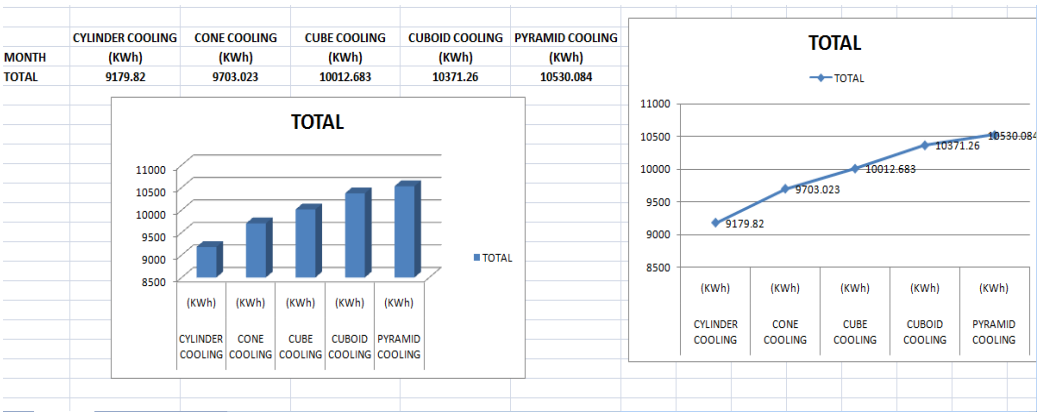


Figure 4.13 Total cooling loads (KWh).

Source: Researcher's Work (2014).

Figure 4.13 indicates the total cooling loads of the forms. The cylindrical form consumes the least amount of energy; therefore it is taken as the base case. From the base case, the energy consumption increases by 5.6% for cone form, 9.7% for cube form, 12.9% for cuboid and 14.7% for pyramid. This shows that total cooling loads for simulated shapes increase by 14.7% from cylindrical to pyramidal form. The differences noticed is caused by variation in façade areas oriented in the same direction. From figure 4.15 above, the cylindrical form consumes the lowest amount of energy for cooling all year round followed by the cone, cuboid and the pyramid is the highest.

4.6.1.3 Passive Gains Analysis: This part shows the analysis of the various forms showing the passive gains breakdown of the form. How much of the total passive gains and losses come from the form fabric, sol-air, solar, ventilation, internal and inter-zonal agencies. This also is presented based on the performance of the forms, from best to worst.

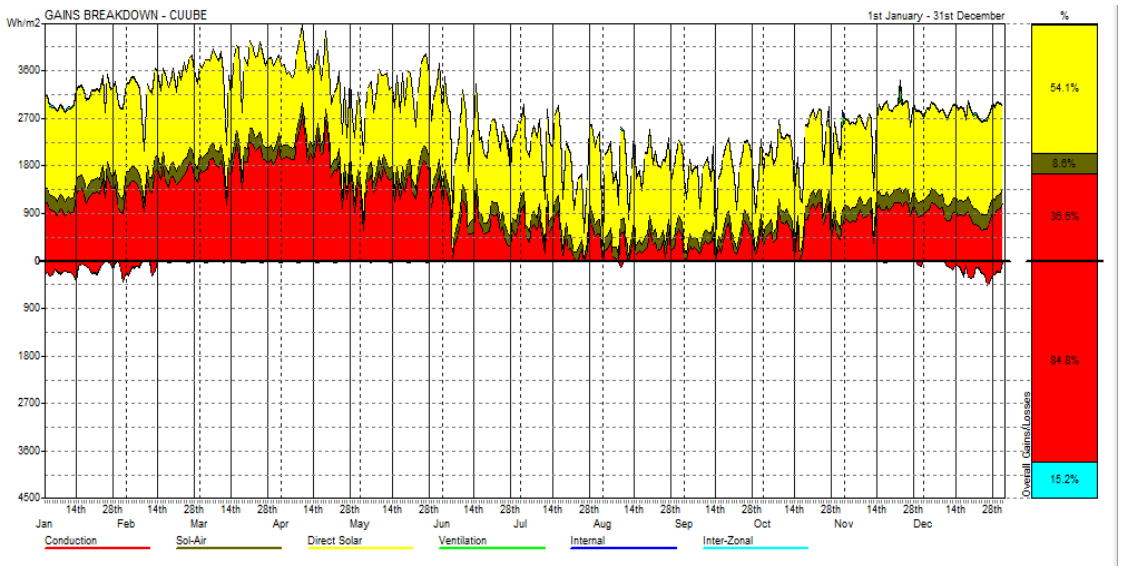


Figure 4.14 Passive Gain Breakdown for Cube

Source: Researcher's Work (2014).

From Figure 4.14 above, the passive gain breakdown of the cube form indicated that the form gains 36.6% of heat from the form Fabric, 8.8% SolAir, 54.10% from Solar, 0.6% for inter zonal. On the other hand, the form looses 84.80% from fabric and 15.20% from inter zonal agencies.

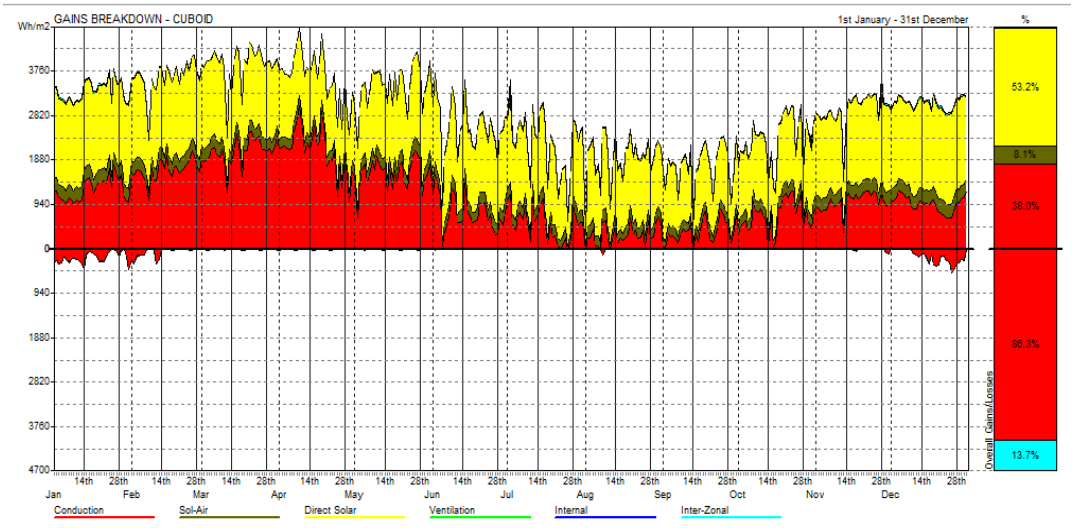


Figure 4.15 Passive Gain Breakdown for Cuboid

Source: Researcher's Work (2014).

From Figure 4.15 above, the passive gain breakdown of the cuboid form indicated that the form gains 38.0% of heat from the form Fabric, 8.10% SolAir, 53.20% from Solar, 0.6% for inter zonal. On the other hand, the form looses 86.30% from fabric and 13.70% from inter zonal agencies.

Figure 4.16 below, shows the passive gain breakdown of the cylinder form indicating 38.90% of heat gain from the form Fabric, 16.80% SolAir, 43.50% from Solar, 0.70% for inter zonal. On the other hand, the form looses 76.30% from fabric and 23.70% from inter zonal agencies.

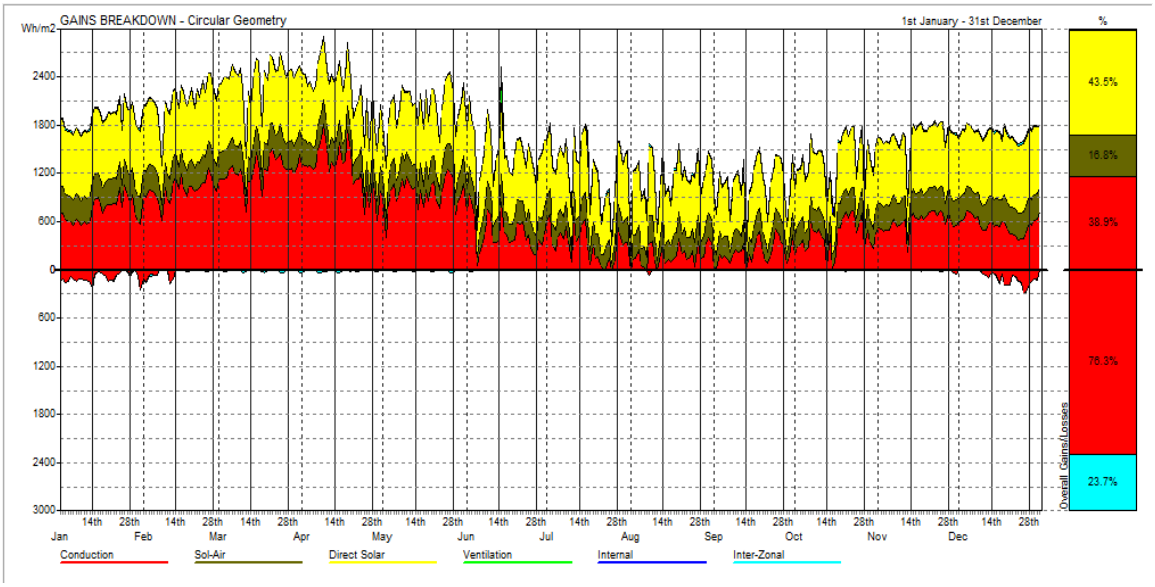


Figure 4.16 Passive Gain Breakdown for Cylinder

Source: Researcher's Work (2014).

Figure 4.17 below, shows the passive gain breakdown of the cone form indicating 62.60% of heat gain from the form Fabric, 24.90% SolAir, 2.50% from Solar, 9.70% for inter zonal. On the other hand, the form looses 19.80% from fabric and 80.20% from inter zonal agencies.

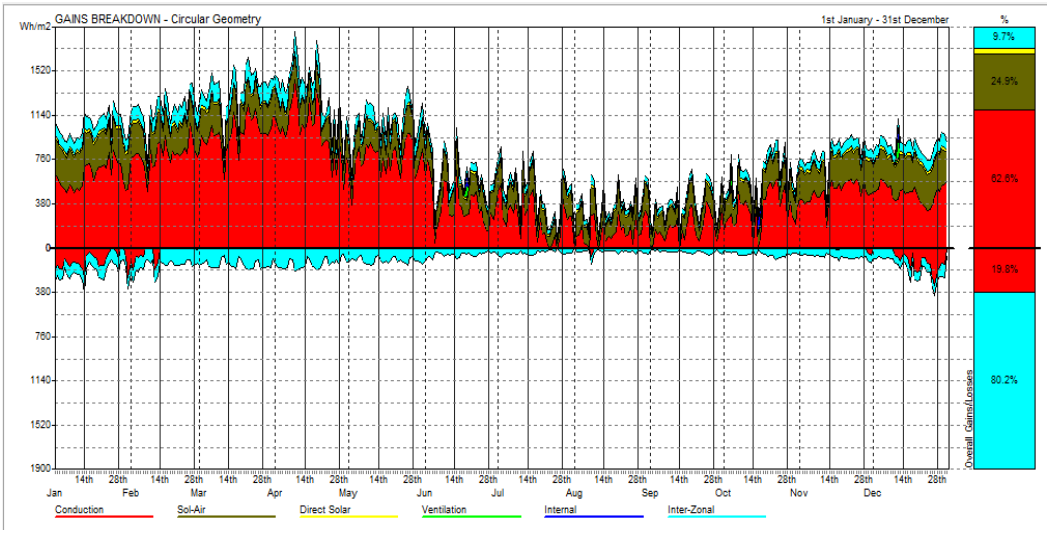


Figure 4.17 Passive Gain Breakdown for Cone

Source: Researcher's Work (2014).

Figure 4.18 below, shows the passive gain breakdown of the pyramid form indicating 64.30% of heat gain from the form Fabric, 34.60% SolAir, 2.50% from Solar, 0.80% for inter zonal. On the other hand, the form looses 76.70% from fabric and 23.30% from inter zonal agencies.

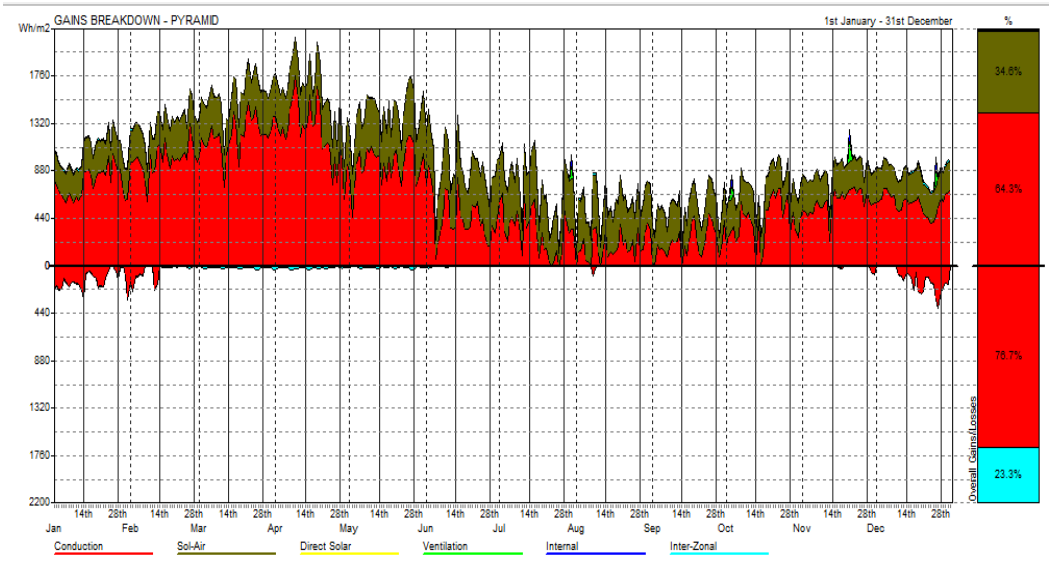


Figure 4.18 Passive Gain Breakdown for Pyramid

Source: Researcher's Work (2014).

From the analysis report from Figures 4.14-18 above, heat gain from the fabric decreases from pyramid (64.30%), cone (62.60%), cuboid (38.90%) cylinder (38.00%) and cube (36.60%). This shows that the cube form has the least percentage of annual heat gains on the fabric. In terms of direct solar heat gains, the cone is the least with 2.50% followed by cylinder (43.50%), cuboid (53.20%) and cube (54.10%). For that of the pyramid form, no result was noticed. Also for Sol-Air heat gain, the pyramid form gains the highest 34.60% followed by cone (24.90%), cylinder (16.80%), cube (8.60%) and cuboid (8.10%) respectively.

The results shows that the cube form performs best with respect to annual heat gain generated through the form fabric. The effect of direct solar heat gain will be highly minimized when using the cone form. And the Sol-Air heat gains will be reduced when using the cuboid form respectively.

4.6.2 Effects of Orientation on Energy Consumption.

Six values of orientation were considered for the cube and cuboid form, seeing that the cylindrical and cone form cannot be oriented and the pyramidal form has a footprint similar to the cube. The values of the orientation considered were 0^{o}N, 15^{o}N, 30^{o}N, 45^{o}N, 60^{o}N, 75^{o}N, and 90^{o}N as shown in the Figure 4.19 below.

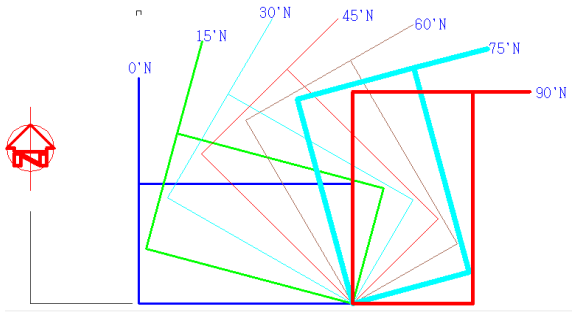


Figure 4.19 Orientation at 15^{o} interval from North (0^{o})-East (90^{o}).

Source: Researcher's Work (2014).

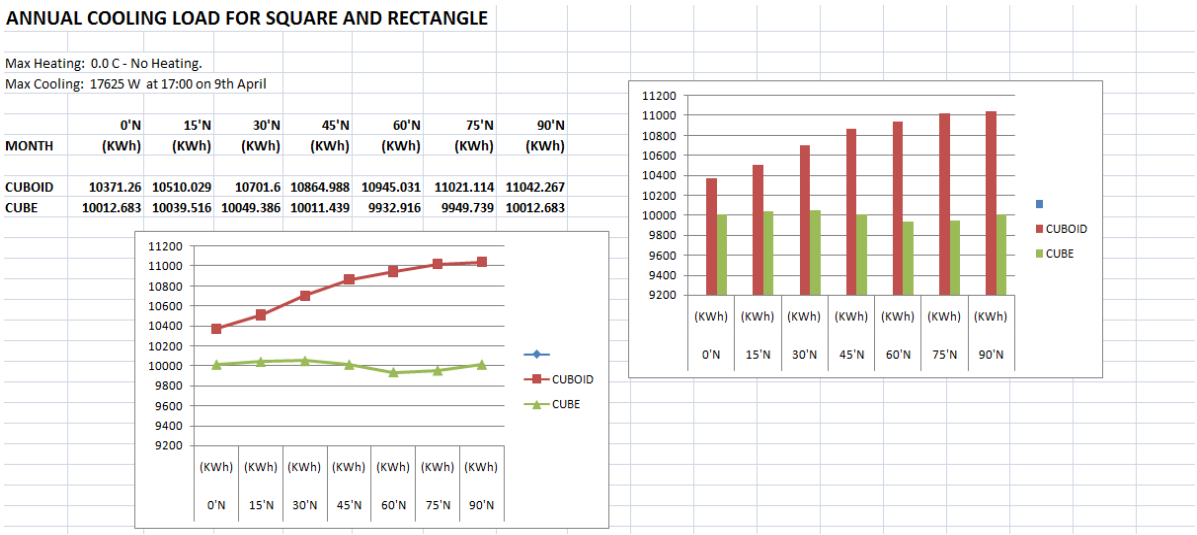


Figure 4.20 Total cooling loads at 15' Interval (KWh).

Source: Researcher's Work (2014).

Changing the orientations of the simulated shapes is seen to have the ability to change the energy for heating or cooling, as it affect the amount of solar radiation falling on the part of the building surface. The result in Figure 4.20 above shows that total cooling loads for cuboid increase by 4.7% from 0N-45N, 5.5% from 0N-60N and 6.5% from 0N to 90N (East-West orientation 0N to North-South orientation 90N). The effect of changing orientation for cube form is less noticeable having less than 1% increase from 15N to 45N and a decrease of 10% at 60N and 75N. This shows that at 60N the cube form is most efficient and least efficient at 30N respectively. Therefore, the best orientation for the cube form in lafia climate is 60N and 0N for rectangular form.

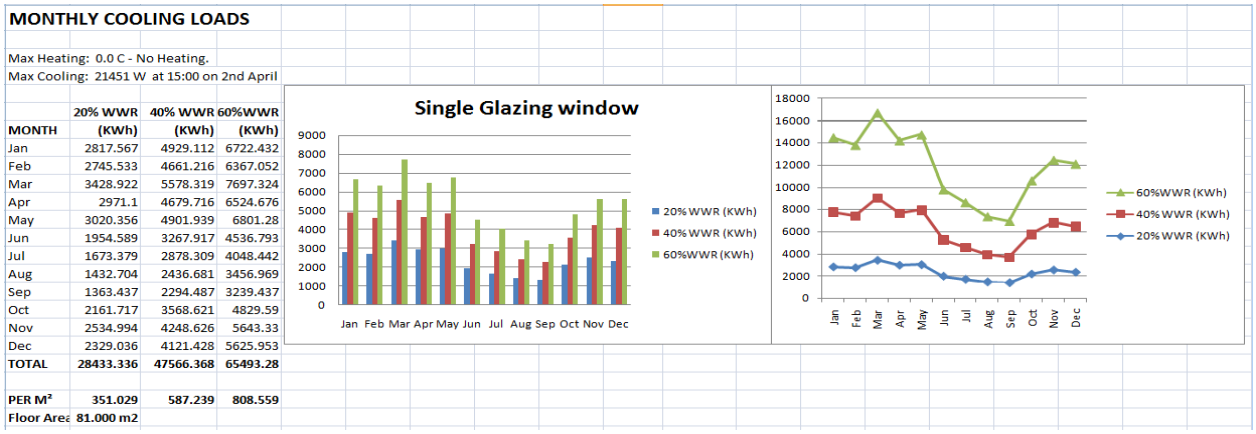
4.6.3 Effects of Glazing on Energy Consumption.

Glazing is considered as one of the weakest thermal component in the building envelope due to its high U-Value. Window selection and placement is a critical step in the design strategy for sustainability. Windows and doors have an enormous impact on heating, cooling, day lighting and security of the building. Window area or window to wall ratio

(WWR) is an important variable affecting energy performance in a building. Window area will have impacts in the heating, cooling and lighting, as well as relating it to the natural environment in terms of access to daylight, ventilation and views. Based on ASHRAE-IESNA, 2004; NRCC, 2007, the recommended fenestration should be limited to 40% of façade area. For thermal performance rating in this simulation, the baseline is limited to 40% window to wall ratio.

4.6.3.1 Effects of Variation of WWR on Energy Consumption.

Decrease or increase in WWR of a particular glazing type has a tendency of affecting the rate of heating or cooling loads of a given form. Reduction of WWR from the default 40% may reduce the cooling load at the expense of proper lightning and ventilation. While, increasing it will provide visual comfort as well as increase in cooling loads due to effects of direct solar radiation entering the building through the glazing member. From the Figure 4.21 below, reducing the WWR from 40%-20% will result to a decrease of 67% in total cooling loads for a cube form.



MONTH	20% WWR (KWh)	40% WWR (KWh)	60%WWR (KWh)
Jan	2817.567	4929.112	6722.432
Feb	2745.533	4661.216	6367.052
Mar	3428.922	5578.319	7697.324
Apr	2971.1	4679.716	6524.676
May	3020.356	4901.939	6801.28
Jun	1954.589	3267.917	4536.793
Jul	1673.379	2878.309	4048.442
Aug	1432.704	2436.681	3456.969
Sep	1363.437	2294.487	3239.437
Oct	2161.717	3568.621	4829.59
Nov	2534.994	4248.626	5643.33
Dec	2329.036	4121.428	5625.953
TOTAL	28433.336	47566.368	65493.28
PER M²	351.029	587.239	808.559
Floor Area	81.000 m2		

Figure 4.21 Monthly cooling loads at 20%, 40% & 60% by ECOTECT.
Source: Researcher's Work (2014).

While increasing the WWR from 40%-60% will amount to 37.6% increase in total cooling loads of the same form. Therefore, it will be preferable to increase the window for more lighting since the energy for the increase is ½ less compare to that of reducing it and providing artificial lighting.

For the annual total loads of both 20%, 40% and 60% WWR glazing, only 20% glazing have its monthly percentage energy consumption in May as 11% and December as 8%. But the entire window sizes are the same for January =10%, February=10%, March=12%, April=10%, May=10%, June=7%, July=6%, August=5%, September=5%, October=7%, November=9% and December=9% respectively. This is to show that for 20% glazing an increase of 1% is noticed in may and a decrease of 1% is seen in December.

4.6.3.2 Window Material types.

Based on the ASHRAE standard for glazing at 40%, using different energy efficient materials of larger WWR glazing and still achieve even lesser energy consumption on heating or cooling loads is visible. Use of window blinds also affects the rate of direct solar radiation entering the building thereby affecting the loads. Low Emissivity (Low-e) Glass; also known as low-e glazing has a special coating to make it an excellent way to let in light but reduce solar gain.

The following window glazing was analyzed and the results gotten are indicated below.

Double Glazed AlumFrame (U-Value= 2.700 W/m^2K); Loads 17543KWh,

Double Glazed Low_E AlumFrame(U-Value= 2.410 W/m^2K); Loads 8719KWh,

Single Glazed AlumFrame (U-Value= 6.000 W/m^2K); Loads 30512KWh,

Single Glazed AlumFrame Blinds (U-Value= 6.000 W/m^{2}K); Loads 14288KWh,

Single Glazed Low_E TimberFrame (U-Value= 2.26 W/m^{2}K); Loads 8694KWh.

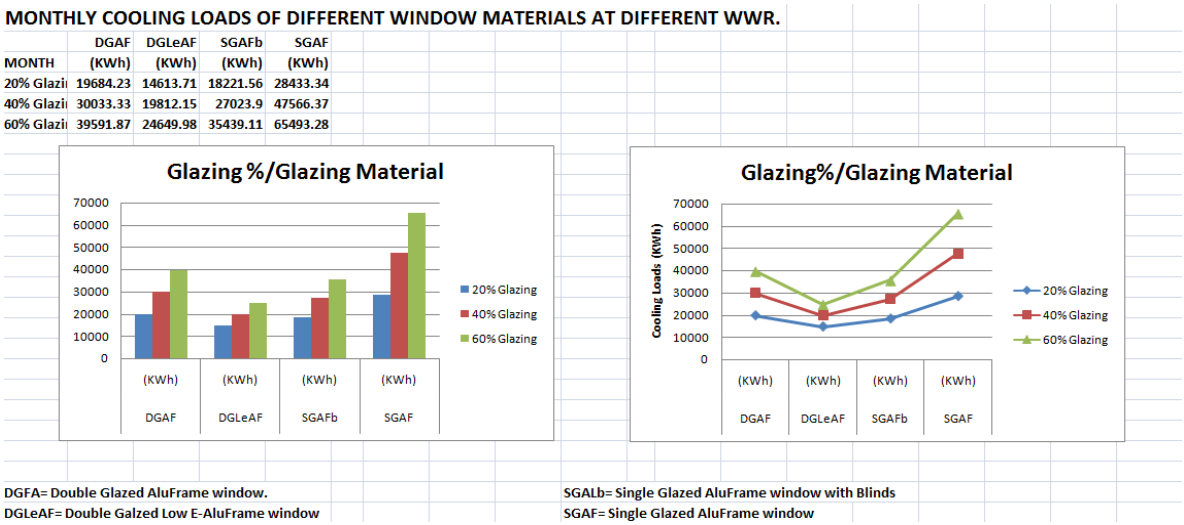


Figure 4.22 Variation of Window materials and sizes.

Source: Researcher's Work (2014).

Therefore, from Figure 4.22 the above, only Double Glazed Low_E AlumFrame and Single Glazed Low_E TimberFrame have low energy requirements. However the use of timber frame will not be good due to high humidity.

Table 4. 9 Percentage difference of glazing materials and WWR.

Glazing Material	20% WWR	40% WWR	60% WWR
SGAF-SGAFb	60%	76%	84%
SGAF-DGAF	44.47%	58%	65.4%
SGAF-DGLeAF	94.5%	104%	165.6%

Source: Researcher's Work (2014).

From Table 4.9 above, over 40% of total heating or cooling loads of a building can be affected by choice of glazing material for windows and other openings in the building.

From the Figure 4.22 and Table 4.9 above, using 60% DGLeAF will reduce the cooling load by 92% against the use of 40% SGAF. Also increasing the single glazing from 40% to 60% but adding blinds to the window will reduce the cooling loads by 34%. The same apply to 40% SGAF with 60% DGAF a reduction by 20% of cooling load will be noticed. Therefore, Double Glazed Low-e Aluminum Frame window is the best in this area due to its low energy load.

4.7 DISCUSSION OF SIMULATION FINDINGS

Thermal comfort in buildings can be achieved by critically examining the factors affecting the thermal performance of the building. The heating and cooling loads of a building can be adjusted in order to minimize energy consumption through considering design parameters such as building form, orientation, envelope composition, glazing size and local climate. The method adopted focuses on different building form which provides comfort with minimum energy consumption. Therefore in order to evaluate the effects of building form on thermal comfort, building form having the same floor area, volume and envelope thermophysical properties and lowest annual heating and cooling loads on energy consumption should be chosen. The result of this study is summarized below.

(i). Building having the same floor area, volume and envelope thermophysical properties, have different rate of energy consumption (heating and cooling loads) due to change in form. From the analysis carried out, the form that consumes the least amount of energy is the cylindrical form followed by the cone, then cube, cuboid and lastly pyramids. The cylindrical form is 5.6% less than the energy consumption for cone form, 9.7% for cube form, 12.9% for cuboid and 14.7% for pyramid. This shows that total cooling loads for simulated shapes increase by 14.7% from cylindrical to pyramidal form.

(ii). Building form oriented in different direction between 0^{o}-90^{o} have an important impact on the annual energy consumption. The result shows that total cooling loads for cuboid increase by 4.7% from 0N-45N, 5.5% from 0N-60N and 6.5% from 0N to 90N (East-West orientation 0N to North-South orientation 90N). The effect of changing orientation for cube form is less noticeable having less than 1% increase from 15N to 45N and a decrease of 10% at 60N and 75N. This shows that at 60N the cube form is most efficient and least efficient at 30N, while the cuboid form is best at 0^{o}N due to its small area exposed to solar radiation along the East-West.

(iii). The glazing is another important parameter that affects the comfort condition of a building. The size (window to wall ratio) and the thermophysical properties of the glazing is also an important factor to consider. Changing the WWR from 40%-20% will result to a decrease of 67% in total cooling loads for a cube form. While increasing the WWR from 40%-60% will amount to 37.6% increase in total cooling loads of the same form.

(iv). Over 40% of total heating or cooling loads of a building can be affected by choice of glazing material for windows and other openings in the building. Using 60% DGLeAF will reduce the cooling load by 92% against the use of 40% SGAF. Also increasing the single glazing from 40% to 60% but adding blinds to the window will reduce the cooling loads by 34%. The same apply to 40% SGAF with 60% DGAF a reduction by 20% of cooling load will be noticed.

CHAPTER FIVE

SITE

5.1 BACKGROUND INFORMATION OF STUDY AREA.

Nasarawa State is bounded in the north by Kaduna State, in the west by the Abuja Federal Capital Territory, in the south by Kogi and Benue States and in the east by Taraba and Plateau States as shown in Figure 5.1 below. The southern landscape of the state forms part of the low plains of the Benue origin. Most parts of the state that lies within the Benue valley composed of sandstones. The high land areas of the state are found towards the north, notably in Wamba, Nassarawa, Eggon and Akwanga Local government Areas. The Eggon rolling hills for example, raise to an average; height of about 1,200m. The Maloney Hill in Keffi is of historical significance.

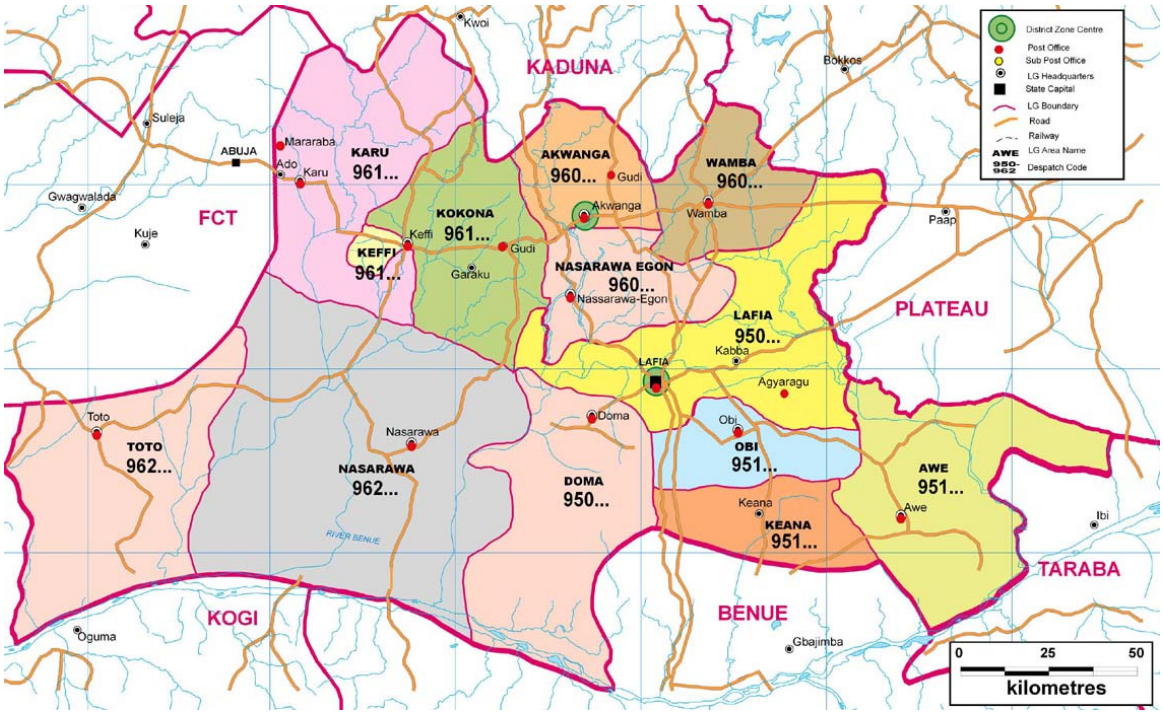


Figure 5.1 Nasarawa State Map

Source: www.maps-online.com

5.2 SITE LOCATION

The site is among the important feature in the design process. A detailed site analysis is done so as to understand the features of the site, which are very important during the design. The purpose of the site analysis is to record and evaluate information on the site and its surroundings, and to use this in the design. The site is located in Lafia the capital city of Nasarawa state central Nigeria as shown in Figure 5.2 below. It is found along coordinates 8.5333° N, 8.3000° E covering a land area of 10,470 sq miles (27,117 km²).

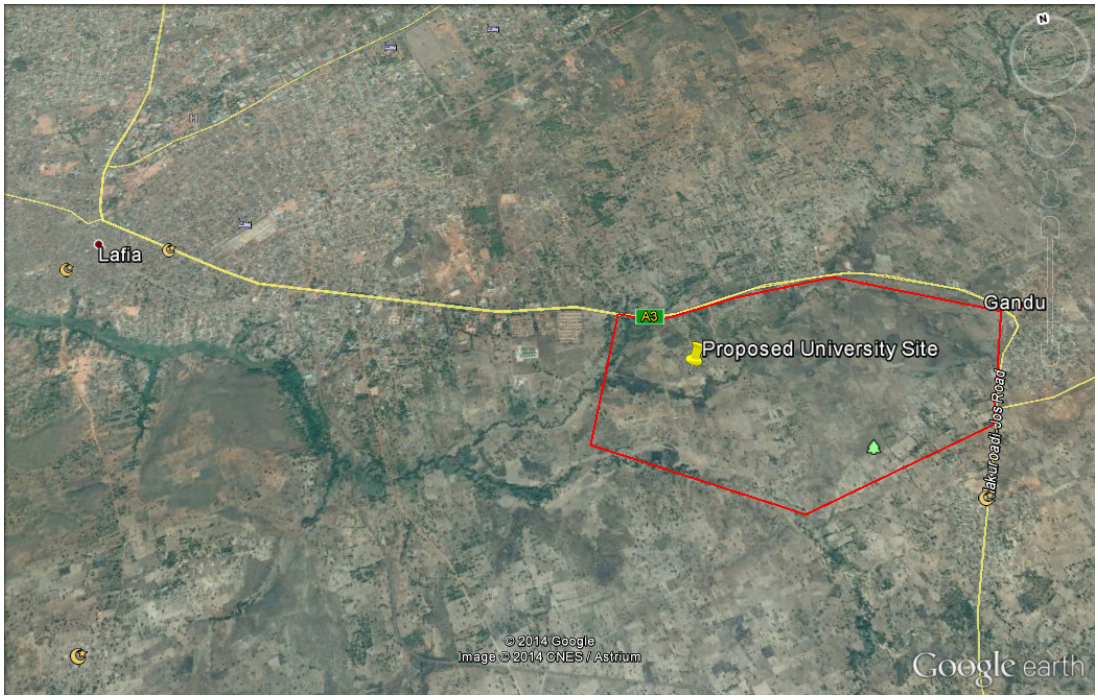


Figure 5.2 Google Earth Site Map

Source: Google earth. (2013).

It is within the proposed permanent site of the university along Benue-Makurdi express road. The site experiences high traffic as it is bounded by two roads along the north and the east side respectively. The main road which is a Major Highway linking the university and the outside express way is by the east while the secondary road is along

the northern side Figure 5.3 below. The main road cannot be used for access into the site so as not to constitute traffic congestion; hence a secondary road will be used to access the site.

Figure 5.3 University Site Map

Source: Planning Unit Federal University lafia.

5.3 SITE SELECTION CRITERIA

The Plate below indicates the plan of the core academic area of the University permanent site along Lafia-Makurdi road. The choice of site here is not really restricted but however, there is a provisional space for the core academic area in the University site plan. However, three sites have been selected within the core academic area as in Figure 5.4 below which is Site "A", "B" and "C" respectively.

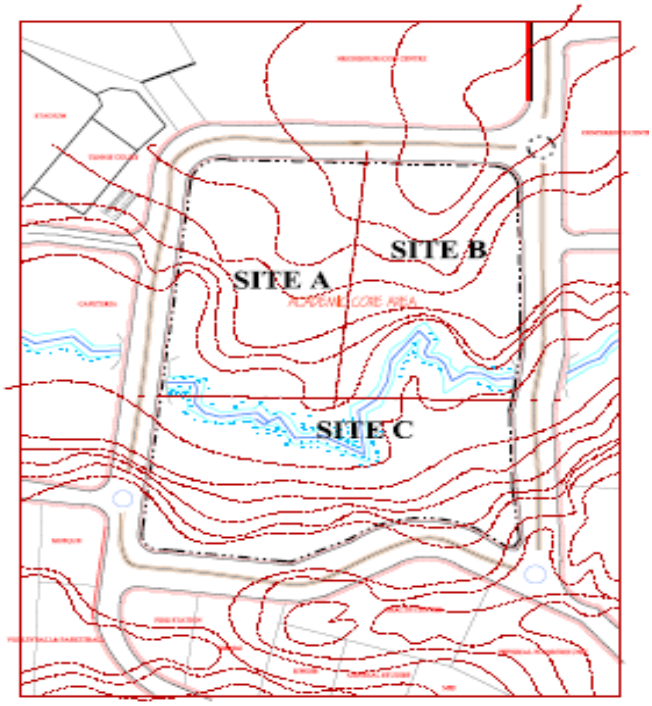


Figure 5.4 University Core Academic Area

Source: Planning Unit Federal University Lafia

The following under listed criteria are used to weigh the suitability of each of the site and thus the most appropriate site is selected. They are:

a) Proximity to community and services

b) Proximity to educational areas

c) Proximity to residential areas

d) Proximity to recreational facilities

e) Proximity to road networks (accessibility)

f) Possibility for expansion

g) Land use compliance

Table 5.1 Site Selection Criteria

s/n	CRITERIA	SITE A	SITE B	SITE C	REMARKS
1	Proximity to community and services	3	5	2	All the three sites are c lose to basic community facilities
2	Proximity to educational areas	3	4	4	Site B and C are close to educational area compare to site A
3	Proximity to residential areas	3	5	5	Site “A” is away from residential areas as compared to site “B” & site “C”
4	Proximity to recreational facilities	5	4	3	Site “A” is closer to recreational areas which s not really good
5	Proximity to road networks (accessibility)	4	5	4	All the site are by access roads but site “A” is bounded to the main high way
6	Possibility for expansion	4	4	2	Site A and B can easily be expanded than site C.
7	Land use compliance	4	5	3	Site B is best suited in compliance to university administrative building

					location
	TOTAL	29	32	23	Site B is best suited for the proposed building
Range: BEST=5, BETTER=4, GOOD=3, FAIR=2, POOR=1					

Source: Researcher's Work (2014).

Hence, from table 5.1, the site selected for the proposed Senate Building is SITE „B" located in top left corner of the core academic area. The whole core academic area will contain other supporting facilities like the matriculation/convocation square, assembly hall, central library, digital information centre as well as green area.

5.4 SITE CLIMATE ANALYSIS

Climate is one of the major environmental factors affecting thermal comfort. It is very difficult to predict the exact weather of a place, due to variation in geographical location and micro-environment. At the preliminary stage of design, it is important to study the micro-climate of the place in order to know how they will affect the building and the occupants. This will determine the building form, spatial organization, orientation and openings. The climatic factors to be considered include: rainfall, temperature, humidity, wind and solar radiation.

5.4.1 RAINFALL

Annual rainfall figures range from 1100 mm to about 2000mm. About ninety per cent of the rain falls between May and September, the wettest months being July and August as shown in Figure 5.5.

Most precipitation falls in August, with an average of 176 mm. The rain comes in thunder Storms of high intensity is noticed, particularly at the beginning and towards the end of

the rainy season. In winter there is much more rainfall in Lafia than in summer. The average annual rainfall is 456 mm. The driest month is December with 0 mm. The difference in precipitation between the driest month and the wettest month is 176 mm.

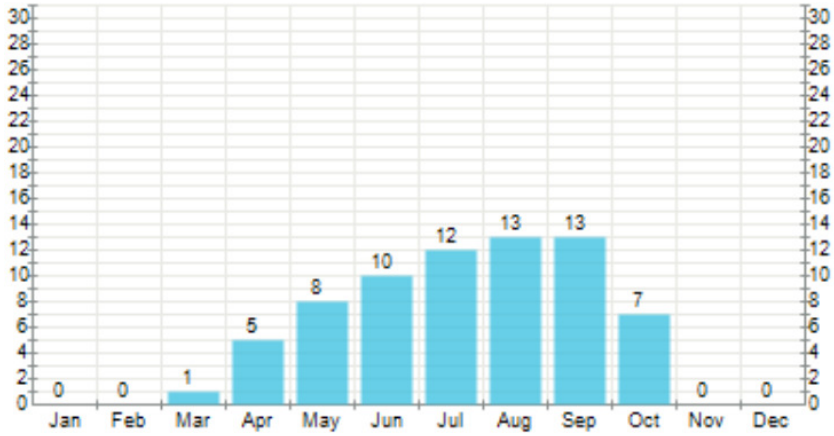


Figure 5.5 Mean Precipitation Chart.

Source: www.myweather2.com

5.4.2 TEMPERATURE

Temperatures are generally high during the day, particularly between the months of March and April. Figure 5.6 shows the mean monthly temperatures in the state, which ranges between 20°C and 34°C, with the hottest months being March/April and the coolest months being December/January.

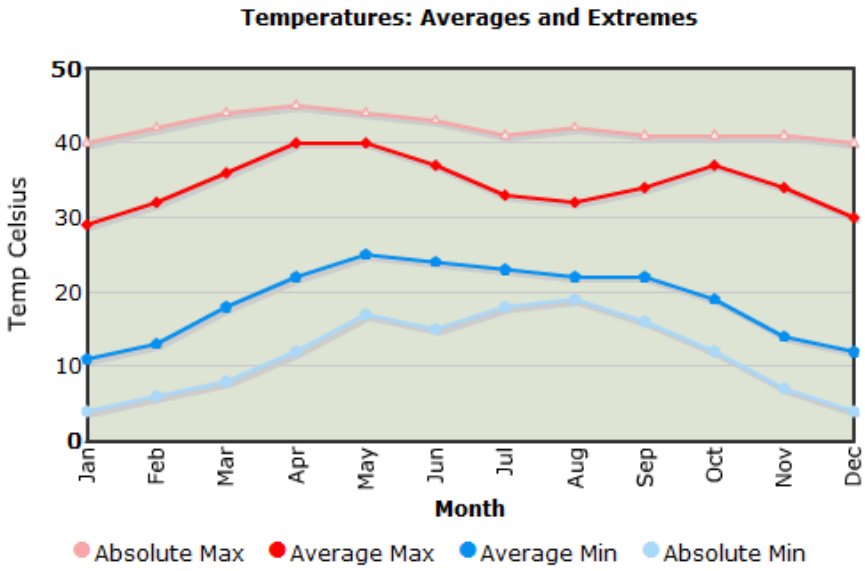


Figure 5.6 Mean Temperature Chart

Source: www.myweather2.com

The average annual temperature in Lafia is 26.8 °C. The warmest month of the year is May with an average temperature of 31.5 °C. In January, the average temperature is 21.6 °C. It is the lowest average temperature of the whole year. The average temperatures vary during the year by 9.9 °C.

5.4.3 HUMIDITY

The humidity in the state is very high in the state. High level of humidity is usually attained during the raining season. Humidity values generally drops during the dry season from November-March.

5.4.4 WIND

Two major air masses dominate the state: the Tropical Maritime Air mass and the Tropical Continental Air mass. The tropical maritime is formed over the Atlantic ocean from the southern part of the country and is therefore moist and worm. The maximum

recorded wind speed in a year is in the month of August and December, with the lowest in November as in Figure 5.7 below. This is responsible for the South-West Trade wind, blowing from the south-west to the north-east. The tropical continental is developed over the Sahara desert; it is usually hot and dry and is responsible for the North-East Trade wind, blowing from the north-east to the south-west. The tropical continental airmass comes with the dry season, while the tropical maritime airmass, the wet season.

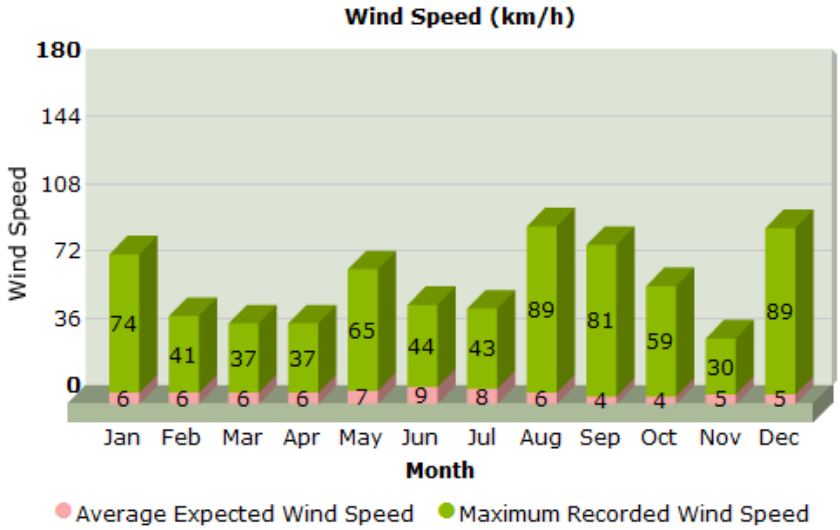


Figure 5.7 Mean Wind Speed Chart.

Source: www.myweather2.com

5.4.5 SOLAR RADIATION

High intensity of solar radiation is usually experienced during the dry season where there is a clear sky cover, and is usually low in the raining season, due to cloud cover.

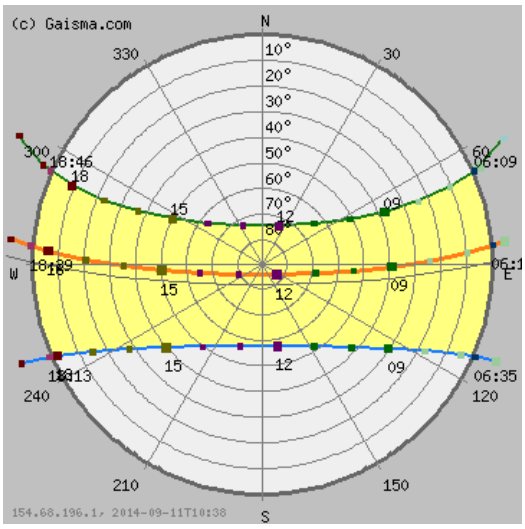


Figure 5.8 Sun Path Diagram

Source: www.myweather2.com

Sun rises from the east between 06:09am and 06:35am and sets in the west between 18:13pm and 18:46pm respectively. Peak period of solar intensity is between 09am-03pm as in Figure 5.8 above.

The site experiences the normal sun-rise and sun-set. At mid-day, the sun overhead can be taking advantage of by converting it to other form of energy (solar). The site climatic condition is characterized by high temperature and humidity caused by incident solar radiation, high rainfall and low wind velocity.

5.5 SOIL TYPE AND VEGETATION

The major soil is derived mainly from the basement complex and old sedimentary rocks. Lateritic crust occurs in extensive areas on the plains, while hydromorphic soils (humic inceptisols) occur along the flood plains of major rivers. Loamy soils of volcanic origin are found around the volcanic cones of Awe. The hilly areas carry shallow skeletal soils.

Many parts of the state are ravaged by both sheet and gully erosion. The major urban centers, particularly Lafia and Keffi, are heavily gulled. Since most of the inhabitants of the state are farmers, extensive areas in the countryside are also cleared for farming, thus exposing wide areas of land to sheet erosion as shown in Plate XXII below.



Plate XXII Site Soil condition

Source: Researcher, 2014

Nassarawa State falls within the southern guinea savanna zone. However, clearance of vegetation for farming, fuel wood extraction for domestic and cottage industrial uses and saw milling has led to the development of regrowth vegetation at various levels of development. Dense forests are few and far apart. Such forests are found in lowland areas, particularly where population pressure is less on the land. Gallery forests are common along major streams and pronounced depressions. The site is composed mainly

of grasses and isolated trees as shown in Plate XXIII below. Trees of economic value, including locust bean, shea butter, mango, citrus and banana are scattered across the site, particularly the lowland areas and southern parts of the site.



Plate XXIII Site Features

Source: Researcher's Work (2014).

The site is relatively flat with a slope of about 5% sloping towards the south part of the site which has a seasonal stream. The drainage systems shall follow site gradient and channeled into the central drain system to dispose organic waste.

CHAPTER SIX

DESIGN REPORT

6.1 PRELIMINARY PROPOSAL

One of the objectives of this research is to incorporate the research findings of thermal comfort analysis in the design of the proposed Senate Building of Federal University in Lafia Nassarawa, Nigeria. The design is such that the users enjoy all the facilities without compromising the need for thermal comfort. Man is affected by factors such as lighting, heat (temperature), ventilation, sound etc. Therefore there is need to consider the steps that should be taken to improve the individual effect of those things that impairs the efficiency of work output/production in the senate building.

In order to fulfill the requirements of the design, the principles of thermal comfort are being employed. This is so because of the ability of the principle to provide solid strategies in terms of material of building envelop (form), thermal mass, shading devices, glazing type and size, vegetation and orientation which enhance the thermal performance of the building.

6.2 BRIEF FORMULATION

As a result of new developments in technology, a comprehensive planning for today's working environment is important in identifying and fulfilling user's needs in all areas so

as to improve efficiency and productivity. Considering the geometric progression associated with change in the university administration, custom designed office spaces shall be discouraged to accommodate the university's administrative variation. The multi-tenancy method, which allows for greater flexibility in the use of an office building, should be adopted. The (Senate) office building must have flexible and technologically-advanced working environments that are safe, healthy, comfortable, durable, aesthetically-pleasing, and accessible. It must be able to accommodate the specific space and equipment needs of the tenant. Special attention should be made to the selection of interior finishes and art installations, particularly in entry spaces, conference rooms and other areas with public access.

Based on the brief as stated above and after careful consideration of the requirements necessary for the design of a Senate Building, the spatial arrangement is broken down to into the following type of spaces: offices, employee/visitors support spaces, administrative support spaces and operation and maintenance spaces.

a. Offices

i. Offices: May be private or semi-private.

ii. Conference Rooms/ Meeting rooms

b. Employee/Visitor Support Spaces

i. Convenience Store, Kiosk, or Vending Machines

ii. Lobby: Central location for building directory, schedules, and general information

iii. Atria or Common Space: Informal and social gathering space

iv. Cafeteria or Dining Hall

v. Toilets or Restrooms

vi. Interior or Surface Parking Areas

c. Administrative Support Spaces

i. Administrative Offices: May be private or semi-private acoustically and/or visually.

d. Operation and Maintenance Spaces

i. General Storage: For items such as stationery, equipment, and instructional materials.

ii. Food Preparation Area or Kitchen

iii. Computer/Information Technology (IT) Closets.

iv Maintenance Closets

6.3 BRIEF DEVELOPMANT

Office design can be either purpose made to accomplish some user requirements or an open form to attract more tenants and make it possible a user to partition the space according to his office requirements. Due to the nature of work performed by each component, the senate building has been divided into seven components as seen in Figure 6.1. This is to ease the administrative work. The components are: Vice –chancellor's office, Planning unit, Registry, Bursary, Student's affair, General administration and Senate / council chamber.

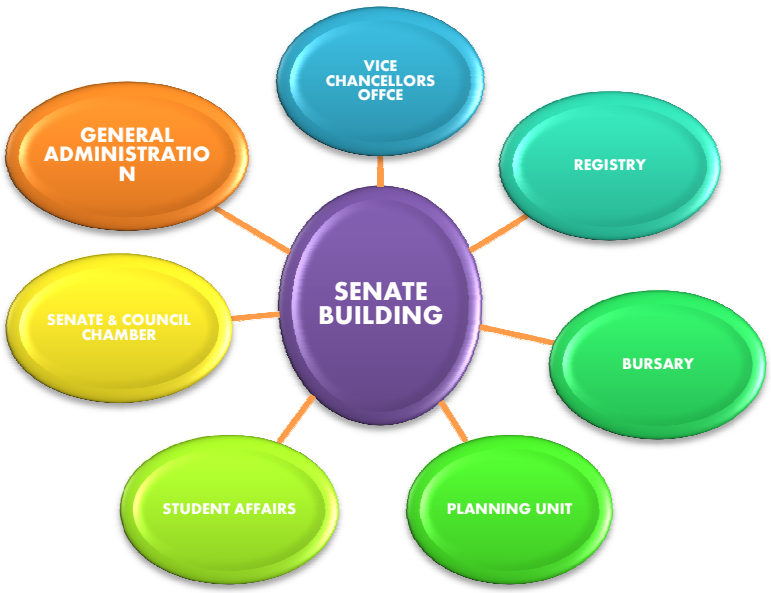


Figure: 6.1. University Administrative Component relationship.

Source: Researcher's Work (2014).

6.3.1 SPACE REQUIREMENTS

For the purpose of this design, more emphasis will be given to office spaces. And the following offices are based on hierarchy of administration. Due to the nature of work performed by each component, the senate building has been divided into seven components. This is to ease the administrative work. The components are:

i. Vice –chancellor's office

ii. Planning unit

iii. Registry

iv. Bursary

v. Student's affair

vi. General administration

vii. Senate / council chamber

6.4 SCHEDULE OF ACCOMODATION

Because of the type of spaces requirements needed in the Senate building, the following spaces and their floor areas given in this schedule is based on findings from case study conducted and literature. The spaces are based on space required from the brief above. Table 6.1: shows the schedule of accommodation for all the spaces provided.

Table 6.1: Schedule of Accommodation

Description	**Area(M^2) Min.**	**Number required**	**Total area(M^2)**
Vice – chancellor's office			
Office of the vice chancellor	37.0	1	37.0
Bathroom/ wc	10.0	1	10.0
personnel assistant and secretary	28.0	1	28.0
Waiting / reception	10.0	1	10.0
Conference room	20.0	1	20.0
Deputy vice chancellor's office	18.5	2	37.0
Two secretaries/ waiting room	18.5	1	18.5
Filing and storage room	8.0	1	8.0
General office	13.5	1	13.5
Adjacent storage room	8.0	1	8.0
Planning unit			
Director of planning's office	18.5	1	18.5
Secretary/ waiting	13.5	1	13.5
Conference room	40.0	1	40.0
Secretary/ filing	7.0	1	7.0
Office of Academic planning officer	13.5	1	13.5
Secretary/ filing	7.0	1	7.0
Office of physical planning officer	13.5	1	13.5
Secretary/ filing	7.0	1	7.0
Registry unit			
Office of academic registrar	30	1	30.0
Secretary/waiting	13.5	1	13.5
Principal assistant registrar	18.5	1	18.5
Record and admissions section			
Admission officer	18.5	1	18.5
Secretary	10.0	1	10.0
Assistant admission officer	13.5	1	13.5
Secretary	7.0	1	7.0

Students record officer	18.5	1	18.5
Secretary	10.0	1	10.0
Assistant student record officer	13.5	1	13.5
Secretary	7.0	1	7.0
Supporting staff	13.5	1	13.5
General office	30	1	30
Admission processing area	40	1	40
Record storage	35	1	35
Record handling office	50	1	50
Student affairs			
Office of dean of students affairs with conference	30	1	30
Secretary	13.5	1	13.5
Office of senior staff	13.5	4	54.0
General office	50.0	1	50.0
Lobby/waiting	13.5	1	13.5

General administration			
Director of administration's office with conference	30	1	30
Secretary	13.5	1	13.5
Office of senior administrative staff	13.5	4	54.0
Secretaries	13.5	4	54.0
General office	40.0	1	40.0
Clerk's room	13.5	1	13.5
General storage and office materials	15.0	1	15.0
Examinations section			
Examination officer	18.5	1	18.5
Secretary	10.0	1	10.0
Assistant examination officer	13.5	1	13.5
Secretary	10.0	1	10.0
Supporting staff	13.5	1	13.5
General office	35.0	1	35.0
Appointment and promotion records	30.0	1	30.0
Bursary unit			
Office of bursar with conference	30.0	1	30.0
Secretary / waiting	13.5	1	13.5
Office of deputy bursar	18.5	1	18.5
Secretary	13.5	1	13.5
Accounting staff offices	13.5	4	54.0

Secretaries	13.5	2	27.0
Custom and passage staff	13.5	3	40.5
General office	30.0	1	30.0
Office of internal auditor	18.5	1	18.5
Secretary / waiting	13.5	1	13.5
Supporting staff for accounting	13.5	5	67.5
for audit & expenditure control	13.5	5	67.5
General account office	50.0	1	50.0
Strong room	18.5	1	18.5
Senate and council chamber			
Senate chamber to sit 150 members	300	1	300
Ante – chamber with cloak rooms	100	1	100
Council chamber to sit 30 members and staff	66	1	66
Conference room to sit 20 members	40	2	80
Senate lounge	30	1	30
Preparation of senate/ council materials	30	1	30
Office of clerk to senate	13.5	1	13.5
Secretary / filing/ waiting	13.5	1	13.5
Office of clerk to council	13.5	1	13.5
Secretary /filing /waiting	13.5	1	13.5
General office	35.0	1	35.0

6.5 DESIGN CONCEPT

Architectural concept s a series of intentions or solutions originated in the mind to solve a particular architectural problem while considering other design factors. The concept used for the design comes from the philosophy that a building should express it identity and still be iconic amidst other surrounding buildings. The building form is conceptualized from the functional identity of the building and simulated results of building forms.

Functional identity- Inspirations are drawn from the academic mortar hat and academic scroll as shown in Figure 6.2. Bing an academic environment, the senate building serves as the centre of academic and administrative authority.

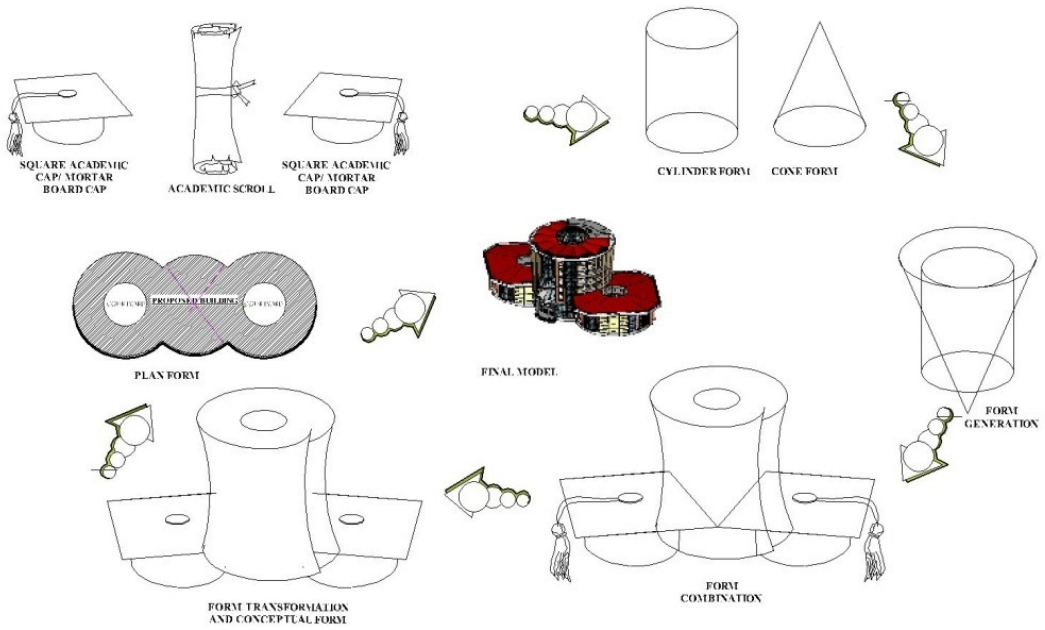


Figure: 6.2. Concept Development.

Source: Researcher's Work (2014).

The two mortar cap representing the undergraduate and postgraduate programme serves as the podium, while the academic scroll (certificate) serves as the tower.

Simulated results- From the simulation conducted of five forms (Cube, Cuboid, Pyramid, Cone and cylinder), the cylinder and the cone performs better than the others n terms of thermal comfort. Therefore, this initiates the use of the circular plan and form in the design. Some of the advantages of these forms are the high reflective angle of solar radiation and less angle of incident solar radiation. Also ease of air circulation and ventilation efficiency as well as good noise control.

6.6 DESIGN CONSIDERATION

The senate building was design primarily to tackle the challenges of design by solving the planning demand of space and circulation as well as utilizing the thermal comfort design

strategies to reduce energy consumption and the building and also to improve the indoor environmental qualities for the general comfort of the building and its occupants.

6.6.1 Form- The form of the building affects the thermal performance as it determines the size and the orientation of the exterior envelope that is exposed to the outdoor environment. The cylindrical form adopted play a large role in determining the amount of solar radiation received by the building's surface and improve the airflow/wind speed around the building for ventilation purpose as seen in Figure 5.9. The use of open elongated form with courtyards is to maximize ventilation and minimize solar radiation, where the main importance is cooling.

6.6.2 Orientation- Orientation has a significant influence on the cooling load. Since comfort is acquired mainly by air movement, the building is oriented at 60^{o}N according to results findings as seen in Figure 5.4. The building is oriented with the longer sides of it to intercept prevailing winds NE and the shorter sides to face the direction of the strongest solar radiation WE, effective ventilation is achieved, while thermal impact from solar radiation is minimized.

6.6.3 Glazing and Fenestration- The glazed system is an important strategy in passive solar design as it can cause the large portion of building's heat gain. The use of Double Glazed Low-e Aluminum windows are employed in order to reduce the intensity of solar radiation entering the building as in Figure 6.12 and 13 below. The Low-e glazing reduces cooling loads by over 40% annually. Also the use of openings and fenestrations along the east and west, stair case hall ways helps improving air circulation within the building Figure 6.12.

6.6.4 Shading- The main principle in shading strategy is to avoid the penetration of direct solar radiation into the building through its opening and heat absorbing materials. Solar shading devices such as trees, overhangs, awnings and blinds which are lightweight, ventilated shading panels attached to walls and roofs are employed in order to avoid unwanted solar radiation in summer and allowing it in winter as seen in Figure 6.9. However, the use of external shading devices are considered the most effective, since they intercept solar radiation before it passes through the building envelope into the interior space as seen in Figure 6.12.

6.6.5 Ventilation and Lighting – The whole building is designed to rotate around a central core, this gives room for optimal utilization of natural lighting and ventilation. Stack and cross ventilation methods are used in the ventilation of the building core as seen in Figure 6.10. This ventilation technique has been found to be effective in this type of structure. Thus artificial ventilation and lighting requirements is minimal.

6.6.6 Landscaping- Emphasis is placed on ample provision of well landscaped environment to aid relaxation and complement activities of the building. Trees canopy, shaded driveways, hedges are put in place to enhance the micro climate within and around the building as shown in Figure 6.4. The planning of the landscape is done following the principles that will create an aesthetic and comfortable environment. Stone paving and interlocking tiles are used on walkways in order to reduce hard landscape. Open courtyards were introduced were introduced in the interior to avoid creating a drastic difference between the interior space and the exterior interior.

6.6.7 Services: These include; water supply, power supply, fire fighting system, waste water disposal, storm water /site drainage and refuse disposal.

(a) Water Supply- The primary source of water supply to the building will be the university water works department. Alternative water supply will be from borehole sunk close to the seasonal stream towards the southern side of the site. Surface as well as overhead water tanks will be provided for adequate water supply in the building.

(b) Power Supply- Power supply shall be tapped from the university power supply grid which is from the Power Holding Company of Nigeria (PHCN). However, the design shall also cater for its own power needs. There are provisions for Energy Glass façade with build in Sun Power technology for power generation.

(c) Fire Fighting System/safety - Fire hydrant for easy collection of water by fire fighters, fire extinguishers, sprinklers and smoke dictators shall be provided in the building according to professional specifications. Fire escape staircase is provided with access to all floors, opened to outside is made available, with fire resistant doors are also provided. Also static storage water tank of 10000ltr min shall be provided to be used as immediate response in fighting fire.

(d) Waste Water Disposal- Waste water and soil from closets will be drained through the central sewer line to the sewage treatment plant for onward disposal into the university central sewage plant. This plumbing will be done considering the slope of the site in order to take advantage of gravity.

(e) Storm Water and Site Drainage- Storm water from the roof can be collected and channeled to an underground tank for further use. While, surface water will be drained using gutters along site slope. Courtyards will be drained using underground piping along site slope also for ease of flow. This can be achieved simply due to the slope of the site towards the south into the seasonal river.

(f) Refuse Disposal- Waste bins will be provided in every usable/occupied workspace and along circulation routs. Small incinerator or waste treatment plant will be provided at a remote part of the site to cope with all refuse generated on site.

6.6.8 Heating, Ventilation and Air Conditioning using Chill Beam- HVAC systems have a significant effect on the health, comfort, and productivity of occupants. Issues like user discomfort, improper ventilation, and poor indoor air quality are linked to HVAC system design and operation and can be improved by better mechanical and ventilation system design.

Chilled beams are predominantly used for cooling and ventilating spaces, where a good indoor environment and individual space control is valued Figure 6.3 below. Chilled beams use water to remove heat from a room and are located in the room space. Chilled beams are primarily used in locations where the humidity can be controlled. Chilled beams provide excellent thermal comfort, energy conservation and efficient use of space due to high heat capacity of water used as heat transfer medium. Chilled beam operation is simple and trouble free due to having minimum maintenance requirements.

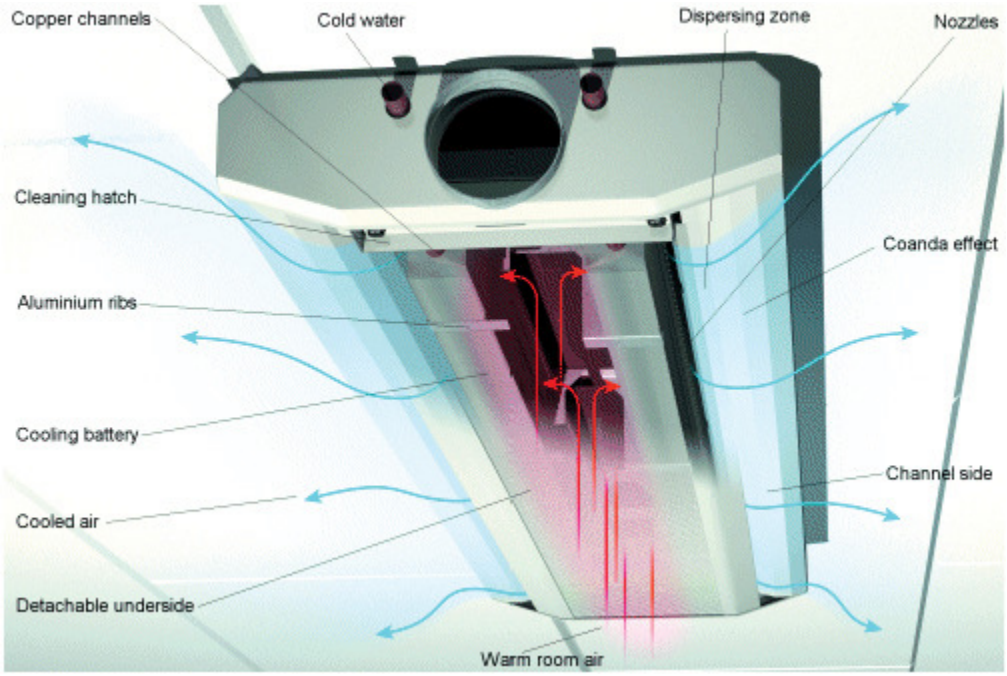


Figure 6.3 Schematic Diagram of Chilled Beam

Source: CPWD (2013).

6.7 DESIGN DISCUSSION

6.7.1. Site Plan

The access to the university site is through the Lafia-Makurdi express way. The site will be access via the minor road linking other functions through the northern part of the site via a secondary road within the university off the man way as in Figure 6.4. This has been analyzed to be the strongest part from which the senate building can be visually appreciated. There are four (4) main defined parking areas designed to take care of the senate building they are;

i. The public/visitors parking area located towards the North-West.

ii. The staff parking area located towards the East and West.

iii. The vice chancellor/executive parking area located at the rear of the building.

iv. The service parking area located at the South-West of the building.

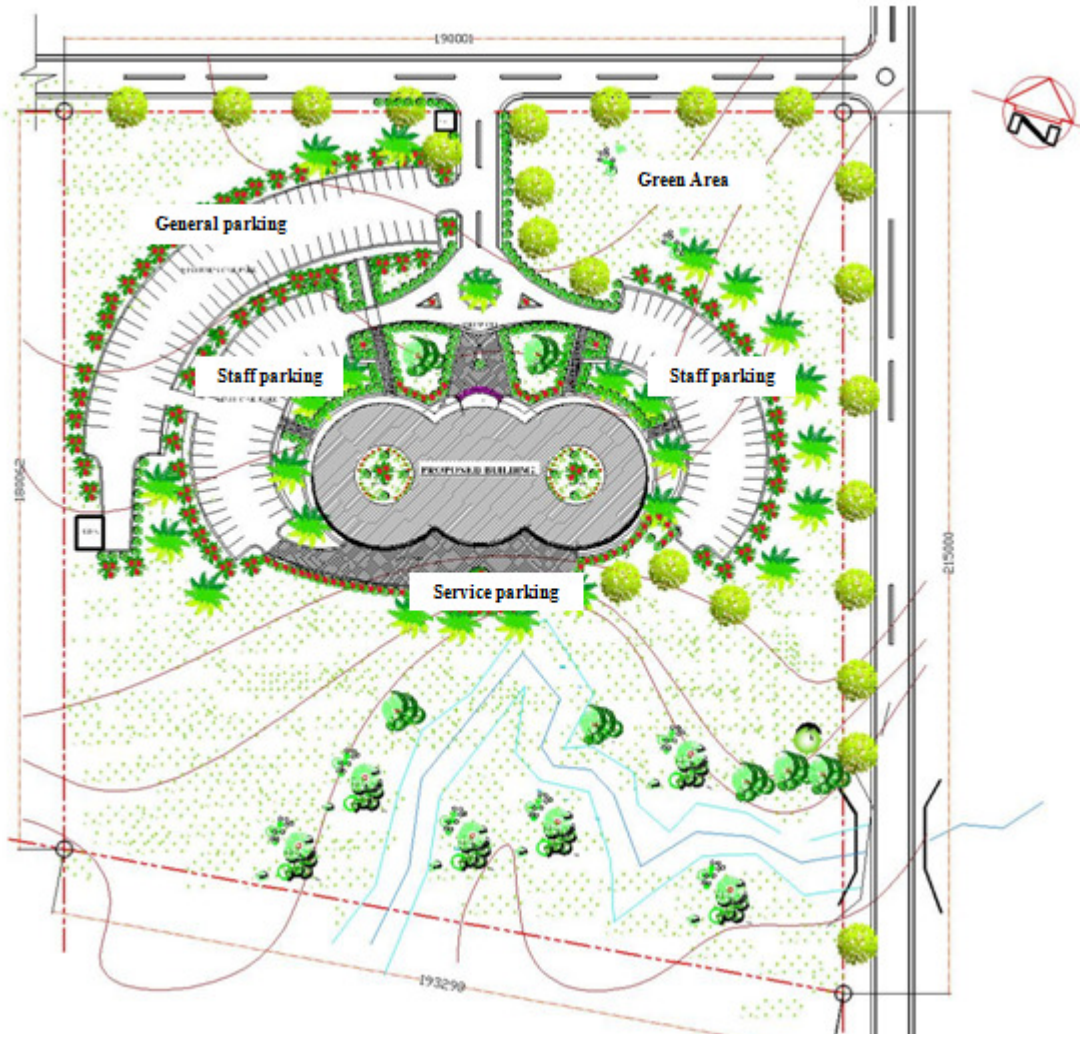


Figure 6.4 Site plan indicating the various parking's

Source: Researcher's Work (2014).

The parking area is paved with purposed made interlocking tiles to minimize solar radiation and allow soaking of surface water. The parking areas are also landscaped with ever green trees to provide shade to vehicles and pedestrian walkways leading to the building.

6.7.2. Floor Plans

The building is composed of three circular shapes arranger along the west-east axis. Having two open courtyards on opposite sides and an atrium in the middle, has its main

entrance facing the north. The main entrance is referred to as the general entrance, while two other entrances along the Far East and West sides serve for both fire escape and ventilation points. The executive entrance is at the rear with a security point. The design explore the use of non structural fins to ensure excessive solar obstruction and serves as excessive wind breaker, helps to maintain interior and resultant thermal conductive environment. There are two additional open and wide centrally located courtyards to enhance the overall building ventilation as in Figure 6.5 below.

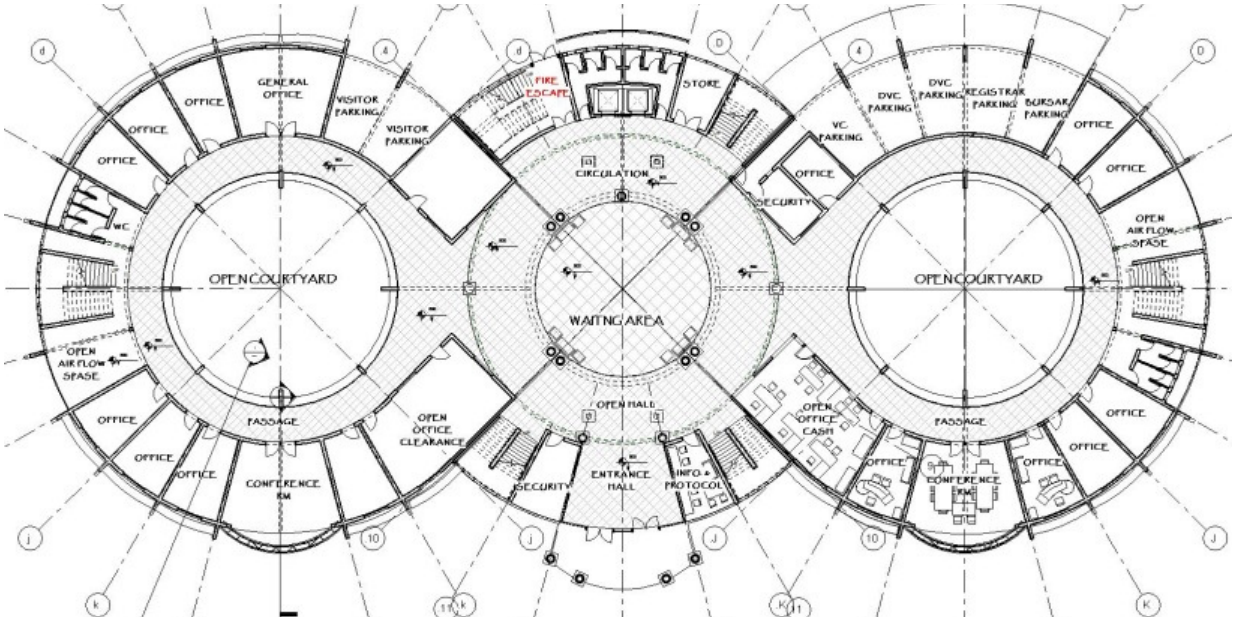


Figure 6.5 Ground floor Plan of the proposed senate building.

Source: Researcher's Work (2014).

The Ground floor Figure 6.5 above, consist of the non essential administrative spaces such as security, reception, accounts, sports, general, alumni, public relations offices and development units etc well linked to each other through the use of lobby, corridors/passages around and within the courtyards. It also serves as the podium, on which the tower stands.

The first and second floor contains other supporting offices to the seven core administrative offices such as staff welfare offices as seen in Appendix 10, exam office, student affairs units, general offices and some allotted offices. All this placement of offices is to ease accessibility to students, visitors and staff.

The third and fourth floor consists of offices for top administrative staff and their units/divisions supporting the five principal offices. Units such as accounting, planning, establishment, staffing, housing and passages, admissions, staff and student records units etc are located at this level refer to Appendix 11. At this level privacy has been observed to curtail movement of users from the ground level.

The fifth floor Figure 6.6 below contains the senate chamber, committee rooms, general offices, senate clerk office, computer preparation room, refreshments office etc. At this level, high privacy and security is maintained on the floor.

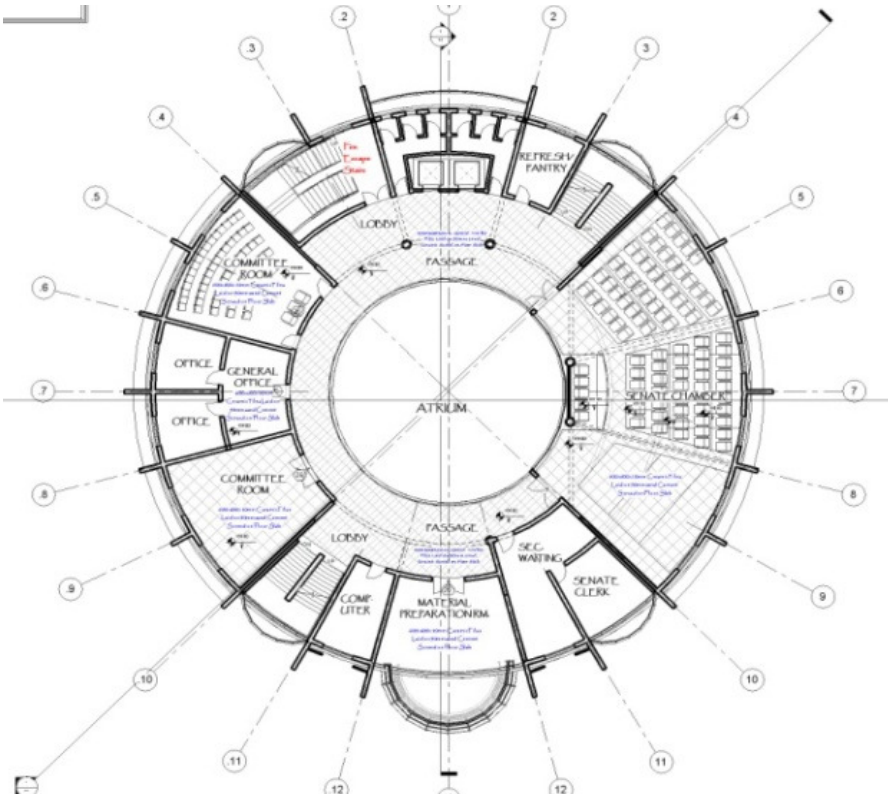


Figure 6.6 Fifth floor Plan of the proposed senate building

Source: Researcher's Work (2014).

The sixth floor contains the executive offices like the registrar, bursar, academic secretary, dean with their deputies and secretaries, director of planning, Liberian and other supporting offices as seen in Appendix 13.

The seventh floor as seen in Figure 6.7 below is the last floor where the vice-chancellors office is located, personal assistant to the vice-chancellor and the secretary, the deputies (academic and admin) with their secretaries, council chamber, and lounge. All the floors on the tower are accessible vertically through the staircase and lifts system, and horizontally by passages and lobby. Fire escape staircase is connected from the ground floor through to the seventh floor with access at all floors. The mechanical service is located at the extreme end for ease of maintenance.

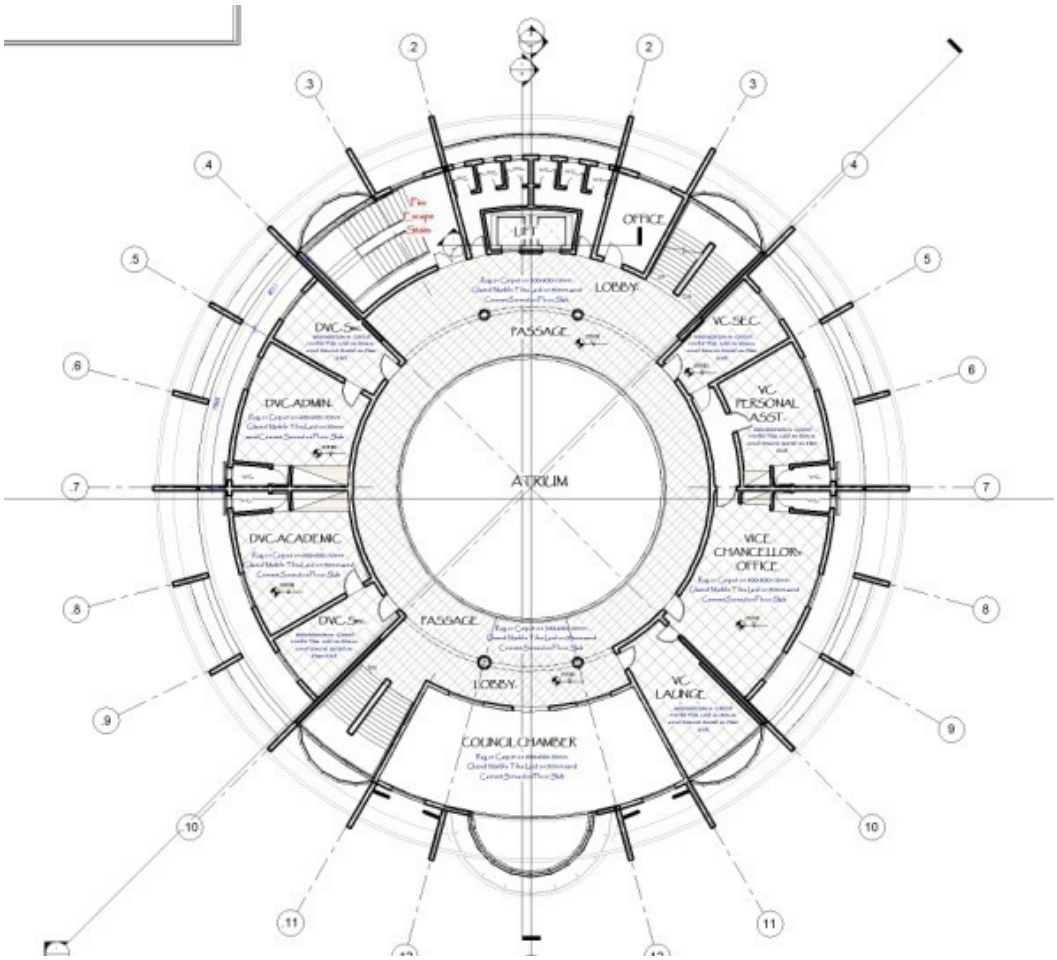


Figure 6.7 Seventh floor Plan of the proposed senate building

Source: Researcher's Work (2014).

The eighth floor Figure 6.8 below is the roof floor contains the machine room for the lift an HVAC central supply system. The roofing comprises of concrete, aluminum barrel vault roofing and transparent dome. Parapet and water drainage systems are properly considered in order to avoid leakage and deterioration of the floor slabs.

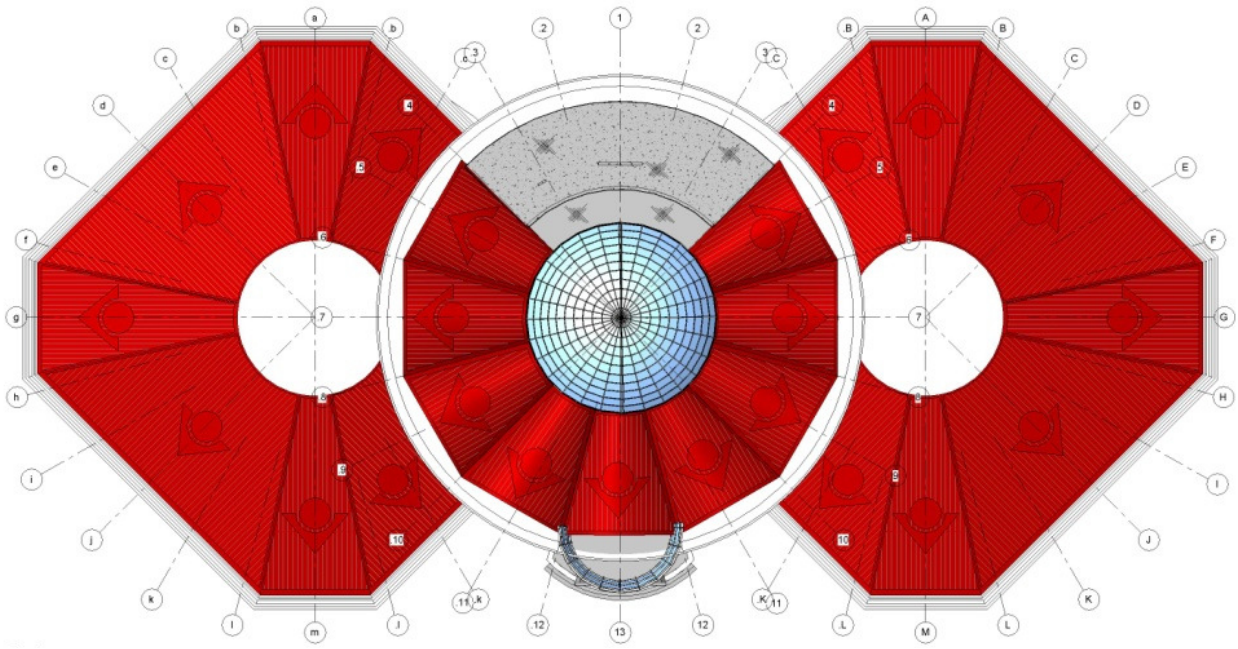


Figure 6.8 Roof floor Plan of the proposed senate building

Source: Researcher's Work (2014).

6.8 TECHNICAL DETAILS

These are details of some features used in the building in order to achieve maximum comfort. These are details of shading, ventilation, glazing and building components materials.

6.8.1 Shading- The design takes into consideration the use of both vertical and horizontal shading device, independent fins, recesses and projections to control and reduce the amount of direct solar radiation entering the building as in Figure 6.9 below. It s also used to break direct effect of wind energy by redirecting as well as reducing same into the building.

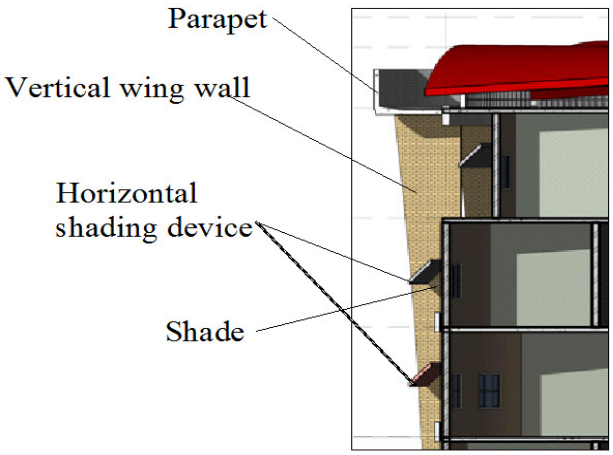


Figure 6.9 Sectional Details of Vertical and Horizontal Shading

Source: Researcher's Work (2014).

6.8.2 Ventilation- The building enjoys both cross ventilation and stack effect for effective ventilation as in Figure 6.10 below. The use of single banking and open courtyards helps in cross ventilation, while the atrium and double volume spaces helps in stack effect in Figure 6.11 below.

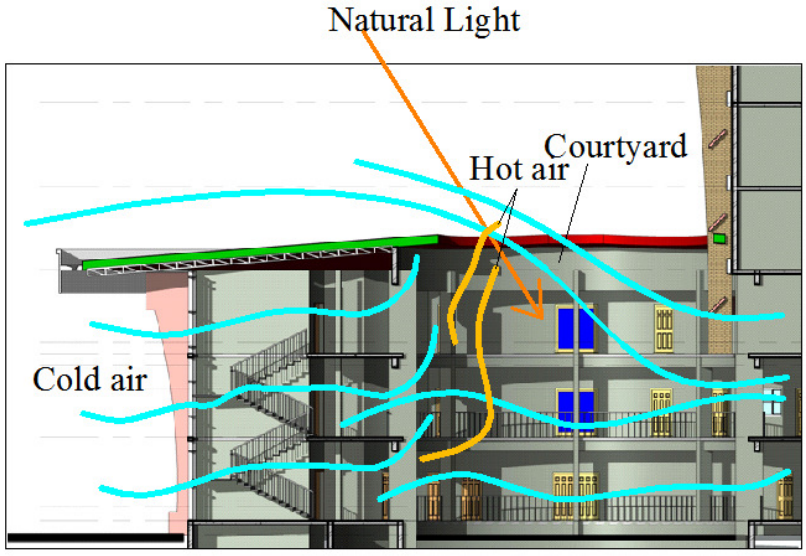


Figure 6.10 Sectional Details of Cross Ventilation in Courtyard

Source: Researcher's Work (2014).

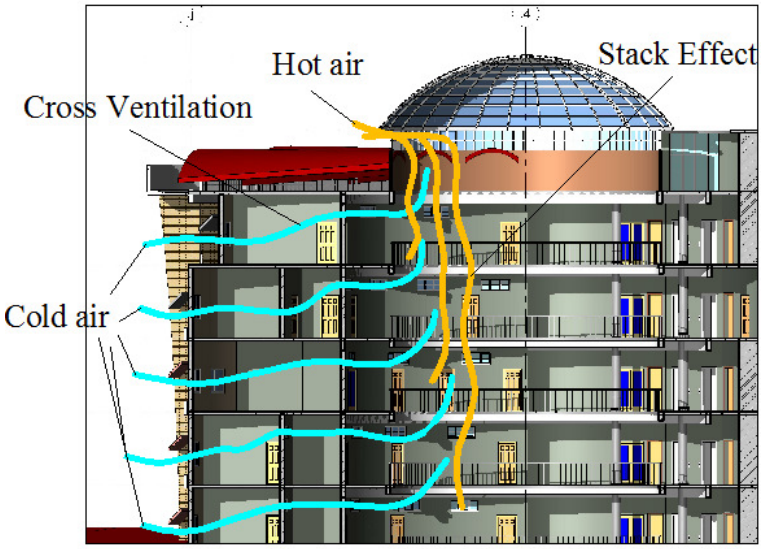


Figure 6.11 Sectional Details of Cross Ventilation and stack effects in Atrium

Source: Researcher's Work (2014).

6.8.3 Glazing and Fenestration- The design takes into consideration the use of low-e glass for lighting and aesthetics. The building use low-e glass for windows and facade glazing to help in reducing the internal heat gain due to direct solar rays entering the building as shown in Figure 6.12 below.

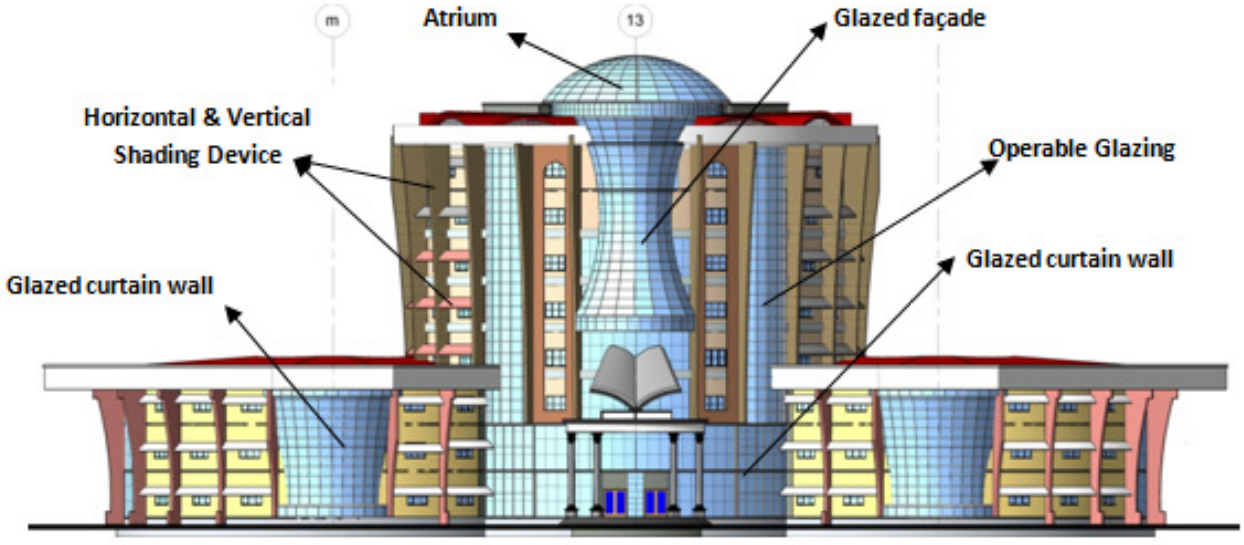


Figure 6.12 Approach Elevation of the proposed senate building

Source: Researcher's Work (2014).

Use of clear glass materials for atrium Figure 6.12 also helps in creating lighting in the building interior. Spaces within these regions are mostly open offices and meeting spaces, where sufficient lighting is required.

6.8.4 Building materials- In order to achieve maximum comfort within the building, the choice of building materials to be used in the building should be greatly considered. This has to be done with consideration to the thermophysical properties of the materials like conduction, transmittance, resistance etc. The materials listed below are proposed to be used in the various components of the building due to its advantages on improving comfort of users.

(i) Wall: the use of Autoclaved Aerated Concrete as a walling material. Autoclaved aerated concrete is a versatile lightweight construction material and usually used as blocks as seen in Figure 6.13. Compared with normal (ie: "dense" concrete) aircrete has a low density and excellent insulation properties. Autoclaved aerated concrete blocks are excellent thermal insulators and are typically used to form the inner leaf of a cavity wall. They are also used in the outer leaf, when they are usually rendered, and in foundations.

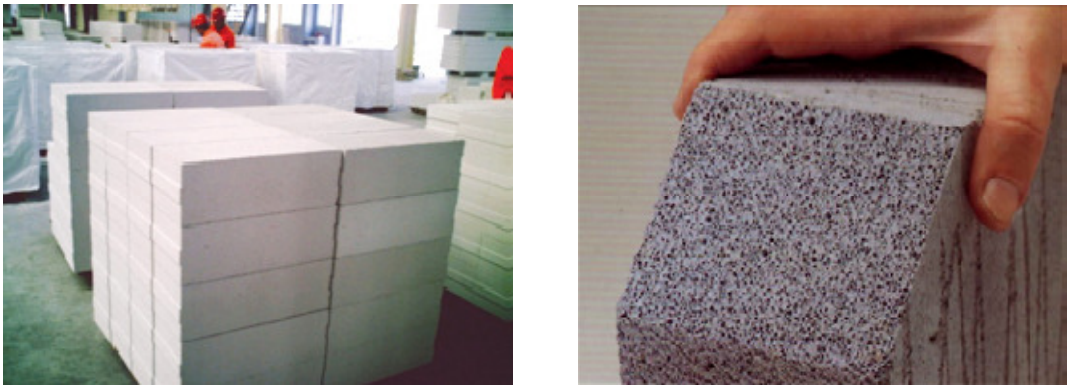


Figure 6.13. AAC Blocks

Source: CPWD (2013).

Aircrete also has good acoustic properties and it is durable, with good resistance to sulfate attack and to damage by fire and frost.

It has the following advantages, excellent acoustic insulation, and environmental friendly, absorb moisture, reduce condensation and controls humidity.

(ii) Floor: The use of Terrazo Tiles as the major floor finishing in addition to ceramic and marble floor tiles in office interiors. Terrazzo consists of marble, granite, onyx, or glass chips in Portland Cement, Portland Cement, or resinous matrix binder Figure 6.14 (a). The Terrazzo is poured, cured, ground, and polished. Terrazzo is typically used as a finish for floors, stairs or walls. Terrazzo is used in both interior and exterior applications Figure 6.14 (b).



Figure 6.14 (a) Terrazo Tile (b)Crazy Marble

Source: CPWD (2013).

It has the following advantages of good embodied energy, low maintenance, environmental friendly and improvement of indoor air quality.

(iii) Doors and Windows: the use of UPVC doors and Low-e Windows glass in the building. The New age window making material UPVC (Unplastisized Polyvinyl chloride) is formed from Polymerization of Ethylene and Chlorine. UPVC is considered

as the most preferred contemporary window making material because of its efficient features as seen in Figure 6.15 below. The Vinyl windows are excellent insulators.

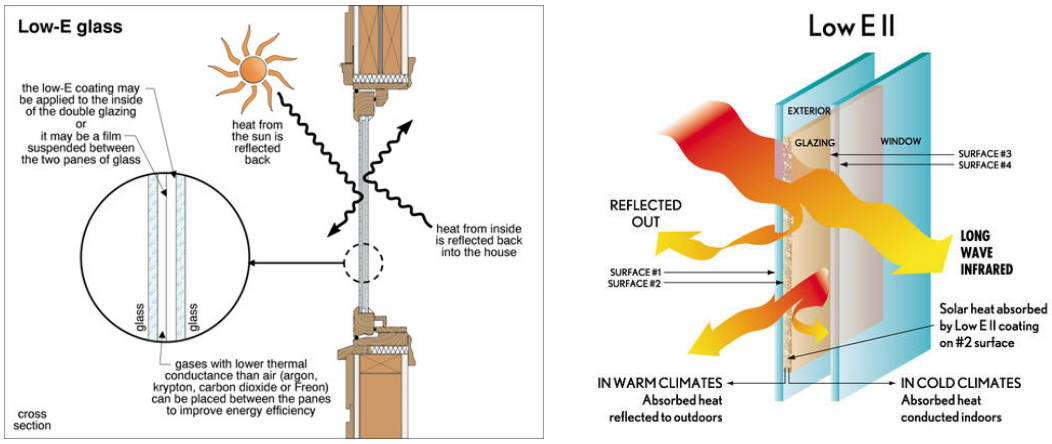


Figure 6.15 Schematic representation of Double Glazed Low-E glass

Source: CPWD (2013).

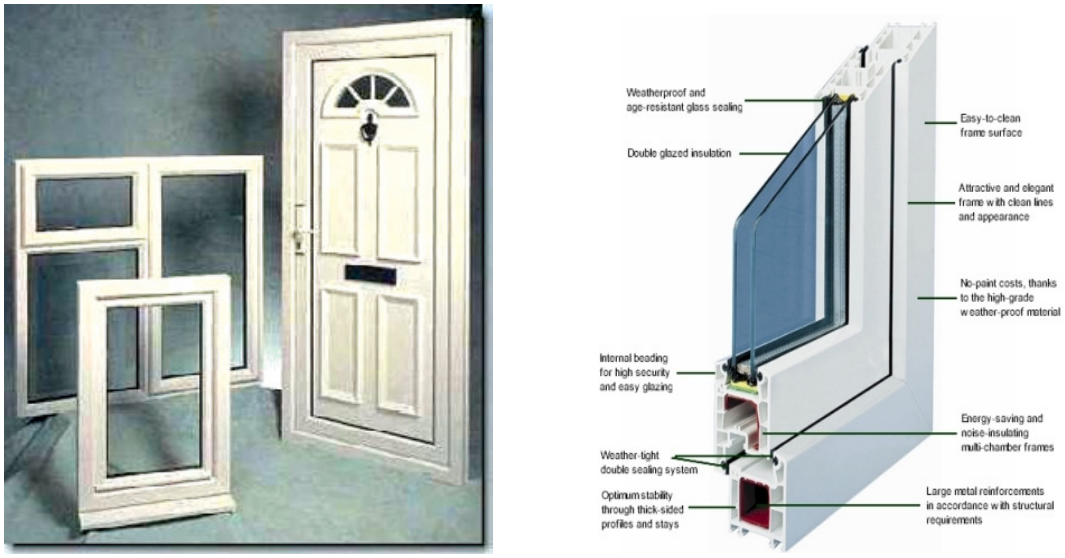


Figure 6.16 UPVC Doors and Windows Window Section

Source: CPWD (2013).

They reduce heating and cooling loads by preventing thermal loss through the frame and sash material Figure 6.15 and 16 above. It is not affected by the weather or air pollution,

salt, acid rain industrial pollution, pesticides, smog and discoloration and structural damage. Its user friendly and Eco Friendly, its readily accepted and safe.

It has the following advantages: No Weathering Effect, Good Thermal Insulator, Acoustic Insulator and Eco Friendly.

(iv) Ceiling: The use of Calcium Silicate Tiles as ceiling materials for suspended ceiling component in the building. Calcium Silicate Tiles are Lightweight with densified edges, to give high edge Strength, which minimizes damage in handling, Transport, storage, and installation of the tiles as seen in Figure 6.17 below.

100% RH Humidity resistance which eliminates Sagging of the product in high humidity Environments and do not lose their physical Integrity even in the case of condensation from air Conditioning ducts.

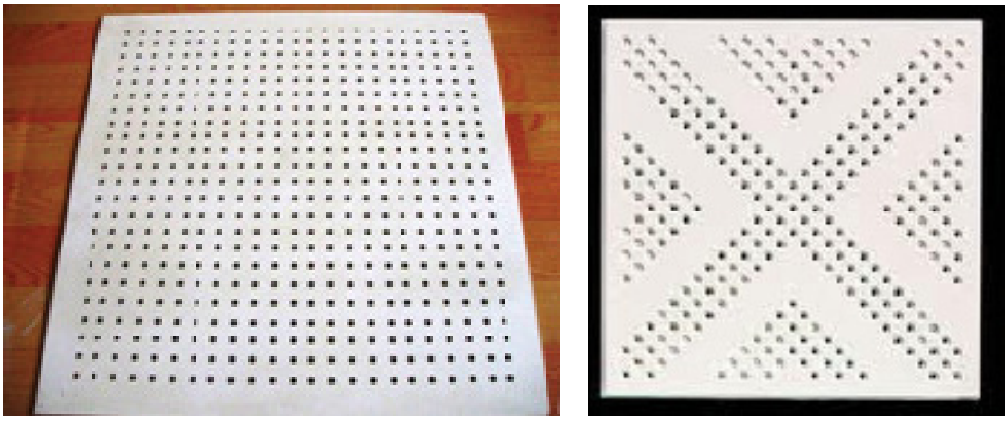


Figure 6.17 Calcium Silicate Tile.

Source: CPWD (2013).

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATIONS

7.1 SUMMARY

The building's form is responsible for determining its envelop and the way it interferes with the surrounding environments and the degree of comfort within the building. It constitutes the exposed envelop which is affected by the climatic factors. Designing buildings to achieve thermal comfort is associated with studying the mechanisms of heat transfer between the building and the outdoor environment. Other strategies such as glazing, insulation, ventilation and shading can be integrated within this envelop for better thermal response.

Selecting the suitable form has a great relation with the climatic factors; solar radiation, wind and humidity. In hot humid areas of Lafia, high temperature and humidity are the most important factor affecting building design as both heating and cooling requirements have to be achieved. However, office buildings in hot humid areas don't take sufficient account to the climatic factor especially the solar radiation. Hence, this study aim to understand the relation between form and energy consumption in order to achieve comfort condition and energy saving. The study clarified the aspect of building's thermal performance and its relation with the heat gain and loss between the building and the environment. Also, the study dealt with the factors affecting the building's thermal performance such as the climatic factors, the design variables and the physical properties of building's materials. The study overviewed the thermal comfort of buildings and its

approaches. After that, the study referred to the climate responsive design and its strategies for achieving thermal comfort in hot humid area.

Case study was conducted and a checklist was used in order to identify the extent to which the design consideration need to achieve thermal comfort is applied in the selected building.

Parametrical studies were conducted using the simulation programs ECOTECT to investigate the effect of the form on the thermal performance and energy consumption. The simulations focus on understanding the relation between the building geometry, area, volume and the thermal performance. This part dealt with geometries as a standalone building to avoid the effect of the adjacent buildings. Changing the building's forms with constant area, volume and thermophysical properties was the subject of the study. Also effects of orientation and the glazing (WWR) were also considered.

7.2 CONCLUSION

From the study carried out, the following conclusions were drawn:

(i) The thermophysical properties of building forms envelope composition is the major responsible factor for thermal response of different geometric forms.

(ii) For the amount of solar heating loads received, the cone is the least followed by the cylinder, cuboid and cube form during the hottest day of the year.

(iii) Heating and Cooling Loads studies shows that total cooling loads for simulated shapes increase by 14.7% from cylindrical to pyramidal form. The differences noticed is caused by variation in façade areas oriented in the same direction.

(iv) Also, form passive gain analysis, the results shows that the cube form performs best with respect to annual heat gain generated through the form fabric. The effect of direct solar heat gain will be highly minimized when using the cone form. And the Sol-Air heat gains will be reduced when using the cuboid form respectively.

(v) Over 40% of total heating or cooling loads of a building can be affected by choice of glazing material for windows and other openings in the building.

(iv) Other design consideration for achieving thermal comfort in hot humid areas needs to be considered in order to come up with a very good building.

7.3 RECOMMENDATIONS

This thesis has explored the effects of various building forms and design strategies needed to provide thermal comfort in hot humid areas, in the proposed senate building, through the use of form, orientation, glazing and other design considerations. The research therefore recommends that:

1. Architectural studies on thermal comfort using computer simulations should be encouraged to adequately explore the potentials therein, and proffer better solutions to the problem of thermal comfort and energy efficiency in office buildings.

2. Application of thermal comfort design strategies should be recommended in the design of office building designs in order to optimize user comfort, protect and enhance environmentally friendly environment for occupant.

3. It is important to eliminate the thermal transfer rate between the building envelop and surrounding environment in ways of conduction, convection and radiation in order to maintain the thermal balance through careful selection of materials.

7.4 CONTRIBUTION TO KNOWLEDGE

The research has the following contributions to knowledge:

1. Over 14% of total annual cooling load of a building can be reduced by using the right form. From the analysis carried out, the cylindrical form s the best followed by the cone form in terms of energy consumption.

2. The best orientation for Lafia climate is 60^{o}N for square form and 90^{o}E for rectangular form. This is to minimize solar impact from solar radiation and to intercept prevailing wind for effective ventilation.

3. Over 40% of internal heat gain generated by direct incident solar radiation entering the building through glazing can be reduced by using Double glazed Low-E aluminum windows.

REFERENCE

Abd El-Monteleb, A. & Ahmed, M. (2012). Using simulation for studying the influence of vertical shading devices on the thermal performance of residential buildings (Case study: New Assiut City). *Ain. Shams Engineering Journal.*

Abed, H.M.H. (2012). Effect of Building Form on the Thermal Performance of Residential Complexes in the Mediterranean Climate of the Gaza Strip. M.Sc. Thesis, Islamic University of Gaza. Palestine.

Adnan, A., Donghyun S. & Moncef K. (2009). Impact of Building Shapes on thermal Performance of Office buildings in Kuwait. *Journal of Energy and Conversion and Management. Pp 822-828.*

Ajibade, E.S. (Nd), Redesigning and redefining administrative roles for improved productivity in Nigerian universities. Retrieved: July 15, 2013.

Al-Tamimi, N., Fadzil, S. & Harun, Wan (2010). The Effects of Orientation, Ventilation, and Varied WWR on the Thermal Performance of Residential Rooms in the Tropics. *Journal of Sustainable Development.* (4)(2): 142- 149.

Anisha N.K. & Nobuo M.(2011). The effect of Building Form on Micro Climate and Outdoor Thermal Comfort in Tropical City. *Journal of Civil Engineering & Architecture.* (6)(11): 1492-1530

ASHRAE, (2004), *Thermal Environmental Conditions for Human Occupancy*, ANSI-ASHRAE Standard 55-2004, retrieved 13 September 2013 from www. ashrae.org/template/Technology Link and/category/163

ASHRAE, 2001. ASHRAE Handbook: Fundamentals, Si Ed., The American Society Of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Ga.

Auliciems, A. & Szokolay, S. (2007). Thermal Comfort, PLEA: Passive and Low Energy Architecture International in association with Department of Architecture, The University of Queensland, Brisbane, Australia.

Autodesk Ecotect Analysis (2011). Retrieved October, 12 2014, from http://usa.autodesk.com/ecotect-analysis/

Autodesk Educational Community, (2014). Retrieved from www.sustainabilityworkshop.autodesk.co

Bahar, Y.N., Pere, C., Landrien, J. & Nicolle, C. (2013), Thermal simulation tool for building and its iteroperatability through the Building Information Modeling (BIM) plateform. Retrieved from www.mdpi.com/journal/building.

Batagarawa, A., Navim H. & Dudek, S.J. (2011). Disaggregating Primary Electricity Consumption for Office Buildings in Nigeria. *21st Conference of International Building Performance Simulation Association.* Sydney.

BBC-GCSE Bitesize (2014). Retrieved from www.bbc.co.uk/schools.

Biket, A. (2006). Architectural Design Based On Climatic Data, 1st International CIB Endorsed METU Postgraduate Conference, Built Environment & Information Technologies, Ankara.

Çakir, Ç. (2006). Assessing Thermal Comfort Conditions; A Case Study on The Metu Faculty of Architecture Building, M.Sc. Thesis, The Graduate School of Natural and Applied Sciences, The Middle East Technical University, Turkey.

Catalina, T., Virgon, J. & Lordache, V. (2011), Study on the impacts of building forms on energy consumption. *21st Conference of International Building performance Simulation Association, Sydney.*

Central Public Works Department CPWD, (2013), A handbook of planning of buildings. Directorate General Central Public Works Department New Delhi.

Charles, K. E. (2003). Fanger's Thermal Comfort and Draught Models, IRC Research Report RR-162, Institute for Research in Construction National Research Council of Canada, Ottawa, Canada.

Chenvidyakarn, T. (2007). Passive Design for Thermal Comfort in hot Humid Climate. *Journal of Architecture/planning Research Studies.* (5)(1).

Conserving Energy in Buildings (1979), *The Architecture Journal,* A.J. Publicaton, Washington, USA.

Darby, S. & White, R. (2005). Thermal Comfort, Background document C for the 40% House report, Environmental Change Institute. University of Oxford, United Kingdom.

Deen, H. (2004), Passive and Active Environmental Controls. The McGraw-Hills Companies, New York.

Depecker, P., Menezo, C., Virgone, J. & Lepers S. (2001). Design of building shape and energetic consumption. *Build Environ Journal*. (30)(2):201–22.

Ecotect Tutorial, (2011). Retrieved from http://squ1.org/wiki/Heat_Gain_Loss_Tutorial.

Energy Conservation Building Code (ECBC). Retrieved July, 2012. www.ecbc.uk/html

Evans, Martin (2007). The Comfort Triangles: A New Tool For Bioclimatic Design, PHD Thesis, Architectural Association, London, United Kingdom.

Fanger, P. O. (1970). Thermal comfort, analysis and application in environment engineering. McGraw-Hill Book Company: New York, USA.

Givoni B. (1969) *Man, Climate and Architecture*, Elsevier, London (1st edition).

Goulding, J., Lewis, O. & Steemers, T. (1992). Energy in Architecture: The European Passive Solar Handbook, B.T. Batsford for the Commission of the European Communities, Directorate General XII for Science, Research and Development, London.

Harmathy, T.Z. (1988). Properties of Building Materials, National Research Conseil Canada "NRCC", Appeared in the SEPE Handbook of Fire Protection Engineering, (1)(26):378- 391, Canada.

Health and Safety Executives (2014). A publication on of health and safety executives, retrieved on 15 August 2014 from www.hse.gov/temperature/thermal.

Hesen J.L.M & Centnerova, L. (2001). Energy Simulation of Traditional Vs Adaptive Thermal Comfort for two Moderate Climate Regions, *Proceedings of the international Conference "Moving Thermal Comfort Standards into the 21st Century"*. In FL Nicol (Ed), pp.78-91.

HK Green Building Technology (2014). Maximizing Building Energy Consumption. Retrieved 14 March, 2014 from www.gbtech.emsd.gov.hk.

Krem, M. (2012). Effect of building morphology on energy and structural performance of high-rise office buildings. Thesis Dissertation retrieved from http://scholarworks.umass.edu/open_access_dissertations.

Learn Thermo, (2014), A publication on thermal properties of matrials. Retrieved 30 October 2014, from www.learnthermo.com.

Leylian, M., Amirkhani, A., Bemanian, M., & Abedi, M. (2010). Design Principles in The Hot and Arid Climate of Iran, The Case of Kashan, *International Journal of Academic Research*, (2)(5): 11-17.

Ling, C. S., Ahmad, M. H. & Ossen, D. R. (2007). The effects of geometric shapes and building orientation on minimizing solar insulation on high rise building in hot humid climate. *Journal of Construction in Developing Countries*, (12) (1).

Marks M. (1997). Multi-criteria optimization of shape of energy saving buildings. *Build Environ Journal* (32)(4):331–9.

Mikler, V., Bicol, A., Breisnes, B. & Labrie, M. (2008). Passive Design Toolkit – Best Practices. City of Vancouver, Canada.

National Air Space Agency (NASA), (2013). Retrieved March 8, 2014. from www.nasa.gov/climate_weather.html.

Nayak, J.K. & Prajapati, J.A. (2006). *Handbook on energy conscious buildings*. Indian institute of technology, Bombay and Solar energy center Ministry of non-conventional energy sources, Government of India.

Neufert, E. & Peter. (2000). Architect Data. Third Edition. (edt) by Bieche, B. & Williams, N. Oxford Brookes University. Retrieved June 17, 2012 from GFX.world.org.pdf.

Nicol, J.F. & Humphreys, M.A. (2002). The Validity of ISO-PMV for Predicting Comfort Votes in Every-Day Thermal Environments, *Journal Energy and Building,* (34): 667-684.

Nik Vigener, P. E. & Brown, M. A. (2009), Building Envelope Design Guide-Glazing. Whole Building Design Guide. A program of the National Institute of Building Sciences. Retrieved on 16 August, 2014 from http://www.wbdg.org/design/env_fenestration.php

Nikpour, M., Zin K. M; Ghasemi, M. & Fallah, H. (2011). Study of the Effectiveness of Solar Heat Gain and Day light Factors on Minimizing Electricity Use in High rise Buildings *World Academy of Science, Engineering and Technology,* (73), 73- 77.

Olgyay, V. (1953). Bioclimatic approach to architecture. *Building Research Advisory Board, Conference.* (5). Washington, DC: National Research Council.

Ridley, L. (1990). Microclimate, Site Planning, and Development. In Fuller F. M. (edt.) (1009). *Environmental control systems: heating, cooling, lighting*, McGraw-Hill Higher Education.

Roos, C. (2008). Principles of Heat Transfer, Energy Efficiency Factsheet, Washington, USA.

Rosenlund, H (2000). Climatic Design of Buildings using Passive Techniques. *Building Issues*, (10)(1): 3-26.

Sensirion, (2010). Conditions of Thermal Comfort; Influence of Humidity and Temperature on Personal Well-Being, Version 2.0.

Shady A. (2010) A Tool for Decision Making. *Zero Energy Residential Building in Hot Humid Climates,*

Shomera, (2014). A publication of thermal performances, retrieved on 25 september 2014 from www.shomera.ie/thermal-performance.

Shuara, J. (2013), Governance of federal universities in Nigeria, general responsibilities of the governing council. *A paper delivered at a retreat of governing council of the federal university of agriculture Abeokuta*, in Lagos Nigeria.

Stelios C. Z., Christos A. T., Anastasios M. K., Dimita, F. & Angeliki, K. (2012). The Role of Building Form in Energy Consumption: The Case of a Prismatic Building of Athens. *Journal of Energy and Buildings.*

Stephenson, D. G. (1963). CBD-39. Solar Heat Gain Through Glass Walls. *National Research Council Canada,* retrieved October 16, 2013 from: http://www.nrc-cnrc.gc.ca/eng/ibp/irc/cbd/building-digest-39.html

The National Austrailian Built Environment Rating System (NABERS). www.nabers.com.au.

Utzinger, M. & Wasley, J. (1997). Building Balance Point. The University of California, Berkeley.

Veal, A.J. (2006). Research Methods for Leisure and Tourism. Third Edition London, Prentice Hall.

Wafi, S.R.S, Ismail, M.R. & Ahmed, E.M. (2011). A Case Study of the Climatic Factor on thermal Comfort for Hostel Occupants in Universiti Sains Malaysia (USM), Penang, Malaysia. *Journal of Sustainable Development.* (4)(5): 75-79.

Wang, W., Rivard, H. & Zmeureanu, R. (2006). Floor shape optimization for green building design, *Advanced Engineering Informatics*, (20): 363- 378.

www.ecowho.com

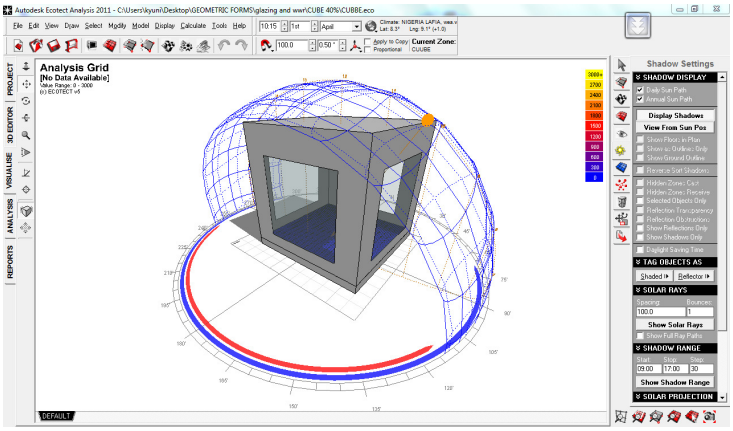
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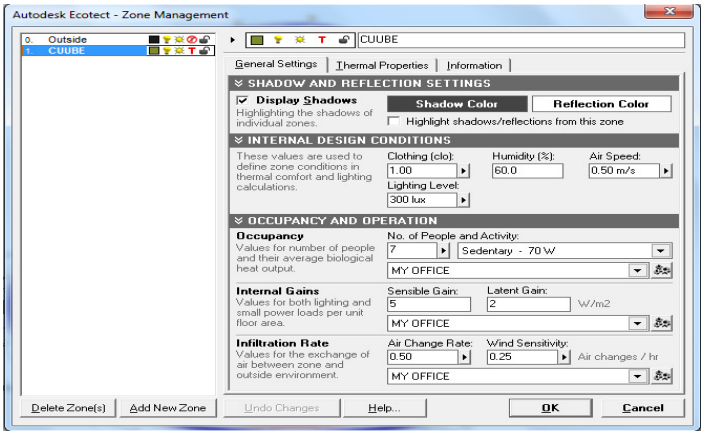
www.myweather2.com

Yu, J., Xu, X. & Tian, L. (2011). Effect of Envelope Design on Energy Consumption Respect to EETP Index, *International Conference on Computer Distributed Control and Intelligent Environmental Monitoring* (CDCIEM).

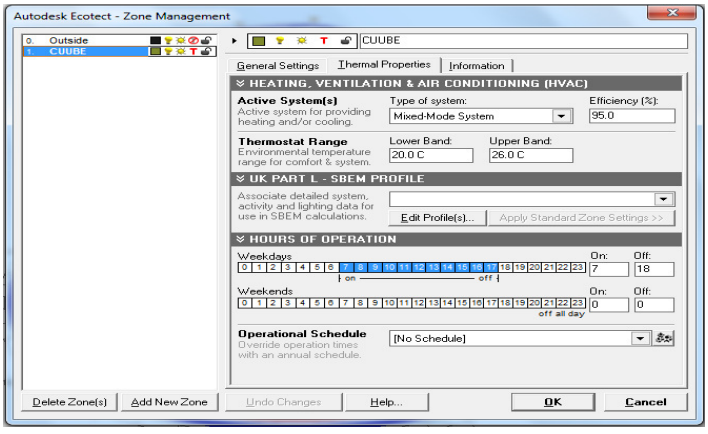
APPENDIX



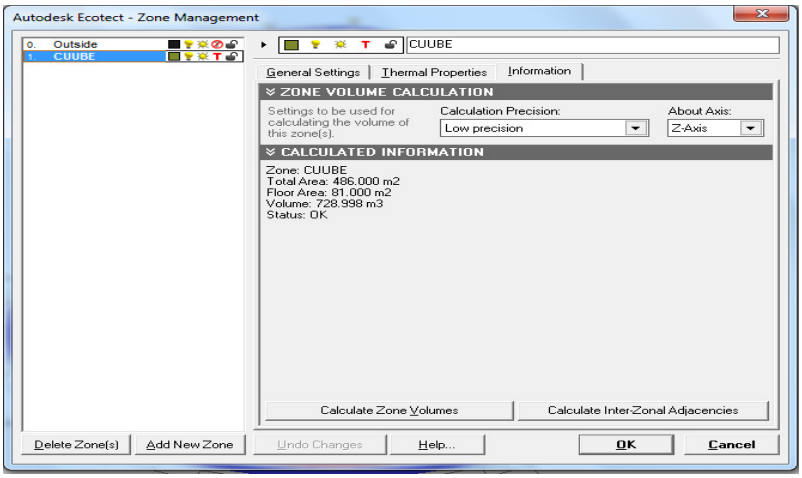
Appendix 1. A typical analysis interface in ECOTECT 2011



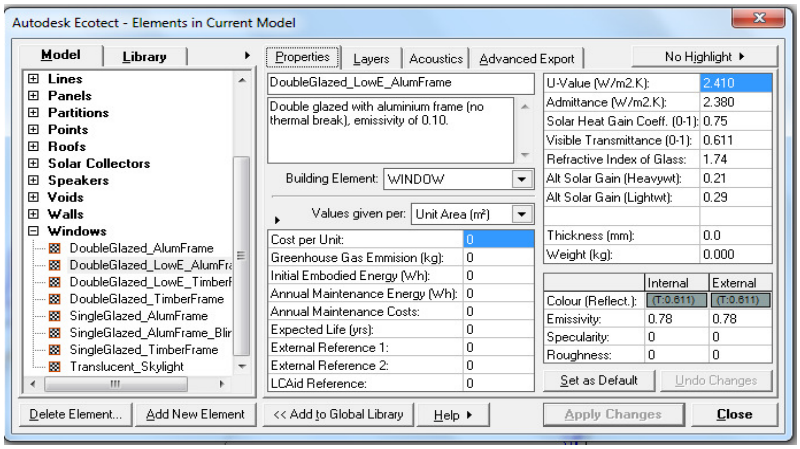
Appendix 2. Zone management general settings in ECOTECT 2011



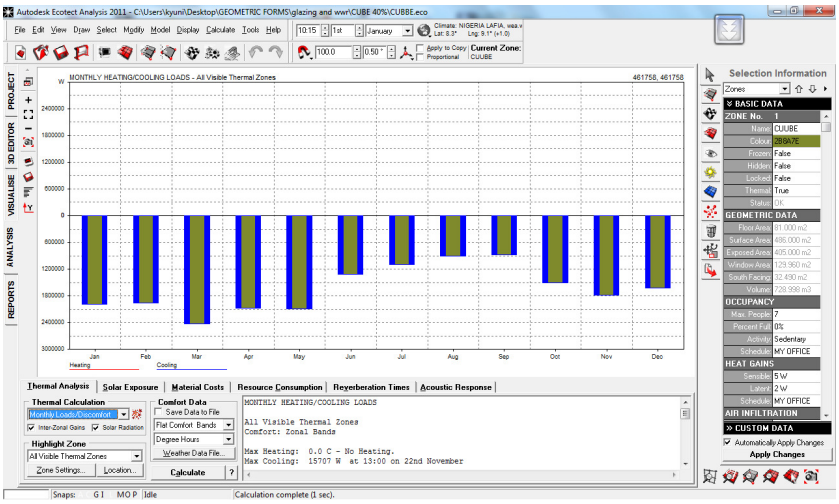
Appendix 3. Thermal and schedule settings in ECOTECT 2011



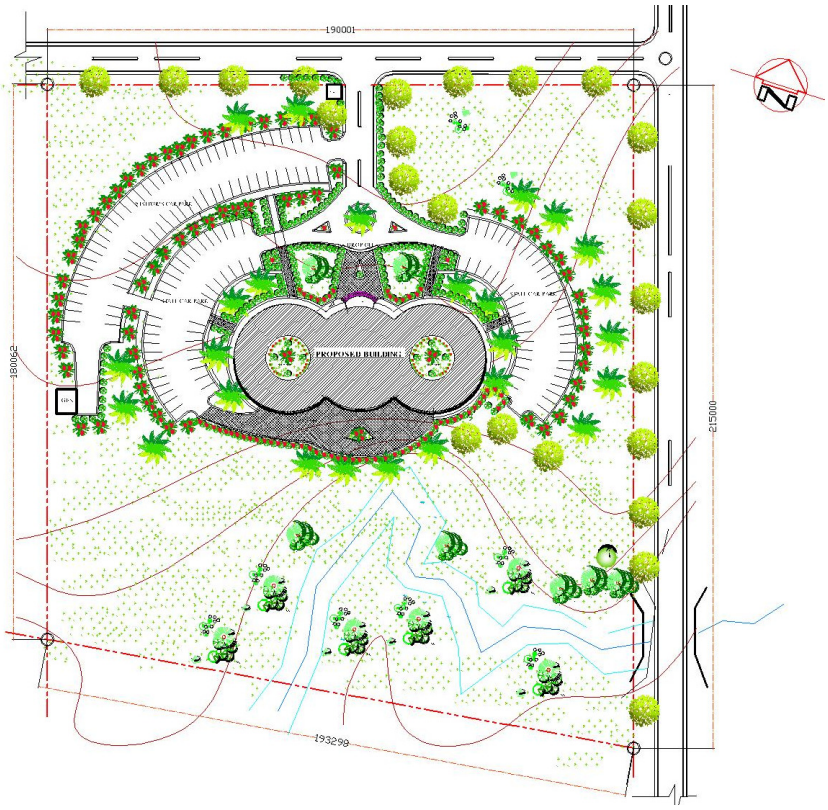
Appendix 4. Zone information in ECOTECT 2011



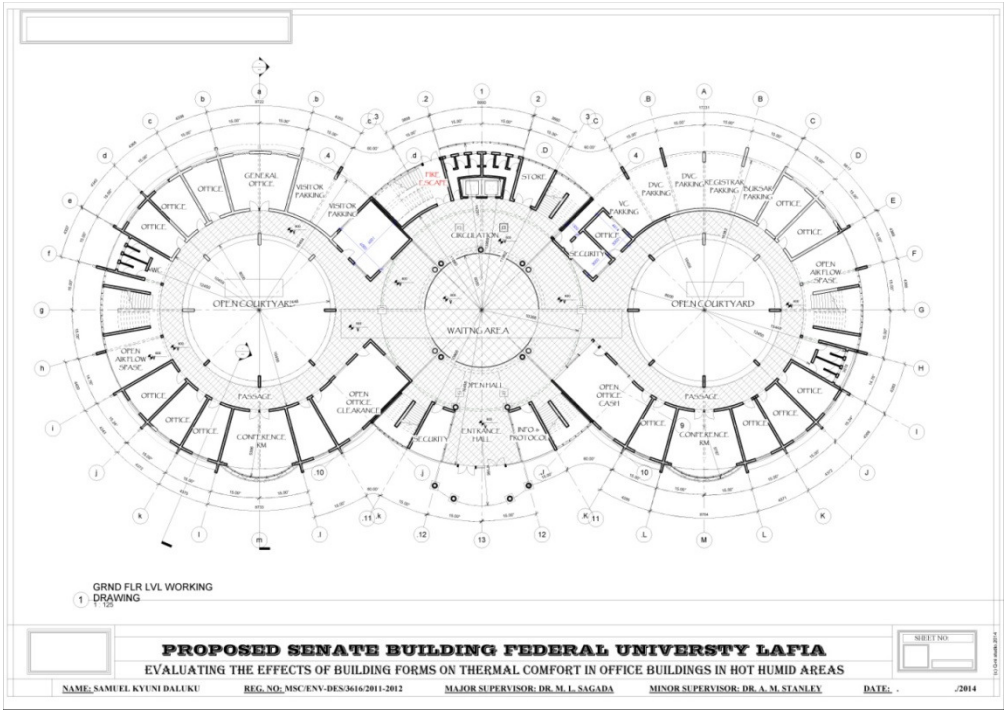
Appendix 6. Building Elements in current model ECOTECT 2011



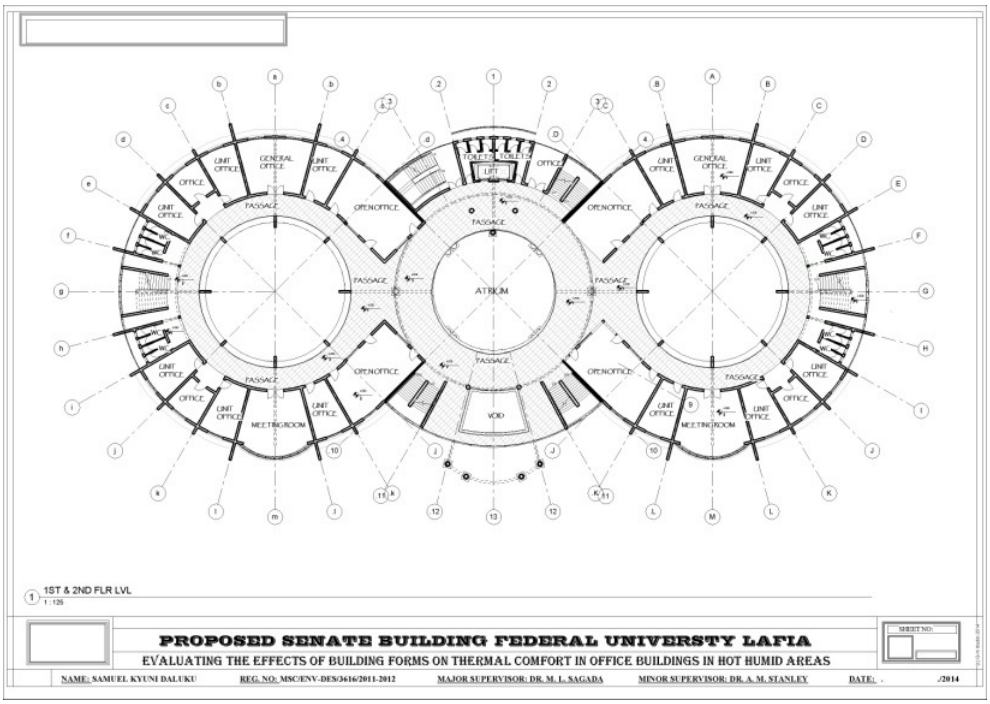
Appendix 7. A typical simulation result generated by ECOTECT 2011



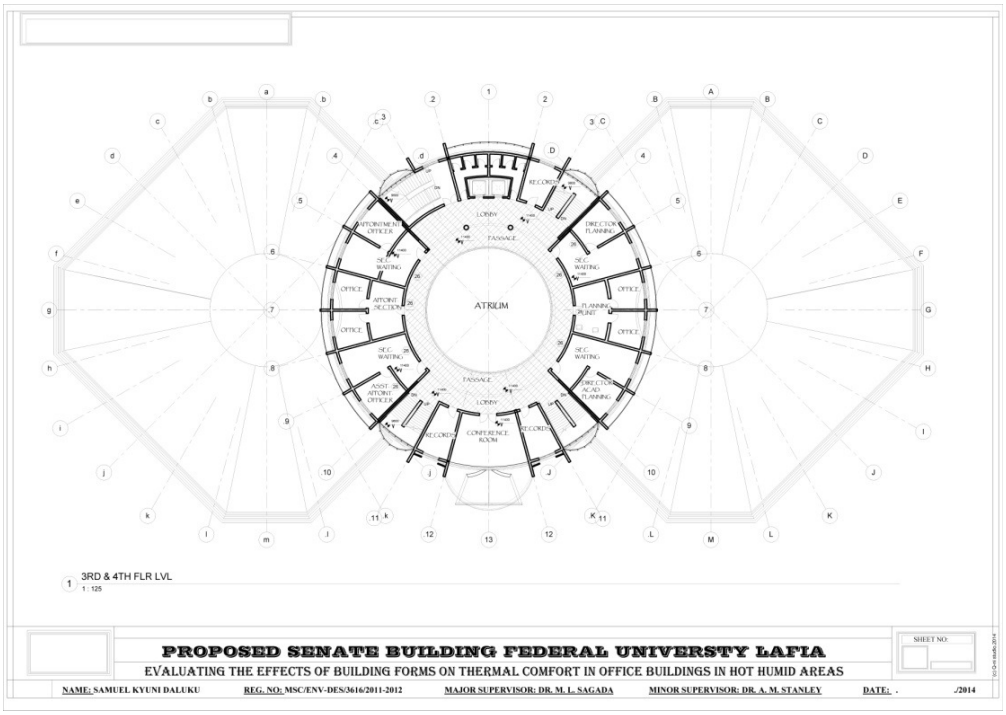
Appendix 8. Site plan indicating the various parking's



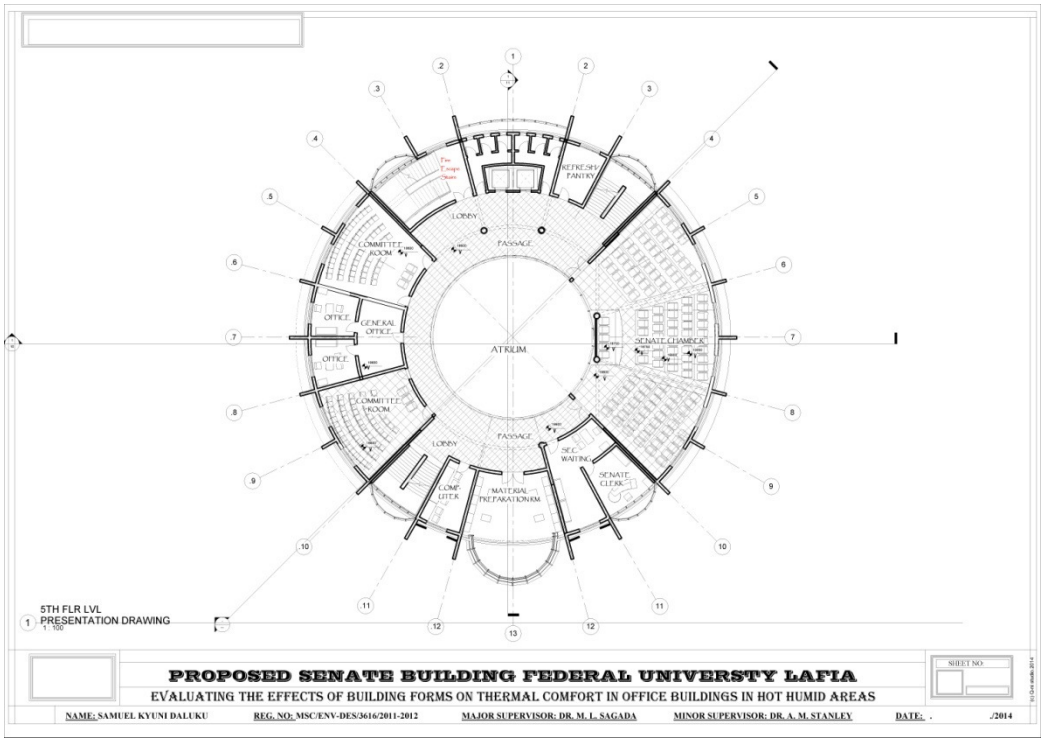
Appendix 9. Ground floor Plan of the proposed senate building



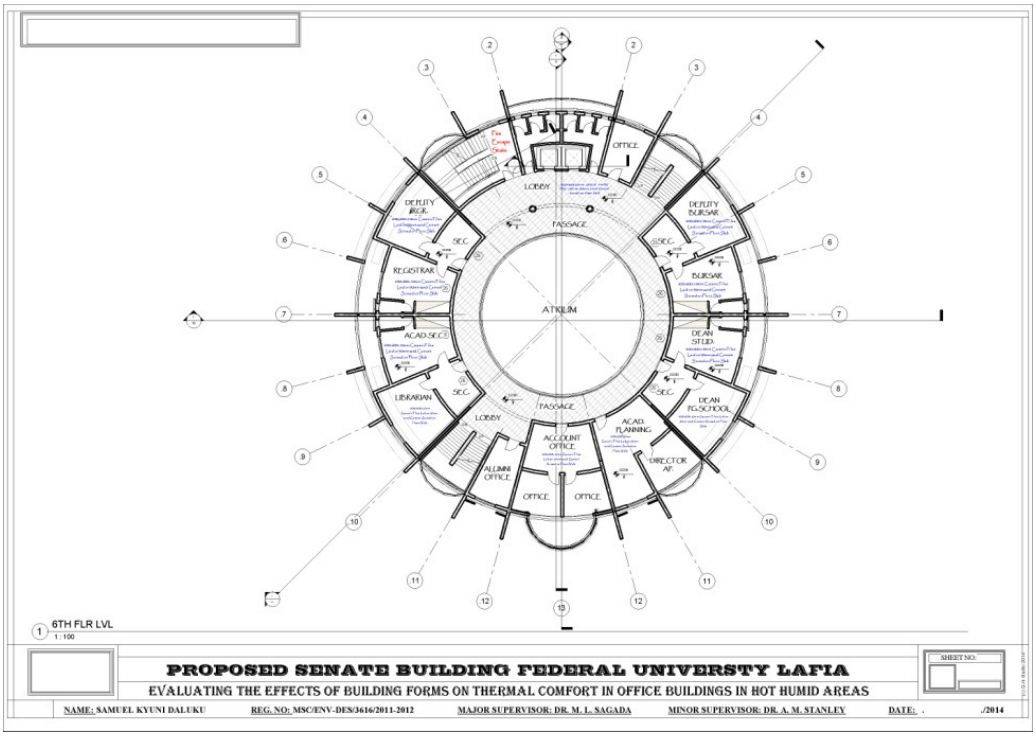
Appendix 10. First and Second floor Plan of the proposed senate building



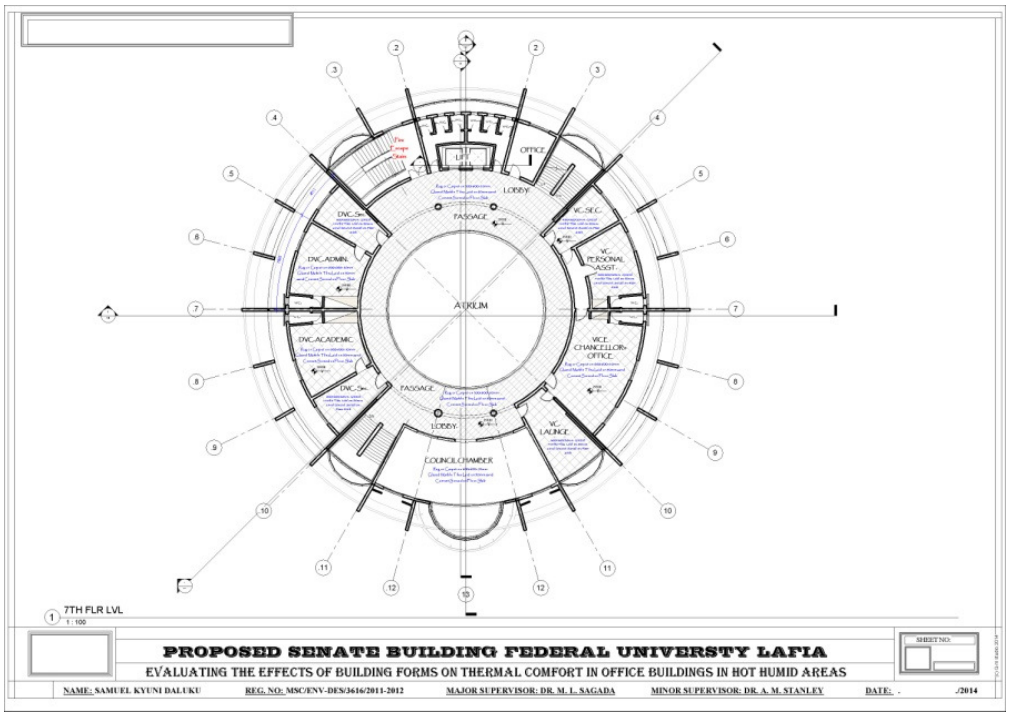
Appendix 11. Third -Fourth floor Plan of the proposed senate building



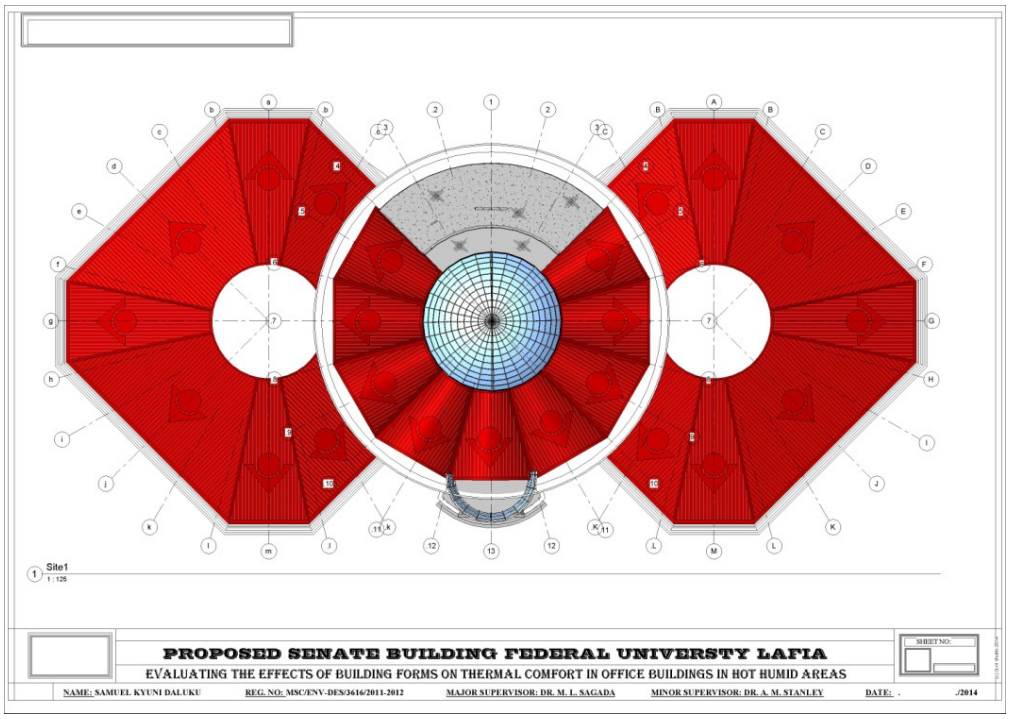
Appendix 12. Fifth floor Plan of the proposed senate building



Appendix 13. Sixth floor Plan of the proposed senate building



Appendix 14. Seventh floor Plan of the proposed senate building



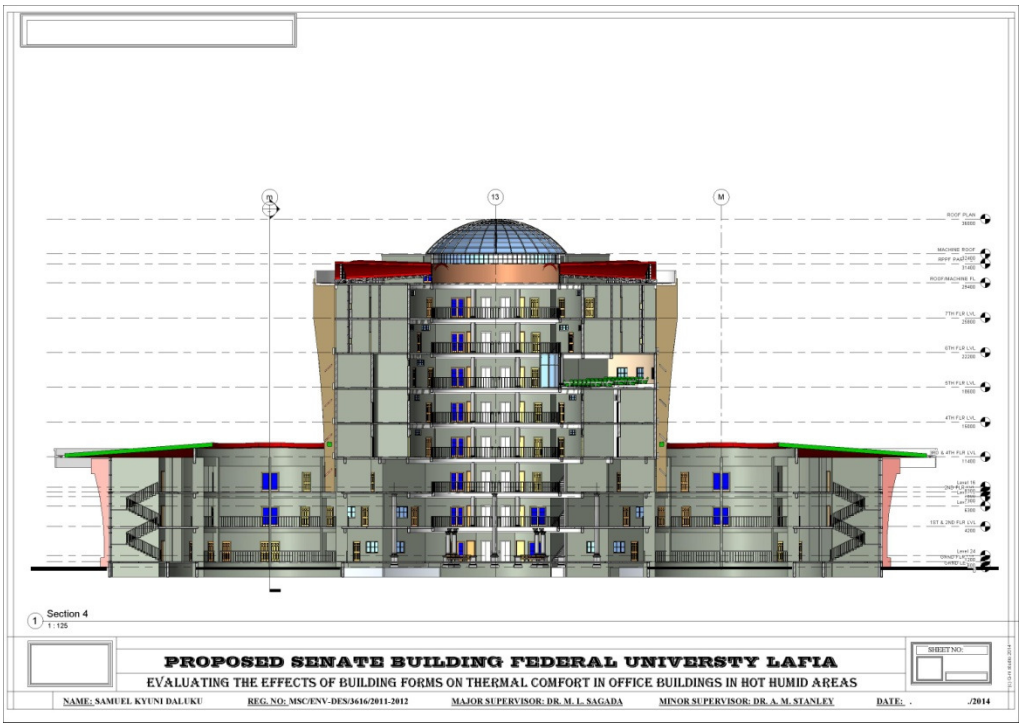
Appendix 15. Roof floor Plan of the proposed senate building



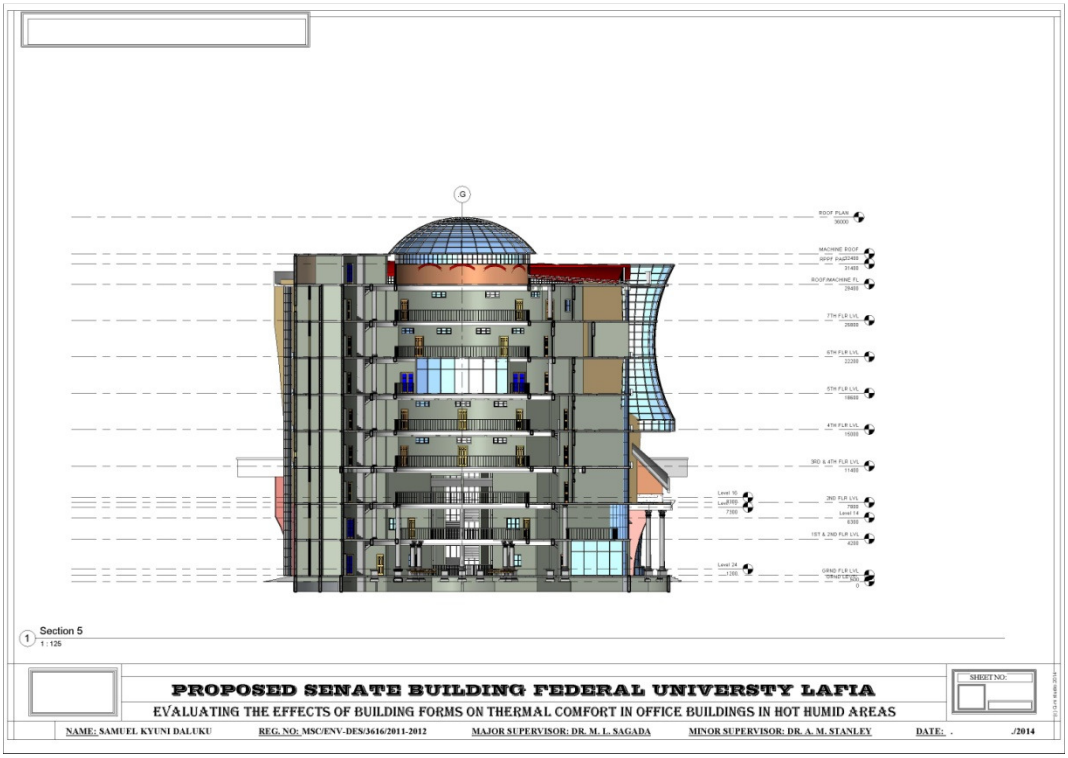
Appendix 16. Approach and Rear Elevation of the proposed building



Appendix 17. Left and Right Elevation of the proposed building



Appendix 18. Section A_A of the proposed building



Appendix 19. Section B_B of the proposed building



Appendix 20. 3D View 1



Appendix 21. 3D View 2



Appendix 15. 3D (Arial view) of the proposed building