# INTEGRATION OF ENERGY EFFICIENT DESIGN ELEMENTS FOR OFFICE COMPLEX ABUJA, NIGERIA

**BY**

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**A THESIS SUBMITTED TO THE POST GRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTERS OF TECHNOLOGY (MTech) IN ARCHITECTURE**

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# ABSTRACT

Climate change is having a tremendous effect on our fragile ecosystem where the acceleration of its effect is believed to have occurred as a result of human activities that release Greenhouse Gases (GHG) into the atmosphere. In the built environment also, energy necessity of buildings has seen an increase over the past years, predominantly is the energy demand for cooling, ventilating, and lighting. The built environment has been identified as one of the major contributors to the immense diminishing of natural resources through the use of artificial energy for cooling and lighting. An energy consumption research estimated that building sector alone accounts for 40% of the world's energy consumption, the research also related one-third of global greenhouse gas emissions where approximately 80% of the energy is through air conditioning systems and artificial lighting. This study aimed at integrating passive energy efficient design elements towards achieving sustainable, low cost and energy efficient office buildings in the Federal Capital Territory, Abuja, Nigeria. To properly describe the functions and characteristics of the variables studied and to allow for multi-dimensional approach to data collection, descriptive survey was adopted. Qualitatively, the research determined the extent at which energy efficient design elements such as building orientation, shading devices, building form, building envelope/colour, landscape elements, courtyard, and skylight have enhanced energy efficiency in office buildings in Abuja. Energy efficient variables such as buildings orientation, buildings colour, landscape elements and natural ventilation techniques were collected through structured observation schedule, these served as the primary data gotten from the field. Secondary data was gotten through information obtained from documented literature by previous related research works. The research adopted the stratified random sampling, this method allowed office buildings in Abuja to be divided into strata such as high-rise and low building and then randomly selecting from the high-rise buildings. Ten (10) office buildings were randomly selected across the Federal Capital Territory. Data collected was analysed using statistical analysis represented with tables and charts. The result showed that office buildings in Abuja were built with little consideration for passive energy efficient design elements as most office buildings depend chiefly on artificial cooling and lighting. It is recommended that energy efficient elements such as courtyards, overhangs, landscaping, building orientation should be incorporated in the design of buildings, particularly office buildings so as to save running cost, reduce energy requirements of buildings, and also reduce the negative effects this energy has on the environment. Also, statutory regulations should be geared towards ensuring that designers and developers adopt energy efficient design elements in the design of buildings. Furthermore, stakeholders (developers and designers) in the construction industry should provide inducements in the form of awards and recognitions for buildings built to achieve energy efficiency through passive design concepts.

## Table of Contents

## LIST OF TABLES

# LIST OF FIGURES

## LIST OF PLATES

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background to the Study

Climate change is now taking a tremendous consequence on our fragile ecosystem, the acceleration of its effect is understood to have happened as a result of the activities of human that discharge Greenhouse Gases into the environment (Golubchicov & Badyina, 2012). It is projected that the built environment accounts for 40% of the energy consumption of the world and associated one-third of global greenhouse gas emissions where about 80% of the energy is through non-natural lighting and air conditioning system (Rupp *et al*., 2015). The 4th assessment report of intergovernmental panel on climate change estimated that greenhouse gas emissions from building associated activities could almost double by 2030. However, the report also established that the building sector has the principal potential for reducing greenhouse gas emissions. Studies have shown that the cheapest and most effective way of decreasing the climate change effects is by adopting energy efficient passive design (Lechner, 2014).

Energy requirement of buildings has witnessed an increase over the past years, principally is the energy required for cooling and lighting buildings. Artificial methods adopted for cooling and lighting buildings have proven to lack reliability in terms of environmental and economic sustainability (Hyde, 2017). As such, there is need to reduce energy consumption of buildings through the application of energy efficient design elements. Bassler and John (2010) in their energy saving research stated that energy saving is locally designing for energy conservation which targets at reducing the use of conventionally powered cooling, heating, and lighting through passive energy efficient design elements. According to the Chartered Institute of Building Services

Engineers (CIBSE) (2012), energy efficient design elements are those elements that are used to provide the necessary internal conditions and services with minimum energy use in a cheap and environmentally sensitive way. This energy efficient design elements can best be achieved during the design stage of buildings. Energy efficient design elements such as the form and orientation adopted for a building, building mass, landscape design, natural ventilation and daylighting are some of the design elements that can be employed to achieve energy efficiency (Gokarakonda & Kumar, 2016). The energy efficient design elements listed above have passed the criteria for sustainable building design. Reduction in the consumption of resources, reduction in environmental impact, and economic viability are some of the benefits associated with the use of these passive design elements to achieve efficiency in the use of buildings (Peter, 2015).

In tropical regions like Abuja in Nigeria, the primary use of energy in commercial buildings like offices is for cooling, lighting and for services such as operation of elevators, operation of office equipment and refrigeration. Adopting energy efficient design elements to reduce buildings energy demands will result in less energy requirement of buildings. Passive energy efficient design can be achieved through using several energy efficient design elements such as operable windows, sun shading strategies, orientation and landscaping. Courtyards also perform effectively in lighting interior spaces. Roof lights, large windows are other energy efficient design elements used to achieve day lighting in office buildings (Anink *et al.*, 2010).

According to the Whole Building Design Guide (WBDG) (2009), office can be defined as any building that fits within a suitably zoned segment, block and lot as recognised by resident authorities for commercial purposes. This information can be authenticated based on the positioning of a structure with respect to an approved zoning map and permitted usage of an office space. The concept of an office differs, but will be best characterised by the building design guides by what spaces it comprises. As stated by WBDG (2009), a characteristic office layout may include an office work space, a lobby, meeting space, office support space; work spaces, storages, folder rooms, copy areas, telephone, mail rooms, rooms for mechanical and communication, rest rooms, restaurants, private conveniences, childcare, fitness spaces, and vehicular packing spaces.

During the time of the early civilizations, office buildings took the form of lightly furnished rooms decorated with artefacts, they were individual offices used for business and as stores for rolled up scrolls. In the time of the industrial age, there was significant growth in commercial and financial institutions, there was also a major growth in the number of office buildings to serve business and corporate purposes (Long, 2014). In the last century, there has been a boom in office building development. Its context has widened also incorporating specialized work and meeting spaces, support spaces such as storages, printing areas, correspondence and waiting areas. As the demand for office buildings increases, the form and layout of offices also were improved upon to properly serve the purposes in which they are built. Some of these office layout includes but not limited to open plan layout, combi layout, office layout in cells, *Burrolanchaft* office layout. Each of these office layouts are used by different organizations to suit the pattern and structure of work in which they carryout.

The consumption of energy in buildings has come to be a central point in world discourse towards eco-friendly development, and its broader interconnections with the surrounding environment. It is estimated that the built environment accounts for about 40% of the total energy consumption globally and linked one-third of global greenhouse gas discharges where approximately 80% of the energy is by air conditioning systems and artificial lighting (Rupp *et al.,* 2015). Since the advent of air conditioning technology, energy consumption of office buildings has been on the increase, minimizing this energy consumption with regards to energy efficient design elements will lessen the amount of energy needed by these buildings. The 4th assessment report of intergovernmental panel on climate change estimated that greenhouse gas emissions connected with activities in buildings could almost double by the year 2030. However, the report resolved that the building sector has the biggest potential for reducing greenhouse gas discharges through energy efficient design. Studies have shown that cheap and effective way of reducing the effects of climate change on the environment is by adopting energy efficient design (Lechner, 2014). Studies also showed that the consumption of energy of the built environment surpasses that of other sectors as well as transportation in many parts of the world (Brown & Dekay, 2010). For example, in the United States of America, buildings use as much as 48% and 76% of the total electricity and energy respectively (Kasozi & Tutesigensi, 2007). In addition, buildings are responsible for a significant amount of greenhouses gas emission.

## 1.2 Statement of the Research Problem

Commercial buildings like office complexes have been recognised as one of the chief contributors to the enormous reduction of natural environmental resources (Lam *et al.*, 2011). Nigeria is confronted with epileptic supply of electricity due to pipeline vandalism and scarcity of fuel for the power plants. The amount of electricity presently generated is far lower than the estimated supply load of 12,800MW for the existing infrastructure (Sambo *et al.*, 2012). This shortfall has made at least 50% of Nigerians not to have access to electricity supply which as a result has led to dependence on back-up generators by office users to cool and ventilate office spaces. This artificial means of ventilating and cooling office buildings using hydroelectricity and fuel generators are neither environmentally friendly nor economically viable. The burning of fuels has resulted into several environmental concerns such as global warming and depletion of natural resources. As a result of this depletion in ozone layer, principles and ideologies aimed at providing more sustainable and cheap alternatives have been created. Energy efficient design elements are one of such ideologies.

Energy efficient designs elements are aimed at reducing the energy demand of buildings through logical application of architectural design concepts. As office buildings remain one of the building types where energy is highly utilized (Santamouris, 2007), adopting the principles of passive energy efficient design elements will ultimately improve the energy conservation quality of buildings. Energy efficient design elements are methods through which the consumption of energy of a building can be lessened while maintaining or improving the comfort of occupants of that building. Reducing energy demand is the most significant principle of energy efficient passive design because they give designers the avenue to design buildings in such a way that tends to decrease buildings' energy demands in the design stages of buildings (CIBSE, 2012).

### 1.3 Aim of the Study

The aim of this study is to investigate passive energy efficient design elements towards proposing a sustainable, energy efficient office building in Abuja, Nigeria.

## 1.4 Objectives of the Study

The objectives of this study are to;

i. Assess the basic energy efficient design elements that can be applied to achieve energy efficiency in office buildings.

ii. Investigate energy efficient design elements that can be employed in the design of office buildings.

iii Propose an office building design which employs the use of energy efficient design elements towards sustainable office buildings in Abuja, Nigeria.

## 1.5 Scope of the Study

Generally, commercial buildings in Abuja have a tremendous impact on the energy supply of the city (Abbas, 2012), the study also confirmed the prevalence of a suppressed energy demand scenario due to shortages in energy supply. However, this limited energy supply is met through fuel generators. As these fuel generators are operated, harmful substances are being emitted into the environment, and this emission has negative effect on the environment. In addition, commercial buildings like office complexes require more energy for ventilation and cooling. This enormous energy demand in office complex can be reduced through application of energy efficient design elements.

This study focused on applying design strategies and ideologies to enhancing energy efficiency of office buildings in Abuja, Nigeria. The office buildings will provide for corporate business activities, meetings, seminars and conference, relaxation and recreation and support spaces. Passive strategies adopted are centred on passive cooling and lighting of the office building as these are usually the primary consumers of energy in buildings within the city of Abuja.

### 1.6 Research Justification

The utilization of energy in buildings have seen a rapid growth in recent years due to the rise in demand for energy required for cooling and heating in buildings (Sartori & Hestnes, 2007). In a quest towards sustainable built environment and conservation of natural resources, many nations have adopted these ecological friendly and energy conservative strategies. However, despite the high energy demand of office buildings, energy efficient design elements have not been adequately utilized in Abuja (Abdullahi, 2015). Today, buildings account for more than 40 percent of world energy use, and as much as one-third of global greenhouse gas emissions, both in advanced and emerging countries. This implies that use of energy efficient buildings elements will offset the global energy demand by 40 percent which could have emanated from housing sector (Asdrubali *et al*., 2012).

This research work proposed a design that takes cognizance of energy efficient design elements. It also sought to provide effective energy efficient design considerations that can be adopted to achieve sustainability. The benefits of applying energy efficient design strategies in buildings to its owners and operators include; cost of savings as the need to use fossil fuel or hydroelectricity power generating sets are reduced to the barest minimum, saving building occupants and owners from the inconvenience of maintenance of active elements and reduction in environmental degradation (Peter, 2015).

## 1.7 The Study Area

The study area for this research work is office buildings in Abuja, the federal capital Territory of Nigeria. Abuja was created in 1976 and built largely in the 1980s. It was officially named capital of Nigeria in 1991 substituting the country's most populous city of Lagos. After the 2006 national census, the city recorded a population of 1,405,201 people, making the city one of the ten (10) most populated cities in Nigeria. Abuja recorded of about 139.7% between the year 2000-2010, putting it among the fastest growing cities in the world. As of 2015, Abuja was undergoing a yearly growth of at least 35%, keeping its place as the fastest growing city in Africa and one of the fastest growing globally. As a result of these growth and shift in the seat of power, companies and industries are now moving their headquarters to the capital city, thus making the demand in office spaces in the FCT to increase geometrically. In addition to this increase in number of office buildings, poor electricity supply is also a menace in the Federal Capital Territory (Abdullahi, 2015). As a result of this shortfall in power supply, total dependence on artificial technique in cooling, ventilating and lighting office buildings is no longer possible. This has led to designers to think of ways to adopt energy efficient design elements in other to passively cool and ventilate office spaces in the Federal Capital Territory.

Abuja is situated in the Savanna region of Nigeria between Iatitude $8^o25$” and $9^o20$” north of the equator and Iongitude $6^o45$” and $7^o30$” east of the Greenwich meridian. Its total land mass is about $8000Km^2$. It has an estimated population of 1,405,201 people according to the National Population Commission (NPC) (2006). As indicated in figure 1.2, Abuja is made up of six local government areas called area councils, they include; Bwari, Abaji, Abuja Municipal, Kuje, Gwagwalada and Kwali Area Council. The state is overseen by the Municipal Area Council which is responsible for the administrative aspect of the city. For comfort and organisation of developmental efforts, the city was separated into phases by its designers, this allows the city's development to take a concentric form with phase one consisting of the city's inner districts- Maitama district, Central Area, Wuse, Asokoro, Garki, and Guzape-at its core and spread outwardly from the bottom of Aso Rock, while phase 5, consist of the Kyami District which was recently created. The city has an international airport-the Nnamdi Azikiwe International Airport, a Federal University, some private institutions.


**Figure 1.1**: Nigeria map showing the location of Abuja
**Source:** Abdullahi (2015)

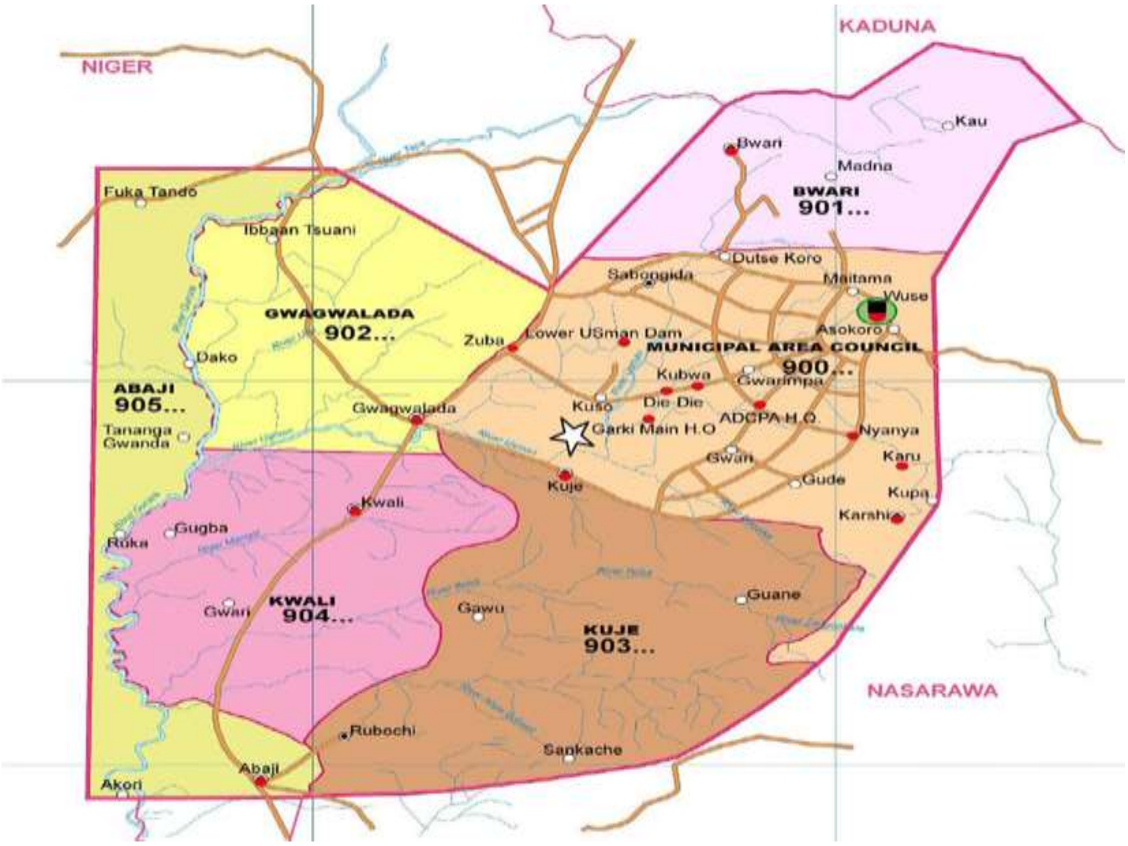



**Figure 1.2:** Abuja map showing the different Area Councils
**Source:** Abdullahi (2015)

As boldly indicated in Figure 1.1, the city is located in the north-central part of the country along states like kogi, Kwara, Benue, Plateau and Niger State. The Federal Capital City is bounded by Niger State, Kaduna State, Kogi State and Nassarawa State.

# CHAPTER TWO

# 2.0 LITERATURE REVIEW

## 2.1 Introduction

The eco-system is at an unprecedented crossroad; ranging from greenhouse gas emissions to the ozone layer depletion, increased sea level and many more. With the increased awareness on global warming and the dependence of built environment on artificial energy for daily life activities, building sustainability is increasingly being emphasized around the world. Occupiers of buildings are now extra conscious of the importance of sustainability for an improved quality of life (Jamaludin *et al.*, 2014). Energy is required for the building's operations and inhabitation. Lighting, insulation, and building controls have been improved upon and these are critical features that aid a building to attain energy efficiency. Hence, it is vital to understand the meaning of "Energy Efficiency".

Energy efficient design elements, such as external shading, thermal mass, orientation of buildings, landscaping, and insulation in buildings, are the key elements of sustainable building. In addition to their less reliance on mechanical system in preserving comfortable internal temperatures, energy efficient buildings have become identical with quality, comfort, and ultra-low energy buildings that require a lesser amount of energy for space heating and cooling (Wimmer *et al.*, 2013). The building envelope plays a significant role on the energy consumption of the building as it includes all the elements that make up the building's interior and exterior such as: walls, windows, roof, doors and foundations. It is vital that all of these components of the building work collectively in order to keep the building warm in the cold season and cool in the hot season (Gokarakonda & Kumar, 2016).

Prior to the early 20th century, energy efficient design elements were mostly employed to control indoor climate. In fact, using natural occurrences to attain indoor comfort has been well recognised since the early periods. The vernacular architecture such as the Malay Kampong architecture has reacted with such phenomena as an excellent result for tropical climate region. It realizes the optimum comfortable indoor temperature through the most days of the yearlong by equating the volume adopting and the space taming with the diverse natural elements forces of the atmosphere, sun, biosphere, and climate which are known in these days as passive design strategies. According to Adenan (2013), the vernacular architecture has been recognized as a climate responsive approach that accomplishes sustainability in human environment, building for sustainability may need to reconsider back these pre-industrial times energy efficient design techniques and principles, so as to draw a stronger insight in encountering the human quality of life in built environment for the modern day.

Due to technological evolution and advancement, artificial systems were introduced in the form of machines to control indoor temperatures and lighting, it became an entirely different profession (Syed & Asif, 2012). This evolution of technology introduced both artificial systems of lighting and air conditioning equipment to improve internal thermal comfort conditions of the buildings. Identifying the global effect that buildings and their construction have on the environment, reduction in the impact of the energy use on the natural environment and exploring ways to attain sustainability through energy efficient design elements will further enhance the built environment.

## 2.2 Building Related Energy

Building-related energy can be seen as the energy needed for cooling, ventilating, heating, and lighting of buildings (Norbert, 2014). The consumption and use of this energy depend on the function and usage of the building. Most of the energy expended on building is for cooling, lighting, heating, and ventilation for the comfort of the occupants of buildings. In recent times, the built environment has contributed largest to greenhouse gas emission as a result of the action of heating, cooling which are carried out by means of fuel generators. Passive energy efficient design elements are ways in which the environment can be saved from this unnecessary emission of harmful gases into the environment.

## 2.3 The Concept of Energy Efficient Design Elements

Energy efficient Design refers to measures put in place to design a building through the use of natural movement of air and heat, inactive solar gain and cooling so as to maintain a good indoor air quality (Gokarakonda & Kumar, 2016). In addition, Cobalt Engineering & Hughes Condon Marler Architect (2012) in their research on energy efficiency defined energy efficient design as a design that works with the environment to omit undesirable heat or cold, taking the advantage of the sunlight and breezes through the use of design elements such as shading devices, form and orientation, and landscaping. Through the use of energy efficient solutions such as shading devices, building form, appropriate building colours, landscape elements, it is possible to eradicate, or to the lowest minimum reduce the use of mechanical systems and the building energy demand as well as the carbon dioxide ($CO_2$) emissions. Energy efficient design involves collecting, storing, distributing and controlling energy flow through natural processes of cooling and ventilating. Energy efficiency becomes very effective with the application of natural energy to preserve conventional energy for attaining thermal comfort. Gokarakonda and Kumar (2016) in their research on passive energy efficiency listed some of the energy efficient elements that can be employed to achieve energy efficiency, they include the form of a building, water bodies, building mass, landscape design, courtyard, skylight, atrium or light well, natural ventilation and daylighting, building orientation, building colour, insulation, use of balconies, building thermal mass and shading. The chief objective of energy efficient design is to lessen or totally remove if possible the necessity for active mechanical systems while retaining indoor air quality.

Designing a passive house requires careful preparation and planning, which consist of the application of these basic principles such as overhangs and shadings, building orientation, insulation, thermal mass, double or triple glazing, appropriate openings, and colour of the building. The Passive House Idea can be explained as follows: A Passive House is seen as a building in which thermal comfort can be assured by post-heating or post cooling the air mass flow needed for indoor air quality (William, 2019). The solar fruit tree shown in Figure 2.0 indicated the result of applying energy efficient design elements.

The Figure 2.0 ranked energy efficient elements according to cost. As the triangle moved from bottom to top, the cost of cooling and lighting the building also moved up. It is therefore advisable to adopt energy efficient elements that can make the building to expend minimal cost in the course of cooling, lighting and ventilating it.

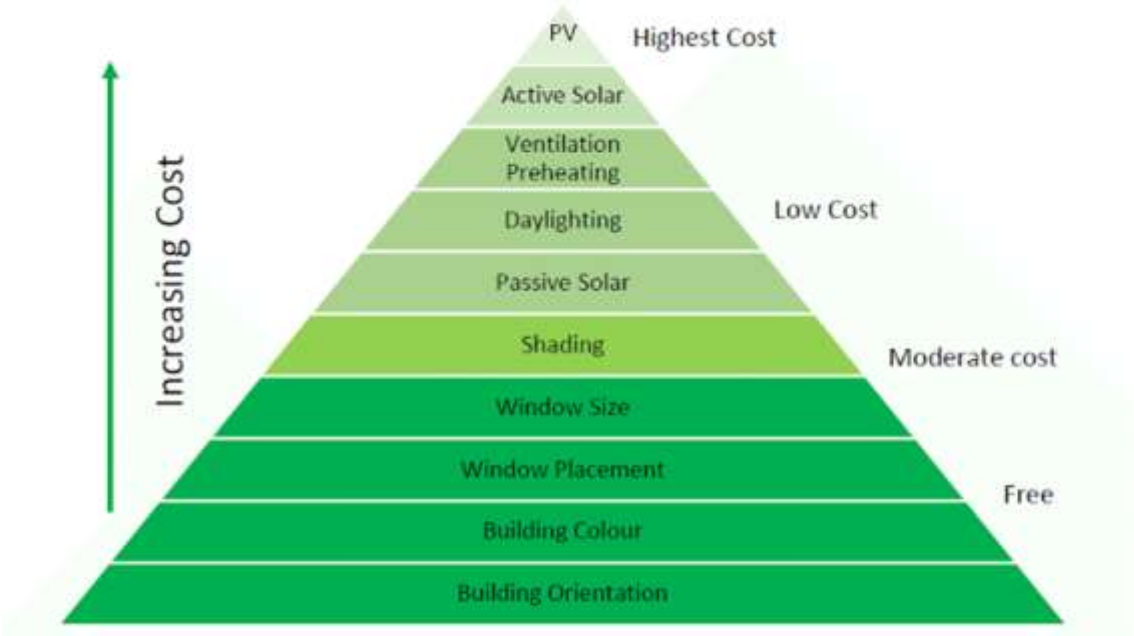



**Figure 2.0:** The solar fruit tree
**Source:** William (2019)

There is little or no cost implication in incorporating passive solutions at the design phase of the building. These solutions aid in decreasing carbon dioxide ($CO_2$) emissions and minimize usage of mechanical means for heating and cooling. The energy efficient design elements are discussed below.

### 2.3.1 Passive design through orientation

McGee and Jeffery (2013) in his opinion stated that orientation is seen as the way a building is positioned on site so as to take advantage of climatic conditions such as sun, wind and rainfall. Walls facing east and west receive the most amounts of radiation, mainly in hot periods. Abimaje and Akingbohungbe (2013) in their research on energy efficiency stated that the best building orientation in the tropics is rectangular with the longer axis running east-west in order to lessen solar heat gain through the long façade. The amount of sun received by the building is dependent on these factors: The geographic latitude of the site which defines the elevation of the sun in the sky, the placement or positioning of the building on the site, positioning of rooms in the building, the season of the year, the conditions of the local cloud which can block the radiation of the sun, the angles in-between the sun and the surface of the building because maximum solar gain take place when building surfaces are at right angles to the sun rays, the type of windows and glazing used in the building as regards its absorption or reflection or radiation.

In summary, the geographic latitude of the site, which determines the elevation of the sun in the sky, and the positioning of buildings on the site are important considerations when orientating a building on site to take advantage of the sunlight. Equally, adopting rectangular building form and making the longer side of the building or the side with the highest number of openings to run in the east-west direction will go a long way to minimize heat gain during the day.

### 2.3.2 Overhangs and shading for energy efficient design

Overhangs and shading help in reducing overheating in hot seasons (Tin- Tai, 2017). Shading devices and sun control that are well-designed can dramatically decrease heat gain and cooling requirements at peak periods, and also enhance the quality of natural lighting in interior spaces. Solar shading and sun control devices such as window blinds, crates, balconies, horizontal and vertical shading elements also help to enhance visual comfort of users by regulating glare and decreasing contrast ratio, this often lead to improved comfort and satisfaction.

The use of overhangs and shading devices is significant to energy efficient design; especially in adopting daylighting and passive solar heating through sun control. During hot periods, external window shadings such as horizontal and vertical shadings, balconies are brilliant ways to avoid unwanted solar heat from having access to interior spaces. Overhangs and shading devices should be properly sized on the surface of the building that receives the most sunlight to ensure adequate shading. Careful design of shading devices must be made considering the size and slope to let in sunlight during cold season and provide shade in hot seasons. The geometry of the building, angle of incidence of sun and visual appearance of the devices are to be taken into consideration at the initial design stage to meet technical and aesthetic aspect in the whole architecture.

As shown in Figure 2.1, ordinarily using roof overhangs can solve a lot of indoor climatic problems. Roof overhangs can prevent sunlight from entering a building during the hot seasons when sunlight is not needed and how the same overhang can be used to direct sunlight into the building during cold seasons to heat up the interior space of the building.

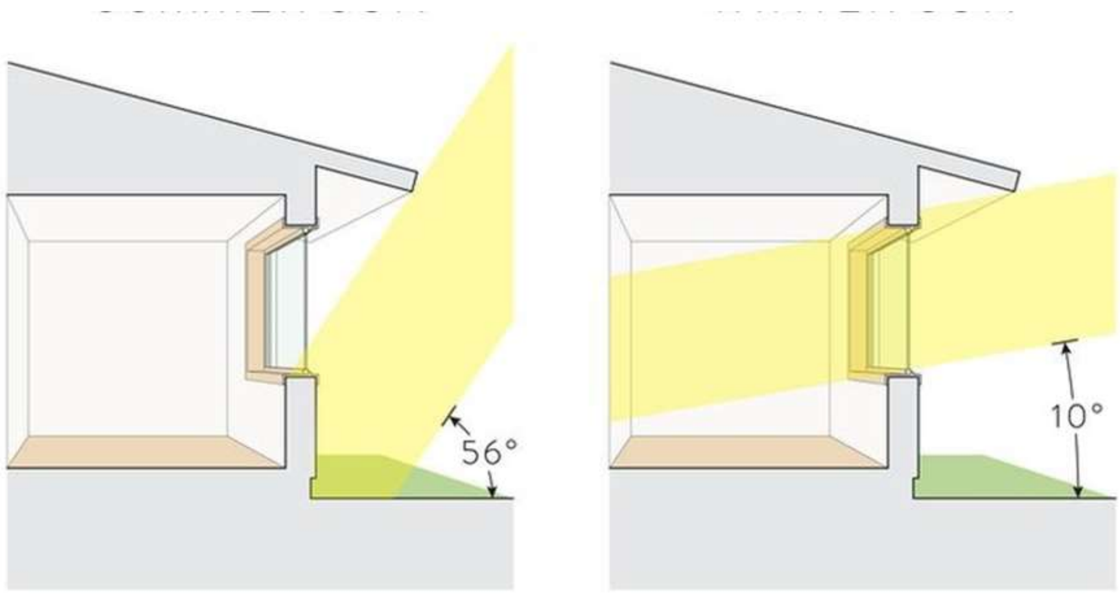



**Figure 2.1:** Overhangs used in shading the building from high sun

**Source:** Tin- Tai (2017)

### 2.3.3 Energy efficient design through building insulation

Buildings should be well-protected in order to retain heat during cold season and keep cool during hot periods. Materials with insulation properties are poor conductors of heat. They form a barricade between exterior and interior spaces and serve to preserve warmth during cold periods between exterior and interior spaces, and maintain cold between interior and exterior spaces in heat periods.

The thermal performance of a building envelope is the main factor affecting energy consumption depending on the building's energy consumption structure. Thus, through the use of proper building envelope, thermally insulated walls can decrease the energy consumption of the building (Fanga *et al.,* 2014). It can be deduced from the above that building envelope has a great influence when it comes to reducing energy consumption of a building, and also, when proper buildings envelopes are selected, the building energy consumption will be reduced as a result. Suffolk (2012) also agreed that energy efficient insulation is important in both warm and cold climates because minimal energy will be expended in cooling the building in hot season and to heat up the building in cold season. In summary, when proper insulation is done for a building through proper selection of building envelope, the energy consumption of that building is substantially reduced and this will result in maintaining a good indoor temperature all year round.

### 2.3.4 Location and sizes of windows and glazing towards energy efficiency

Energy efficient openings are the openings that assists to reduce the use of artificial cooling and heating in buildings through appropriate sizes of fenestrations and materials. In many parts of the world, keeping solar heat out of the home is the priority, except during cold seasons, when solar heat gains and preservation of warmth becomes imperative. Energy consumption can be greatly reduced through the use of energy efficient windows with low emissivity and air tightness. Most importantly, reducing air leakage significantly can reduce infiltration load with simple weather stripping techniques and incorporation of photovoltaic panels also can produce electricity while absorbing radiation from the sun and minimizing heat gain through the envelopes of buildings (Kwon *et al.*, 2013). Heat gain or heat loss usually takes three (3) modes: heat transfer by radiation, heat transfers by conduction and heat transfer through infiltration. Ideally, this calls for tough solar shield for windows on the east and west sides, but different window solution for different orientation. This will improve thermal energy performance of the building envelope.

Glass doors and windows have very significant roles in allowing natural lighting and fresh air into office buildings. However, they are the major sources of unwanted heat gain in the tropics (McGee & Jeffery, 2013). In designing an energy efficient office, it will be ideal to design only north and south openings and remove east or west windows to avoid heat gain through radiation. When only south and North facing windows are not achievable, the number of west and east windows should be reduced and the number of south and north windows increased. Allowing openings on the east and west facades of buildings to be smaller than the openings on the north and south facades is another cheap approach to preserve energy and improve energy efficiency in office buildings (Lechner, 2014).

As illustrated in Figure 2.2, window panels can be used to reduce heat gain in office buildings. The technology involves designing windows with double glass panel with an air fill in between the window panels. This air fill will serve as storage for the hot air that is coming from the building surrounding. The internal glass traps the hot air and disallow it from moving into the office space. The weathers stripping is a technology installed the window to prevent heat loss or heat gain through gab between the window sashes and frame because even a little gap between the sashes and frames can be a source energy waster.

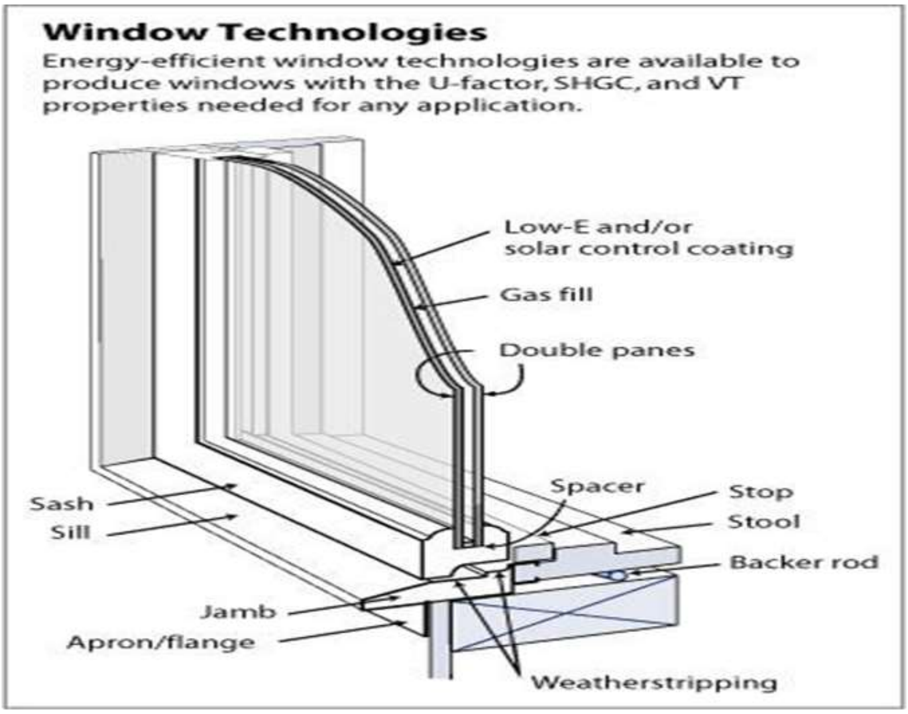



**Figure 2.2:** Cross section of a double-paned glass with solar control coating
**Source:** Lechner (2014)

### 2.3.5 Thermal mass for energy efficient office building

Energy efficient thermal mass involves materials or medium that absorbs and stores warmth when needed. Excess solar heat gain is stored and used up in conditions where there is no sun, as during the night. The heat absorbed during the hot season by the thermal mass materials such as concrete and brick keeps the house comfortable through the early evening hours, while the heat stored in these materials during cold season is given off at night to keep the house warm.

There are two ways thermal mass can function in an energy efficient house: through direct or indirect solar gain (Chiras, 2012). Thermal mass regulates the temperature of indoor spaces, minimizing the necessity for mechanical or artificial cooling in hot seasons and heating in cold seasons. It is most cost effective to take advantage of the thermal mass in buildings. Thermal mass elements could be tile or solar slab (called thick concrete floors), bricks used in the building design. Thermal mass elements can also be a large brick or an internal wall that is made of adobe or brick. Masonry walls or concrete wall (known as trombe wall) or water filled vessels (known as tube-wall) can also be used to collect heat and cold.

### 2.3.6 Achieving energy efficiency through day-lighting

Day-lighting is minimizing the need for artificial lighting in buildings through efficient use of natural light (Cuttle, 2013). Day-lighting is achieved via the use of controlled approaches and adapted components which are characterized into Conduction components (spaces used distribute natural light to the interior spaces buildings), Transparent components (example include windows - which allow natural light to move from one space or part of a building to the other), and Control components which are specially designed to regulate the manner at which light passes through transparent components.

Day-lighting design combines energy conservation and passive solar design with the aim of making the most benefit from sunlight. As illustrated in Figure 2.3, day-lighting uses alternative techniques such as roof lights and skylights, large windows to allow natural light enter spaces, using shallow plan to allows daylight to penetrate corridors and rooms, light wells can also be introduced in the centre of the building to allow light into the building.

Spaces are lit up mainly from side openings or windows, these spaces can be shaded away from direct sunlight by the use of deep reveals, protruding eaves, and overhangs and shading devices. Small openings are also used to allow day-lighting in buildings without unnecessarily causing much heat transfer. Roof lights are widely applied to meet the combined needs of daylighting and stack ventilation; while the full height concourse permits daylight into the central part of the building.

As illustrated in Figure 2.3, there are different methods and techniques that a designer can use to achieve day-lighting in an office building. these methods involve appropriate sizing of window openings, positioning of window opening to allow for maximum light into the building, the use of skylight, and light shelf. The Figure 2.3 also discussed how the light entering the interior spaces of buildings can be maximized and the intensity reduced through the use of filter materials, overhangs, louvres, vegetation by the windows, and screens.

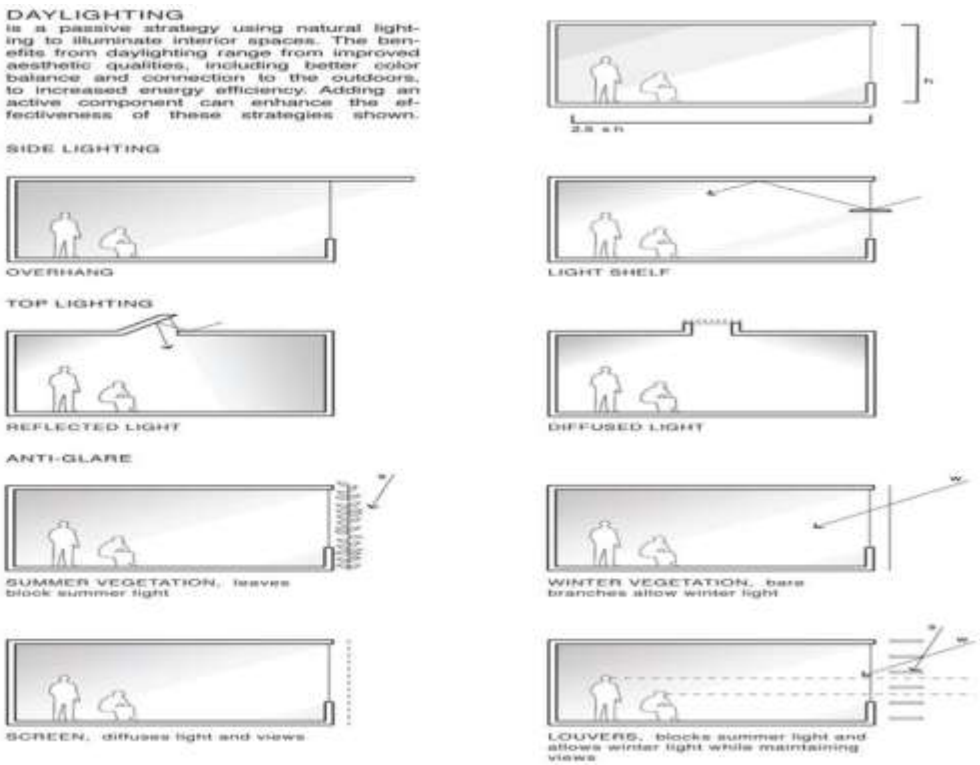


**Figure 2.3:** Showing day-lighting in the interior of the building
**Source:** Cuttle (2013)

### 2.3.7 Passive solar heating for energy efficient buildings

In cold seasons, east facing windows provide access for solar heat and also act as insulation against cold. In hot seasons, the strategy is to admit sunlight and conserve heat. Large windows are positioned due east for maximum solar access in the case of passive renewable energy. Materials that can equally absorb and release heat from the sun should be used for east glazing. The primary requirements to enhance the use of passive solar heating is buildings orientation. Building orientation should be within 30˚E to take benefit of the early morning sun, while giving those placed on the South and West to take advantage of midday sun thereby cutting back the evening heating period, concentrated east-glazing is considered in order to meet heating requirement of the living rooms.

### 2.3.8 Energy efficiency through landscaping

The heating and cooling cost of buildings represents one of the major expenses for any organization. High energy usage for indoor climate control is not only costly but contribute excessive amount of harmful gases such as carbon di-oxide to the environment. Various strategies can be used to reduce the effect of this energy on the environment, but well-designed landscaping can and should make office buildings more energy efficient. Proper landscaping around a building can save as high as 30 percent of the cost of heating and cooling (Mary *et al.*, 2004). Appropriate addition of just three trees will save an average household between two hundred and fifty ($250) to one thousand dollars ($1000) annually in energy cost. By incorporating some well-designed and planned landscaping elements into the general building design, returns on what was initially invested can be realised within a period of eight years.

For instance, using shady landscaping elements keeps a building from direct sunlight during the hot seasons and permits more sunlight to reach through openings during cold seasons (Hartungi & Jiang, 2011). In addition, trees planted on the southern and western sides of a building can keep the building cooler because they stop sunlight from directly reaching the building during the cold periods; then, after the trees shed their leaves, the trees give sunlight more access to the building during hot seasons.

As illustrated in Figure 2.4, landscaping elements used at the right time and at the right places can lead to reduction in energy consumption through energy efficiency. Furthermore, tall deciduous trees can be used to shade the west and south side of a building. trees planted on the west and south sides provide the greatest energy savings since they shade from the afternoon’s hottest sunlight. On the northern sides of buildings, evergreen trees can be planted to block the *Harmattan* wind and serve as wind breakers. On the eastern side of buildings, large trees can be planted to provide shade from the morning sun. small trees planted around building windows can serve as purifiers for the air entering the building.

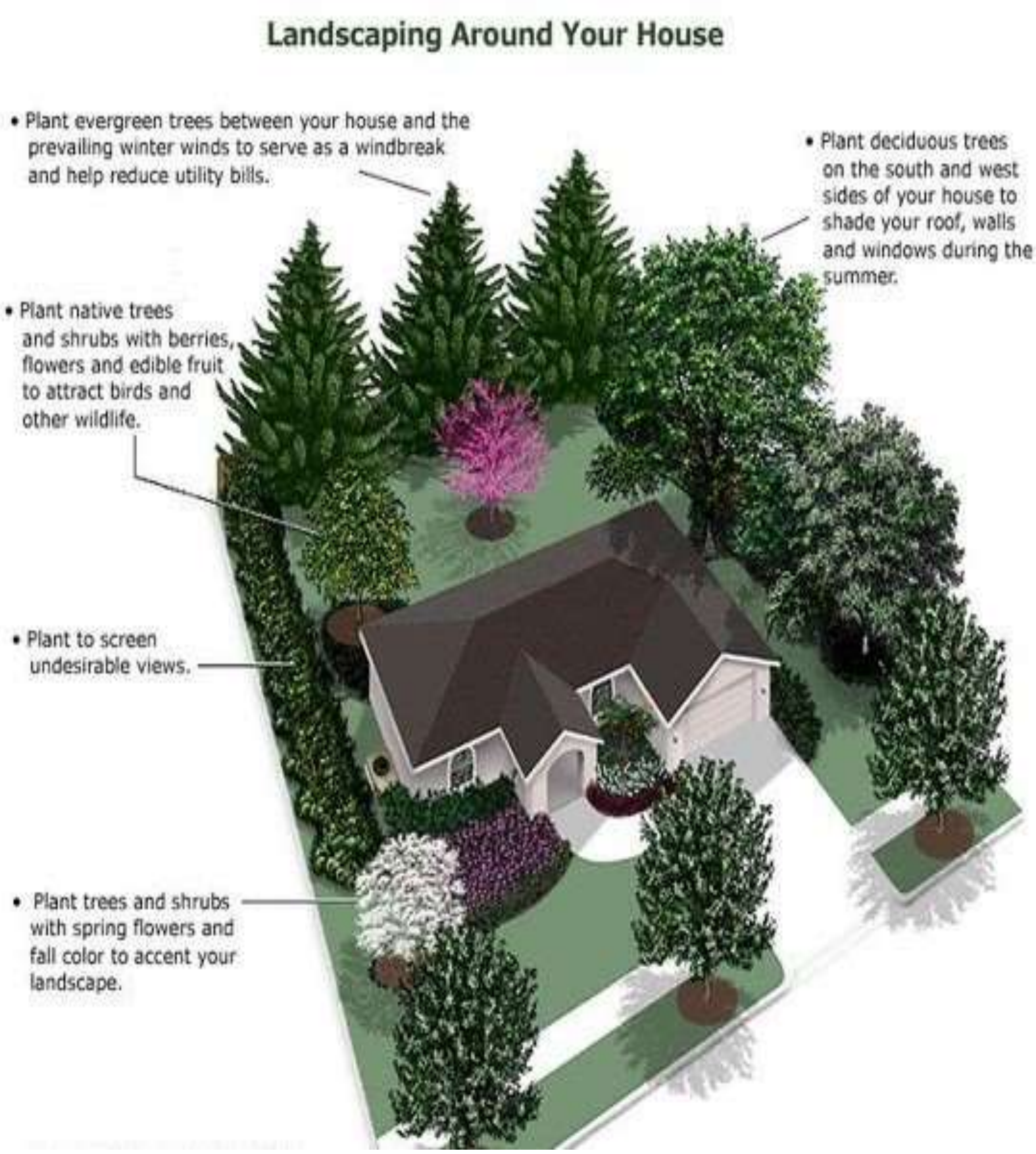



**Figure 2.4:** Showing how vegetation can be used for energy efficiency
**Source**: Mary *et al*., (2004)

## 2.4 Passive Cooling Towards Energy Efficient Office Buildings

Natural means of cooling were used in buildings before the introduction of refrigeration technology. These means include; Breeze that flow through openings or windows, water that evaporates from fountains and springs, and large quantities of earth and stone to absorb heat at daytime.

These methods minimized, and in some other cases eradicate the need for mechanical means of conditioning the air. Many modern buildings have high internal gains, and thermal comfort would mean to keep the indoor temperature lower than 24°C, comfort refers to balance between humidity and temperature. By using passive cooling techniques in modern buildings, cost of equipment and cooling through mechanical air conditioning is reduced or eliminated.

### 2.4.1 Energy efficiency through natural ventilation

Ventilation through natural means is an effective method to save energy expended in buildings and to enhance quality indoor air. Natural air circulation can reduce the energy needed in buildings, bring about thermal comfort, and also maintain good indoor environment (Zhao & Xia, 2002). Usually, the cost of energy for a building which is ventilated naturally is 40 percent less compared to an air-conditioned building (Energy Consumption Guide (ECG), 2003). This natural method of cooling uses mainly air movement to ventilate occupants' spaces (Chen, 2019). The forces that drive natural ventilation are buoyancy and wind. The difference in the pressure of wind along the facade and the differences between external and internal temperature generate a natural air exchange between internal and external spaces. The opposite sides of the building have windows positioned to improve the process of crossed ventilation. Designers decide on enhancing natural ventilation with the use of tall spaces within buildings in the form of stacks or chimneys since there is no absolute control over the occurrence of natural breeze.

The openings are positioned close to the top of the walls to allow warm air to discharge, while cooler air moves into the building from the openings at the lower level. For buildings to be well ventilated, they are to be opened during the day for air flow (Freire, 2013). Figure 2.5 illustrates the different types of natural ventilation and the ways in which a space can be naturally ventilated; the types of ventilation include the crossed ventilation in which openings are created at two sides of a space preferably the opposite sides, and the single sided ventilation in which opening (s) are created on one side of a space.  Figure 2.5 also showed the different performance of openings when they are placed on any sides of a building.

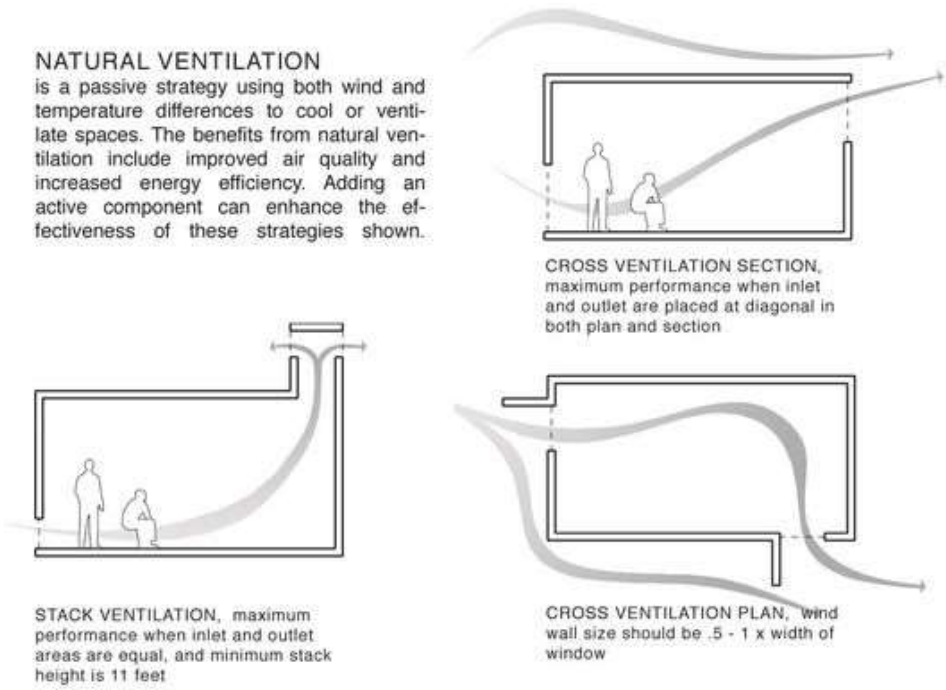



**Figure 2.5:** Natural ventilation with the assistance of air blown into an indoor area
**Source:** Freire (2013)

### 2.4.2 Achieving energy efficiency through evaporative cooling

Indoor air temperature can be reduced by the process of evaporative cooling through evaporating water. This is usually done directly in space in dry climates, but through indirect approaches like roof ponds, evaporative cooling can be used in more temperate climates too. Evaporative cooling and ventilation are often complemented with artificial means, such as electric fans. They require considerably little energy to maintain comfort when likened to air conditioning system (Brown & Dekay, 2010). It is equally possible to adopt evaporative cooling in an entirely passive system that need no additional machine to operate. An evaporative cooler is used to cool the hot air that comes out from the building. the evaporative cooler contains water, when the hot air from the interior of office buildings comes in contact with the water, it cools down the air and the cool air goes back into the building. This process is repeated, thereby keeping the office spaces cool. Water bodies around the site or around the building can also serve as coolant for the hot air that comes from inside the building.

## 2.5 Energy Efficiency in Buildings

According to Hyde (2017), the building's energy efficiency can be achieved through energy efficient design elements and reduction in the energy requirements through passive building materials, passive heating, cooling and lighting. An energy efficient building is a building that applies passive technologies while functioning as per design, supplies the features and amenities appropriate for that type of building, and which can be operated in a manner as to have less energy use compared to other related buildings (Gokarakonda & Kumar, 2016).

Public buildings include a wide range of building types such as offices, health institutions, academic institutions, police stations, religious worship centres, warehouses, accommodations, libraries, shopping centres, and parks. These different types of building have varying activities and unique energy needs but, as a whole, office buildings consume more than half their energies combined for cooling, heating, and lighting.

The most common sources of power used in the operation of office buildings in Nigeria are hydroelectricity and power from fossil fuel generators. Occasionally, office buildings also employ other energy sources in the form of district energy in heat and/or power form. This source is more used in situations where a good number of buildings are situated close to each other such as is in cities, university campuses, where it is more effective to have a central heating and cooling system that distributes energy in the form of steam or chilled water to many buildings (Oyedepo, 2012).

## 2.6 Energy Performance in Office Buildings

The need to conserve and use energy more efficiently in buildings has made researchers and designers to look for measures aimed at achieving energy efficiency. Energy Consumption in buildings can be categorised into three (3): Primary energy (which is the high energy value of the fossil fuels in their crude state), secondary energy (usually processed and produced from primary source of energy, and the useful energy (energy needed for undertaking a set task. The amount of energy demanded by a building is influenced by different factors and all of these factors are relatively dependent on each other. These factors include; Climate of the surrounding environment, indoor climate and function of the building, building envelope design, form and configuration, heating and ventilation system, lighting, appliances.

### 2.6.1 Energy audit of office buildings

Energy consumption in buildings has become a focal point in global discourses towards sustainable development and its wider interconnections with the environment. Studies have shown that energy consumption of built environment exceeds that of other sectors, including transportation (Brown & Dekay, 2010). More so, research has also shown that commercial buildings and office buildings in particular, account for a significant proportion of greenhouse gas emissions (Kasozi & Tutesigensi, 2007). Africa is characterised by poor energy supply infrastructure. electricity consumption in Africa accounts for only 4% of the global electric energy availability. in fact, only 40%, of the populations in Nigeria, have electricity.

## 2.7 Energy Growth and the Need to Address its Effects in Office Buildings

In terms of energy consumption of office buildings in the tropics, mechanical cooling through the use of air conditioners requires a more energy compared to heating (Alders, 2017). However, some countries in the tropics that fall within developing countries consume little amount of energy when compared to those in advanced countries. In addition, some countries in the humid climate consume very small energy when compared to developed countries.

In tackling the need to minimize the effects of the current energy crises and impending energy demands, four main aspects have been reached for preserving energy resources, these include: Reduction in the consumption of energy in buildings through the management of energy and passive energy conservation measures, urgent need for replacements and renewable sources of energy, buildings design for the realisation of thermal efficiency which include better insulation, water conservation.

## 2.8 Benefits of Energy Efficiency in Buildings

Energy consumption is an essential element of development. Though increased energy usage undoubtedly has numerous advantages, we are equally becoming even more aware of the harmful effects of using these energies (Yamba, 2016). We globally and locally experience these destructive impacts in the form of climate change and dilapidation of local environments in terms of poor quality of air, soils degradation, depletion of resources, and also as noise pollution. However, more efficient use of energy at all phases of the supply/demand chain could reduce the negative impacts of energy consumption, while still allowing the same economic development. Some of the benefits are discussed below.

### 2.8.1 Reduced resource consumption and minimized life cycle cost

In addition to the general environmental benefits that comes as a result of passive energy efficient buildings, there are equally economic benefits attached. Reduction in heating and electrical bills are chief benefits that will make one to improve a building to gain energy efficiency. Also, according to the Environmental Protection Agency (IEA) (2015), installing these energy efficient elements will work effectively to "future-proof" the building through creating investments that will be selling points into the future. Generally, even when there is an initial sum of money that must be invested to enhance energy efficiency, proprietors or investors will often recover these monies in a short period of time because of reduction in energy expenses. This time for payback according to the Natural Resources Canada (NCR) (2015) can be really short, taking only a few years. Methods of integration are being researched in different countries as many buildings were not designed from beginning with all-inclusive operational approach. However, to minimize energy demand in current development trends, building owners and occupants are reconsidering the incorporation of different systems in their buildings; for instance, buildings are now integrated with water management and alternative power generation with sustainable roofs and Living walls to bring down costs (Francis & Lorimer, 2011).

Life cycle costs of a building depend on the insulation performance of the walls, shape of the building, area of floor and ceiling; ventilation and air conditioning systems, heating and cooling requirements (Pitts, 2017). Minimizing the amount of energy used for the building's operation will improve its energy efficiency and reduce maintenance and running costs significantly.

### 2.8.2 Reduced environmental impact and healthier indoor environment

The need to use fossil fuels to power generating sets to provide energy for operation is reduced when the building is energy efficient and as a result, greenhouse gas emission is reduced. Also, relying on non-renewable fuel sources lacks sustainability and it involves usage of more and more damaging processing means to acquire these fuels. The built environment as stated by the United States Green Building Council (USGBC) (2015) accounts for nearly 40% of total energy use in the United States of America, thus passively designing these buildings with energy efficient elements will reduce the dependence on non-renewable fuel. Reducing the number of greenhouse gases also has both local and global environmental benefits, this is because monies that should have been spent of acquiring these fuel can now be channelled into other aspects that can improve the locality.

An energy efficient building will promote a healthy indoor environment for its occupants. There are significant considerations in creating comfort conditions during the design phase. For example, size of openings to allow sufficient ventilation and natural light will minimize the use of artificial lighting to brighten up work and living spaces. However, introduction of vegetation in the form of Living walls and sustainable roofs can reduce airborne pollutants like dust and pollen. Plants also filter noxious gases given off from the furniture and fittings placed inside the building. It is estimated that one meter square ($1m^2$) of grassed rooftop takes away 0.2kg of airborne particles from the air every year (Young *et al*., 2015).

### 2.8.3 Emissions and health benefits

According to the IEA (2017), fossil fuel-based electrical power generation generates air pollution particles that poses risks to the health of living things which include respiratory illness from fine-particle pollution and ground-level ozone. Burning of fossil fuels for power generation is the major source of greenhouse gas emissions from human activities, it also contributes to global climate change as stated by the United States Environmental Protection Board (USEPA) (2017). Enhanced energy efficient designs and increased use of renewable energy can lead to massive reduction of fossil fuel-based generation and its related adverse health and environmental consequences.

### 2.8.4 Improvement in designing of building envelope

Location and surrounding features influence the temperature of a building. For instance, trees, shrubs, and topography provide shade and serve as wind brakes. Solar passive heating is achieved in cooler climates by positioning windows southwards to increase the amount of sunlight into the building. compact design of buildings including energy efficient window materials, proper thermal insulation of walls, well sealed doors, can reduce heat loss by 25% to 50% (Lam, 2000). Improved thermal insulation, low emissivity glazing, and photovoltaic panels are other options to improve the performance of building envelopes. The addition of thermal insulation for building surfaces can be a cost-effective measure to improving energy efficiency (Lam *et al.*, 2011).

## 2.9 Energy Efficient Office Layout

Building energy performance has a vast effect on architectural designs, and energy-efficient design is therefore frequently studied (Pacheco *et al.*, 2011). Space arrangement design is one of the most significant jobs in architectural design. It is done around the phases of ‘scheme design’ and ‘design development’ in the initial design stage. The architectural space layout can be seen as the apportionment of different spaces which is decided based on the positions of interior partition walls as well as exterior walls. The variables of space layout design include functional allocation, space dimensioning (width, length, height), space form, interior partitions and interior opening.

The interior layout of office spaces can affect the energy in buildings predominantly by maximizing the benefits of daylight harvesting (Lobos & Donath, 2010). For buildings where harvesting of daylight is adopted, the internal arrangement of the office spaces will impact the energy consumption of the building significantly. For example, individual spaces in offices are usually apportioned to the more senior staff. These senior staff typically spend greater amount of their time outside of their own allocated office spaces. Ironically, it is also a common idea to assign the best office spaces with adequate daylighting to these staff. This will then cause the provision of daylighting to unoccupied office spaces, while electrical bulbs are switched on for all occupied open plan offices that are typically situated away from daylight. When these office spaces are swapped such that the office spaces with daylighting are used as open plan offices, more energy will be preserved leading to energy efficiency. There are several types of office layout, they are discussed below

The closed plan office structure uses complete height (floor to ceiling) wall to demarcate spaces into cellular offices. Services for office support are positioned along lobbies or in other spaces that were shared. The advantages of this layout include confidentiality, security and physical separation. However, organizations that practice this types of office arrangement will spend more resources in cooling the building as the offices are enclosed or partitioned. This type of office arrangement is not energy efficient as individual office spaces will require a cooling system. Other drawbacks of this kind of office layout are that it does not give room for flexibility when redesigning office furniture placement and it also reduces efficiency in the work output (Tiantian *et al.*, 2020).

Closed layout plan are mostly used by large corporations where the division of tasks are of high level. The idea of this office type began around 1960 to enhance efficiency and flexible areas that are based on working environments that are transparent. This office layout was established to create a clear work spaces and also bring improvement in group work. The open plan layout generated both visual and acoustic problems and this brought about the gradual refusal of this type of office layout. However, the open plan office layout is better than the closed plan/cellular layout as it allows a large working space to be ventilated and lit up without obstruction. The open plan office layout encourages energy efficiency because the spaces are not divided or partitioned and so do not require individual cooling systems.

An example of the office layout is shown in Figure 2.6, the individual office spaces will tend to consume more energy for cooling and lighting while the group office space will save more energy. This is because the individual office will require an independent cooling system just to make one staff comfortable, but the group office will only use one cooling system to make more than one staff comfortable.

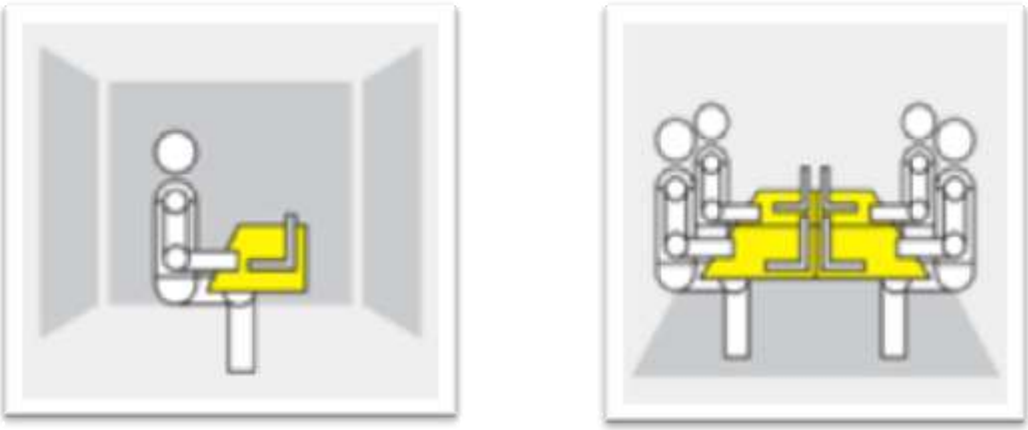


**Figure 2.6:** Illustrates the activities in a single space and group work space
**Source:** Chiras (2012)

### 2.91 Summary of Findings

Data collected from several secondary sources indicated that energy requirements of office buildings is increasing with the most demand being energy for cooling, lighting, and ventilating office buildings. With the mechanical technique used in cooling, lighting, and ventilating office buildings proving to have negative effect on the environments through emitting harmful gases such as carbon di-oxide, researchers are looking for methods in which this negative effect on the environment can be eliminated or reduced. Energy efficient design elements is a passive strategy that can be used to reduce the effect of this mechanical technique on the environment. These passive energy efficient elements include the use of landscape elements, appropriate building orientation, building form, appropriate shading device and building colour. These energy efficient design elements if properly used and adopted in office buildings can lead to energy efficiency, thereby bringing about environmental and economical sustainability which is the aim of every nation looking to save the world.

# CHAPTER THREE

## 3.0 RESEARCH METHODOLOGY

Due to the nature of the research as it dealt with the characteristics and functions of design elements of buildings, the descriptive survey method of research was adopted. Data was collected through the use of observation schedule as it is a suitable instrument for collecting data in this type of survey. Critical observation was conducted on the office buildings to assess the energy efficient design elements that were employed in their design and construction. The observation schedule was used to access energy efficient design elements like building form, insulation against heat, building colour, orientation, shading devices, evaporative cooling strategies, daylighting strategies, thermal mass and landscaping elements used.

Building observation was done for the different office buildings sampled. This method of observation can be adopted because of the practicality and reliability of the research (Debois, 2019). Observation method can also be used to uncover the trends in energy efficient office design by detecting the passive methods that previous designers have used to reduce energy consumption and enhance energy efficiency.

### 3.2 Data Types and Sources

The energy efficient design data that were collected for analysis in this research were obtained from both the primary and the secondary data sources. The primary data such as building orientations, building forms, daylighting strategy adopted, landscape elements adopted in the sampled office buildings were gotten from the field through the observation schedule prepared. Secondary data were gotten from review of past works by researcher. Systematically, the qualitative and quantitative methods of data analysis were both employed in this research, this was done in order to provide answers to questions about passive energy efficient elements in office buildings.

The qualitative research method was employed as it is useful for gathering the meaning, concepts, characteristics and descriptions of the energy efficient elements adopted in the sampled buildings. The qualitative method obtain insight on the problems of energy consumption in office buildings and equally develop ideas on how these problems can be solved through passive energy efficient design strategies. The quantitative method will be used to statistically measure the research by generating data that can be converted into useful figures, these data include size of openings, number of openings, size.

### 3.2.1 Primary data

For this research, primary data was obtained through survey. Direct observations were carried out by the researcher by visiting the different sampled office buildings in Abuja, Nigeria. As shown in Table 3.1, the office buildings were selected using the random sampling technique; this technique involves the researcher choosing the office buildings to be studied by chance with each member of the population having an equal chance, or probability of being selected (Helen & Saran, 2018). Observation schedule was used as the instruments in obtaining data from the field. The observation schedule presented checklist derived from the techniques and strategies obtained from literature; they include the landscape elements used and the extent of its application, appropriate building orientation, appropriate building form, appropriate shading device, daylighting strategies and building insulation against heat.

**Table 3.1: Sampled office buildings in the Federal Capital Territory**

| S/N | Names of Building. | Location |
|---|---|---|
| 1 | NNPC Towers | Central Business District |
| 2 | Churchgate Building | Central Business District |
| 3 | PTDF | Wuse Zone 4 |
| 4 | Bank of Industry | Maitama District |
| 5 | World Trade Centre | Central Business District |
| 6 | Corporate Affairs Commission Headquarters | Maitama District |
| 7 | Yakubu Gowon House | Maitama District |
| 8 | NCC Building | Maitama District |

**Source:** Author's fieldwork (2020)

The survey was conducted in two stages. The first stage was to compile the list of the sampled office buildings and then preliminary survey was conducted on one of the buildings to ascertain that every checklist was in order and that questions written were in line with the purpose of the research. The second part of the research involved visit to the sampled office buildings and compilation of the energy efficient data. Figure 3.1 indicated the type of energy efficient design elements data that were observed on the field.

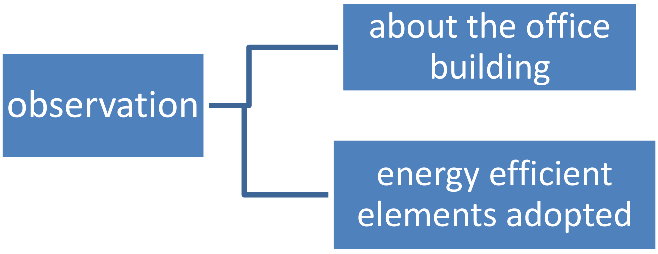



**Figure 3.1:** Type of data collected through observation schedule

**Source:** Author's work (2020)

Part of the quantitative data collected is ratio of number of persons using an office to the square area of that office space, this was used to determine whether standards are being followed when it comes to space occupation.

### 3.2.2 Secondary data

Secondary data was obtained from extensively reviewing literature on the passive energy efficient elements used in passively enhancing the energy efficiency of office buildings. Secondary data was obtained from relevant literature, conference papers, journals, presentations and online sources of data. The secondary data gotten are some energy efficient design elements such as building orientation, buildings form, shading devices, landscape elements. These energy efficient design elements are shown in Figure

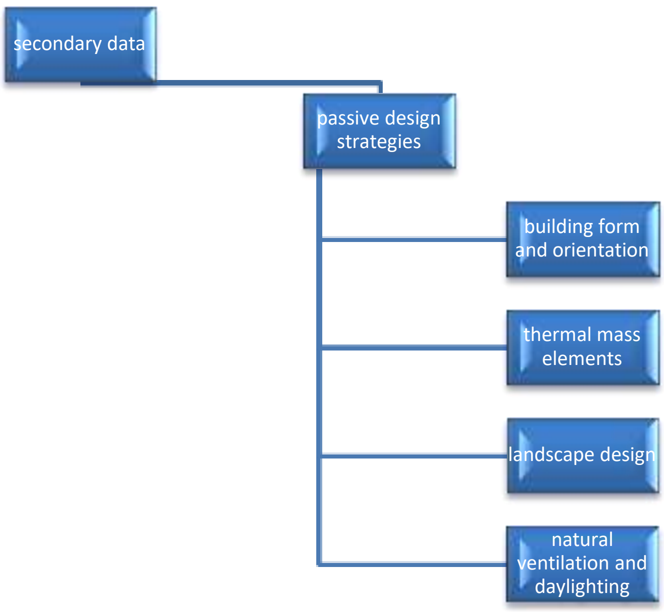



**Figure 3.2:** Passive design elements gotten from secondary data source
**Source:** Gokarakonda and Kumar (2016)

the secondary data presented in Figure 3.2 were some of the energy efficient strategy stated by Gokarakonda and Kumar (2016). They represented some passive energy efficient design elements used in the design of office buildings.

## 3.3 Data Collection Instruments

Based on the Qualitative nature of the research, observation schedule was adopted as instrument for data collection. Observation schedule is flexible, reliable and suitable data collecting instrument for this type of research work (Stephan, 2019). The observation schedule contains checklists that were used by the researcher to collect relevant information about the passive energy efficient design elements adopted in the existing office buildings. The prepared observation schedule was used to assess the individual office buildings based on the passive energy efficient design elements used.

### 3.3.1 Observation schedule

The observation schedule used was divided into two (2) sections namely sections A, and B. Section A provided information about the office buildings studied. The Section A consist of information which include; the name of the office building, the name of the organization occupying the office building, the location of the office buildings, the nature of work carried out by the organization occupying the office building, the organization to building fit, the type of office layout, and the type of office building. Section B provided information about energy efficient design elements used in the buildings, they include; form of the building, the orientation of the building, construction materials, type of shading devices, daylighting and ventilation strategy, construction materials, building insulation, building colour, and landscape design were outlined in checklist form. Section B also provided information regarding the passive design elements used in cooling and lighting the office buildings.

Figure 3.2 provided information that are used by the researcher to collect information from the site through observation. It provided the names of the office buildings selected for observation in the Federal Capital Territory, Abuja. The table 3.2 provided the information on the variables in the observation schedule. These variables were used on the sampled office buildings one after the other, it also contains information from the both sections of the observation schedule prepared.

**Table 3.2: Observation checklist for assessing office buildings**

| S/N | Variables. |
|---|---|
| 1 | Name of the building |
| 2 | Name of organization occupying the building |
| 3 | Ownership |
| 4 | Location |
| 5 | Activities carried out by the organization |
| 6 | Organization to building fit |
| 7 | Form and orientation of the building |
| 8 | use of operable windows |
| 9 | Overhangs and shading devices if any |
| 10 | Building insulation against heat |
| 11 | Landscaping elements used |
| 12 | Colour of the building |
| 13 | Daylighting strategies |
| 14 | Ventilation and cooling strategies |
| 15 | Construction materials |

**Source:** Author’s work (2020)

## 3.4 Sampling Technique

The method of sampling employed for this research work is the stratified random sampling. The stratified sampling technique shared the population into strata, this division was based on their shared characteristics. High-rise office buildings were chosen due to their expanded need to apply the passive energy efficient elements in other to reduce dependence on artificial means of cooling and lighting office buildings.

Therefore, eight (8) office buildings as shown in Table 3.1 above were chosen across the Federal Capital Territory.

## 3.5 Data Analysis and Presentation

Method of data analysis refers to the technique of providing answers to relevant research questions. For the purpose of this research work, SPSS version 2.1 was used in analysing the data derived through the observation schedules. The results were then transferred to Microsoft Excel which was used to generate the tables and charts presented in this research work. These tools were used because they are simple and provide accurate results and answers to the research questions. Tables, figures, charts were adopted to provide space analysis for the proposed office building design. Also, Plates were used to show the physica1 environment in the studied office buildings. Where required and necessary, photographs of the sites were captured to support and present more understanding and views of the study.

Sketches, plates and charts were also used to describe some of the features of the proposed office building. plates were used to show the results of the simulation conducted for the proposed office building. this is in other to ensure that the energy efficient elements adopted were adequate and function to reduce energy requirements of office buildings.

## 3.6 Summary of Findings

in summary, the research adopted the descriptive method of research in which data was collected through observation schedule and questionnaire as instruments for data collection. Primary and secondary data sources were used to generate data for the research. The research also adopted the stratified random sampling method in which eight (8) high-rise office buildings in the Federal Capital Territory were selected for study. The result gotten from the field was then analysed through SPSS version 2.1 and also through statistical method. Also, Users' perception was analysed statistically and measured with the Likert scale which is a universally accepted scale for measuring data in research.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSIONS

This chapter was used for the presentation of the results of the data analysis generated in the course of the study through research methodology as discussed in the previous chapter. These results and implications are presented based on the objectives of the study outlined in chapter one above.

### 4.1 Assessing the Basic Energy Efficient Design Elements that can be Applied to Achieve Energy Efficiency in Office Buildings.

There are several passive design elements that can be applied in the design of buildings to achieve energy efficiency depending on the condition of the weather and the environment in which the building is situated. Some of these elements are discussed below;

#### 4.1.1 Energy efficient building orientation

Generally, orientation of buildings can be decided by the influence of views, prevai1ing winds, site landscape or topography, housing arrangements, adjacent buildings. In other times, urban planning is dependent on existing planning, road layout that are in existence, road camber, and ease of execution can simply determine orientation, as indicated in figure 4.1. Sometimes, it is unfortunate that the building design does not put into consideration the energy-savings that comes along with proper building orientation. Take into account that prevailing wind, building layout to achieve cross ventilation, or rotating the building to achieve solar gains in cold season are restricted by the above reasons.

McGee and Jeffery (2013) referred to building orientation as the way a building is positioned on the site so as to take advantage of climatic features such as cooling breezes and sun. Walls facing east and west receive the highest amounts of radiation from the sun, particularly in hot seasons. According to Abimaje and Akingbohungbe (2013), rectangular form is the best building form to adopt in the tropics, with long axis of the building running east-west in order to minimalize heat gain through the lengthy façade.  As shown in Figure 4.1, the amount of sun received by the building on site is dependent on the geographic latitude of that site, the altitude of the sun in the sky, the position of building on site with respect to the rooms in the building, the season in the year, the conditions of the local cloud which can block solar radiation, the angles between the building surfaces and the sun (highest solar gain happens when building surfaces are at right angles to the sun rays), the type of windows and glazing used in the building as regards its absorption or reflection or radiation.

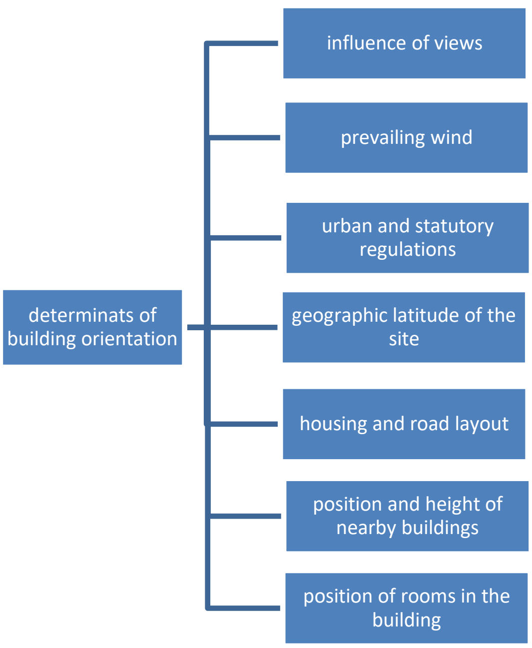



**Figure 4.1:** Determinants of building orientation
**Source:** McGee and Jeffery (2013)

Table 4.1 shows the different buildings orientation on site. The best orientation in the tropic is when the side of the building with lengthier axis runs in the east and west direction. In cases where the only options are to orientate a building in the north-south direction, then it will be recommended that the number of windows facing the east and west direction should be minimized to reduce radiation.

**Table 4.1: Building orientation in the tropics**

| S/N | Building orientation in the tropics (longer axis) | Checklist | Recommendation |
|---|---|---|---|
| 1 | North-south building orientation | x | Windows and openings facing west and east should be minimized to reduce radiation into spaces |
| 2 | East-west building orientation | ✓ | Windows and other opening should be designed to take advantage of the less radiation in this orientation. |

**Source:** Abimaje and Akingbohungbe (2013)

### 4.1.2 Energy efficient overhangs and shading

Energy efficiency is recognised presently as one of the suitable and fastest approaches to decrease any energy associated emissions which is related with air pollution, global heating and change in climate (Dincer, 2008). Air conditioning trailed by artificial lighting take the biggest percentage of energy consumption for buildings in hot-humid climate (Igbal & Al-hamoud, 2007). Apart from improving the aesthetic appearance of a buildings, overhangs and shading devices on facades of buildings help to lessen building energy consumption. Several scholars have carried out studies on enhancements and effect of shading devices on the energy consumption of building where numerous kinds of energy efficient design elements can be employed. Study conducted in Hong Kong revealed that an energy efficient covering or envelope could decrease as much as 35% of entire cooling demands (Chan & Chow, 1998).

Overhangs and shading help in reducing overheating in hot seasons (Tin- Tai, 2017). Well-designed shading and sun control devices dramatically decrease building peak heat gain and cooling requirements and improve the daylighting quality of interior spaces. Solar shading and sun control devices such as blinds for window, crates, horizontal and vertical shading elements equally help to increase visual comfort of user by reducing contrast ratio and controlling glare, this often lead to improved comfort and satisfaction.

Overhangs and shading devices should be properly sized on the surface of the building that receives the most sunlight to ensure adequate shading. Careful design of shading devices must be made considering the size and slope to let in sunlight during cold season and provide shade in hot seasons. The geometry of the building, angle of incidence of sun and visual appearance of the devices as indicated in Figure 4.2 are to be taken into consideration at the initial design stage to meet technical and aesthetic aspect in the whole architecture.

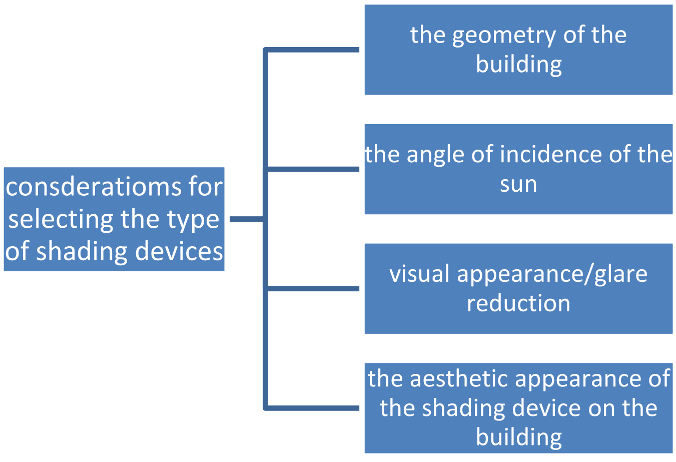


**Figure 4.2:** Consideration for selecting the type of shading devices
**Source:** Author's work (2020)

As indicated in Table 4.1, different building orientations can have different shading types in other to get the shading of the building correctly. It has also been suggested in the table 4.2 that adjusting the horizontal and vertical shading devices to suite different weather conditions can also lead to a more effective energy saving.

**Table 4.2: Orientation and suggested shading type**

| S/N | Orientation | Recommended shading type |
|---|---|---|
| **1** | North | Horizontally placed fixed or flexible shading devices over openings. |
| **2** | East and West | Flexible vertical screens outside window |
| **3** | North-West and North-East | Flexible Shading devices |
| **4** | South-West and South-East | Shading with vegetation |

**Source**: Tin- Tai, 2017

### 4.1.3 Energy efficient building insulation

As stated by the Electrical and Mechanical Services Department (EMSD) (2001), the increased consumption of electricity by the built environment, particularly in the heat period, is instigated by the increasing demand for air conditioning systems to create indoor comfort for occupiers of buildings. The usage of air-conditioning systems has increased from 50% in 1989 to 90% in 1993 (Lam, 2000). The phenomenon proposes that through energy efficient building insulation, the necessity for air conditioning in office buildings can be lessened thereby leading to reduced energy consumption and resultant greenhouse gas discharges. Buildings should be well protected so as to hold heat during cold seasons and keep cool during hot season. Insulation materials do not conduct heat, create barricade between external and internal spaces, and help to preserve warmth in cold seasons between interior and exterior spaces and maintain cold between interior and exterior spaces in hot season.

Depending on the structure of building's energy consumption, the main factor affecting energy consumption is the thermal performance of buildings envelope. Thus, through proper building envelope and thermal insulation of walls, energy consumption of the buildings can be reduced (Fanga *et al.*, 2014). As researched by Cheung *et al.*, (2005), the thicker the insulation material added to a building, the more the lessening in both annual needed cooling energy and cooling load, irrespective of the location of thermal insulation materials. In summary, when proper insulation is done for a building through proper selection of building envelope, the consumption of energy for that building will be decreased and this will result in maintaining a good indoor temperature all year round. For proper selection of insulating materials, the physical and chemical characteristics of various insulating materials have been analysed in Table 4.3.

**Table 4.3: Characteristics and types of insulation materials**

| S/N | Materials | Density ($kg/m^3$) | Specific Heat (J/kgK) | Thermal conductivity (W/mK) |
|---|---|---|---|---|
| **1** | Concrete | 2400 | 653 | 2.16 |
| **2** | Cement/Sand Plaster | 1860 | 840 | 0.84 |
| **3** | Ceramic tile | 1900 | 800 | 0.38 |
| **4** | Quarry tile | 1700 | 900 | 0.80 |
| **5** | Gypsum | 1120 | 837 | 0.71 |
| **6** | Vinyl tile | 32 | 800 | 0.04 |
| **7** | Wood | 112-849 | 2301 | 0.022 |
| **8** | Polystyrene | 200-800 | 1130 | 0.03-0.04 |
| **9** | Aluminium | 2698 | 871 | 225.0 |
| **10** | Granite | 2750 | 790 | 1.6-7.7 |

**Source:** Cheung *et al.* (2005)

### 4.1.4 Energy efficient thermal mass

External climatic parameters (outdoor temperature, solar radiation) and extremely inconstant internal loads (human actions, equipment) are the two factors that principally affect indoor air temperature. During the hot season, these parameters result in swing of temperature, with peak taking place around noon and early afternoon periods. In these times of the day, high outdoor temperatures eradicate the use of simple substitute passive cooling methods like natural ventilation. As a result, to preserve thermal comfort through these hours, it is essential upon entry to immediately take away all excess heat from the room by a high energy demanding mechanical system. This process requires an enormous system that has the capability to handle the short period peaks of the cooling loads.

In reducing cooling load peaks and indoor air temperature, and in transferring the load to a future time in the day, there is possibility of storing heat in the material of the outer covering and the building interior mass. The material for storage is the construction mass itself also referred to as thermal mass. The thermal mass is enclosed in walls, ceilings and floor of buildings which are constructed of materials whose heat capacities are high, they include brick, concrete, and tiles as shown in Table 4.3. During heat and cold seasons, the thermal mass of a building can have very constructive effect on the indoor situations. The available energy from the high solar gains in the day is deposited and later released into the indoor environment. During the late afternoon and evening hours of cold seasons, the heat stored is transferred back into the interior spaces when it is needed most. This process satisfies part of the heating load and prevent high temperature and distress during the hot period of the day.

Heat is stored in the thermal mass element during heat season, this reduces cooling load peaks. As the remainder of the portion of the internal and external heat gain is contained inside the thermal storage materials, a reduced portion of the load will have to be taken away from the indoor space, while the deposited heat is gradually freed to the building interior. Due to the above, indoor air temperature differences persist within the comfort range for a good part of the day. This process reduces energy for cooling which can be about 20% in commercial buildings. Direct solar gain or indirect solar gain are the two ways thermal mass can properly function in an energy efficient house (Chiras, 2012). Table 4.4 has shown some of the thermal mass materials alongside their recommended positions within the building.

**Table 4.4: Thermal mass materials**

| S/N | Thermal mass materials | Recommended positions |
|---|---|---|
| **1** | Concrete | Can be used both for floors and walls |
| **2** | Bricks | On the wall of buildings |
| **3** | Tiles | Both floors and walls of a building |
| **4** | Stone or masonry | Floor and wall of buildings |

**Source**: Chiras (2012)

### 4.1.5 Energy efficient landscaping

The heating and cooling cost denotes one of the principal expenses for any organization. Aside from being expensive to purchase, high use of energy for the control of indoor climate contributes excessive amount of harmful gases such as carbon di-oxide to the environment. Various approaches can reduce this energy effect on the environment, but well planned landscaping should and can make office buildings more energy efficient. Proper landscaping around a building can lead to saving as much as 30 percent on heating and cooling cost (Mary *et al.*, 2004). According to Minfang (2002), the appropriate addition of just three trees will save the average household between one thousand dollars and two hundred and fifty dollars annually in energy cost. Landscaping that is well designed will lead to energy savings and can yield what was initially invested within eight years.

By incorporating energy efficient landscaping into the general building design, reduced energy cost is assured. For example, during the hot season, shady landscape design can keep a building from direct sunlight and allows enough sunlight to enter through windows during the cold seasons (Hartungi & Jiang, 2011). Additionally, trees planted on the west and south side of a building can keep the building cool as they block sunlight from falling on the building directly during cold seasons.

As illustrated in Table 4.5, trees planted on the west and south sides provide the greatest energy savings since they shade from the afternoon's hottest sunlight. On the northern sides of buildings, evergreen trees can be planted to block the *Harmattan* wind and serve as wind breakers. On the eastern side of buildings, large trees can be planted to provide shade from the morning sun. small trees planted around building windows can serve as purifiers for the air entering the building.

**Table: 4.5: Vegetation for landscape and recommendation**

| S/N | Building facade | Landscape elements recommendation |
|---|---|---|
| **1** | West side | Tall deciduous trees can be used to shade the building from then afternoon's hottest sunlight. |
| **2** | North side | Evergreen trees can be planted to block the *harmatan* wind and serve as wind breakers |
| **3** | Eastern facade | Large trees can be planted to provide shade from the morning sun. small shrubs can also be planted around the windows to purify the air. |

| | | |
|---|---|---|
| **4** | Southern facade | Tall deciduous trees can be used to shade the building from then afternoon's hottest sunlight. |

**Source:** Mary *et al.* (2004)

### 4.1.6 Energy efficient building form

The form of a building affects its total energy consumption as well as the solar energy that it obtains (Minfang, 2002). The radiation of the sun that hits a building can lead to increased cooling energy requirements up to twenty-five (25) percent (Elasfouri *et al.*, 2001). Accordingly, the form of a building does not only define the total area of the roof and façade that collects radiation but also the building surface open to the outside, and thus to loss of energy. As a building is designed, the proportion between its total volume and its outer surface should be as small as possible and should tend towards the ideal case of a hemisphere (Aksoy & Innali, 2006). Nevertheless, because of the issue in design and construction, this form is not achievable in many projects. For this reason, many researchers have begun studies of forms that are attainable with respect to energy efficiency.

Rectangular forms are encouraged in the tropics where lessening the effect that heat has on buildings is the main design concern. According to Abimaje and Akingbohungbe (2013), the finest orientation for buildings in the tropics is rectangular with the longer side running east-west to cut down heat gain through the long surface. Therefore, the impact of solar radiation on the rectangular building form is lessened as such, they need less energy than buildings with circular and oval forms. Table 4.6 shows the forms of the sampled office buildings.

## 4.2 Investigating Energy Efficient Passive Design Elements Employed in the Design of Office Buildings.

### 4.2.1 Forms of office buildings.

The form of any building which determines the outlook of its envelope has considerable effect on the energy requirement of the building. Reduction of the consequence of the heat on buildings is the main worry for buildings design in the tropics, this has led to the encouragement of rectangular forms. Buildings in the tropics should adopt rectangular form with their longer faces orientated to run in the east-west so as to curtail solar heat. Therefore, the impact of sunlight on some of the sampled office buildings like the CAC and the WTC buildings is reduced, as such, they require less energy when compared to some other sampled buildings like the PTDF and the BOI buildings that adopted circular and oval forms. Table 4.6 shows the different forms adopted by the sampled office buildings in the Federal Capital Territory. The forms of the PTDF and the NCC buildings have been shown in Plate i and Plate ii respectively. The PTDF building adopted different forms while the NCC building adopted the circular form.

**Plate i:** Form of the PTDF building in Abuja
**Source:** Author’s fieldwork (2020)


**Plate ii:** Form of the NCC building in Abuja.
**Source:** Author’s fieldwork (2020)

As shown in the table 4.6, most the of the office buildings visited have rectangular forms which conform with the standard in reducing energy requirement of office buildings. Other office buildings like the Bank of Industry, the PTDF Building, and the NCC Building are either circular or oval in form and therefore do not conform with the building code to reducing energy requirement of buildings.

**Table 4.6: Form of sampled office buildings**

| S/N | Name of building | Building form | Remarks |
|---|---|---|---|
| 1 | NNPC Towers | Rectangular | Conforms to reduce heat gain |
| 2 | Church Gate | Rectangular | Conforms to reduce heat gain |
| 3 | PTDF Building | Oval, rectangular, circular | Does not conform to reduce heat |
| 4 | Bank of Industry | Oval | Does not conform to reduce heat gain |
| 5 | World Trade Centre | Rectangular | Conforms to reduce heat gain |
| 6 | Corporate Affairs Commission office | Rectangular | Conforms to reduce heat gain |
| 7 | Yakubu Gowon House | Rectangular | Conforms to reduce heat gain |
| 8 | NCC Building | Circular | Does not conform to reduce heat |

**Source**: Authors' fieldwork (2020)

The figure 4.3 further analysed the forms of sampled office buildings into percentages. The rectangular formed office buildings made up 80% while the circular and oval are made up of 10% and 10% respectively.

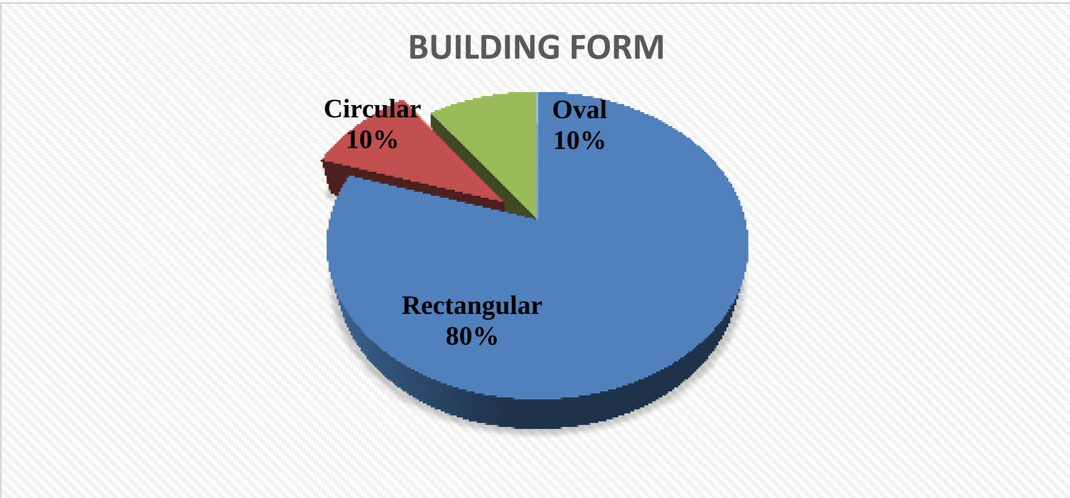



**Figure 4.3:** Analysis of office building forms
**Source:** Authors' fieldwork (2020)

### 4.2.2 Energy efficient building orientation

Another key determinant of the impact of the sun on a building is its orientation. How buildings are positioned on site with regards to the position and path of the sun have direct impact on the amount of heat the building receives during the day. To minimize heat, it is encouraged that the longer parts of the building do not face the east or west directions. Sun rises from the east and sets in the west. Its effect is felt more along that path. Table 4.7 shows the orientation of the sampled office buildings on their respective sites. As indicated in the table 4.7, all the sampled buildings conform with the best practice when it comes to orientation with their longer axis running east-west direction. Only the Bank of industry building does not conform with this rule as its longer axis/the side with most windows run in the East-west direction.

**Table 4.7: Orientation of sampled office buildings**

| S/N | Name of building | Orientation | Position of building on site |
|---|---|---|---|
| 1 | NNPC Towers | North-West | Conforms to reduce heat gain |
| 2 | Church gate | North-South | Conforms to reduce heat gain |
| 3 | PTDF Building | North-South | Conforms to reduce heat gain |
| 4 | Bank of Industry | East-West | Does not conform to reduce heat gain |
| 5 | World Trade Centre | North-South | Conforms to reduce heat gain |
| 6 | Corporate Affairs Commission | North-South | Conforms to reduce heat gain |
| 7 | Yakubu Gowon House | North-South | Conforms to reduce heat gain |
| 8 | NCC Building | North-South | Conforms to reduce heat gain |

**Source:** Authors’ fieldwork (2020)

The table 4.7 shows that all the office buildings observed except Bank of Industry are orientated in the North-South direction to reduce the amount of heat impacted on the building from the sunlight. Energy needed for cooling these buildings is considerably minimized. The Bank of Industry building which has its longer part facing East-west will be exposed to too much sunlight. As a result, the walls facing the east-west direction will be heated up in most part of the day thereby causing the interior office spaces to be hot. This heat will lead to occupants of the office not comfortable and as a result will require active source to cool the building.

### 4.2.3 Thermal mass

Thermal mass is another reliable strategy used in reducing the amount of heat in a building consequently reducing the energy requirement of the building (Chiras, 2012). Thermal mass elements employed in the design of the office buildings observed include concrete or Trombe Walls (23%), Concrete or Solar Slabs (39%), and Ceramic Tiles (38%). These materials are good heat absorbers thereby reducing the amount of reflected heat into the interior spaces within the building envelope. Other thermal mass elements such as Bricks and water filled containers (Tube Walls) were not utilized. Figure 4.4 illustrates the use of thermal mass elements in the studied office buildings. A large percentage of the office buildings adopted ceramic tiles as their thermal mass element, while the other buildings have used solar slabs and trombe walls.

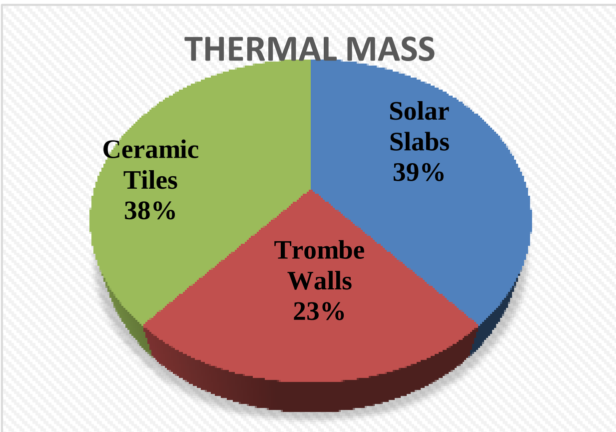


**Figure 4.4:** Thermal mass used in the office buildings
**Source:** Authors' fieldwork (2020)

### 4.2.4 Landscaping elements used in office buildings in Abuja

The use of soft landscaping elements to achieve passive energy designs cannot be overemphasized. When floras are introduced in environmental and building surroundings design, they help to reduce radiation from the sun and enhance regulation. Furthermore, trees can be strategically planted to serve as sun screen (Simpson, 2002). Presence of open green spaces also reduce congestion and aid proper air flow. Another means by which passive cooling can be achieved is the use of water bodies in the form of ornamental pools and aquariums for evaporative cooling. It was discovered in the course of the survey that considerable attempt was made to use landscape in curbing the effect of the sun on the buildings. As shown in Table 4.8, and as seen in Plates iii and iv, most of the office buildings adopted shrubs as a way of purifying the air around the building and reducing the effect of the sunlight. There is a case of excessive use of hard landscape elements, leading to inadequate use of soft landscape elements. Plates iii and iv have also shown the different landscape elements used in the studied office buildings, the landscape elements range from shrubs, groundcover to trees.

**Plate iii:** Extensive use of ground cover at the PTDF building in Abuja
**Source:** Author's fieldwork (2020)

**Plate iv:** Use of asphalt at the Corporate Affairs Commission building in Abuja
**Source:** Author's fieldwork (2020)

**Table 4.8: Landscape elements used in the sampled office buildings**

| S/N | Name of building | Landscape elements | Remarks |
|---|---|---|---|
| 1 | NNPC Towers | shrubs, water bodies, | Landscape elements are inadequate |
| 2 | Church gate | Shrubs, trees, ground cover | Scanty trees and shrubs, |
| 3 | PTDF Building | Groundcover, shrubs, trees | Adequate shrubs and ground covers used |
| 4 | Bank of Industry | Trees, shrubs | Does not conform to reduce heat gain |
| 5 | World Trade Centre | Shrubs | No adequate ground covers used, |
| 6 | Corporate Affairs Commission | Shrubs, water bodies, ground cover | The site is covered with asphalt, no adequate shrubs |
| 7 | Yakubu Gowon House | Scattered shrubs | No adequate soft landscape elements used. |
| 8 | NCC Building | Water body, shrubs | No adequate soft landscape elements used |

**Source:** Authors' fieldwork (2020)

Also, according to the Table 4.8, only the Corporate Affairs Commission Building and the PTDF building have adopted the use of water bodies in the form of fountain to reduce the effect of sunlight on the interior spaces. Trees were also used in some buildings like the PTDF building, the Bank of Industry, the Church gate building, and the Metro plaza.

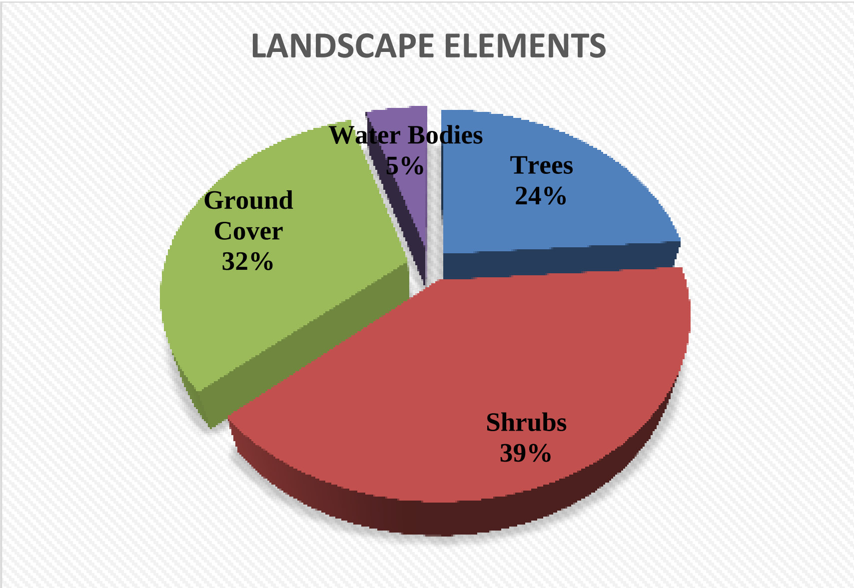



**Figure 4.5:** Landscape elements adopted in the sampled buildings
**Source:** Authors' work (2020)

According to the Figure 4.5, the predominant element employed was shrubs which amount to 39%, 32% of the elements used were ground cover while 24% was trees. Water was minimally used at 5% only. Most of the office building used more of hard landscape elements than the soft, thereby making the soft landscape inadequate.

### 4.2.5 Passive cooling building elements

These are building components that help in cooling the building by shielding it from direct sunlight. They are positioned strategically to curb the effect of direct sunlight on the building. Components such as roof overhangs, shading devices and green roofs act as screens while indoor gardens help in regulating the temperature and providing greater indoor air quality of interior spaces. As shown in Figure 4.6 below, shading devices and laminated windows dominate the passive cooling building elements used. Representing 34% and 33% respectively. Roof Overhangs amount to 25% while only 8% of them have interior gardens. None of the office Buildings Observed used Green Roof.

**Table 4.9: Showing passive cooling elements used in the buildings**

| S/N | Name of building | Passive elements |
|---|---|---|
| 1 | NNPC Towers | operable windows, internal garden |
| 2 | Church gate | Operable windows, shadir devices, |
| 3 | PTDF Building | Shading devices, operab windows |
| 4 | Bank of Industry | Shading devices, operab windows, |
| 5 | World Trade Centre | Shading devices, gardens |
| 6 | Corporate Affairs Commission | Operable windows, wat fountain |
| 7 | Yakubu Gowon House | Operable window horizontal shading devices. |
| 8 | NCC Building | Operable window balconies, |

**Source:** Authors' work (2020)

As indicated in the Table 4.9, most of the office buildings have operable windows except for the church gate and world trade centre which are artificially ventilated. The Church Gate building, NNPC Towers and the CAC building all have internal gardens that helps in cooling the surrounding air. Most of the office buildings also have shading device such as balconies, horizontal shading and overhangs except for the CAC building, the and the Church Gate towers which do not have any form of shading for the windows and openings.

### 4.2.6 Natural ventilation strategies

Natural ventilation involves allowing natural air into building interiors. Natural ventilation can be influenced significantly by the positioning and size of fenestrations in buildings. Other components such as chimneys and courtyards can also be employed to naturally ventilate indoor spaces (Freire, 2013). Figure 4.6 shows the degree to which these elements were used in providing natural ventilation to the interior of the office buildings studied. It was observed that most of the buildings, the window to wall ratio is about 35-45% to achieve the minimum total primary energy demand. The Plates v and Plate vi indicated extensive use of glass at the World Trade Centre Buildings and the Church Gate buildings respectively, these provides daylighting into the buildings.

**Plate v**: Extensive use of glass in the World Trade Centre buildings
**Source**: Author's work (2020)

**Plate vi:** Extensive use of curtain wall for lighting at the Church Gate building
**Source:** Author's work (2020)

The large windows amounted to 56% of the elements used. Courtyards and stack windows which also enhance air exchange between interior and exterior spaces were also employed. They amounted to 22% each. It was also observed that Solar Chimneys were no employed in any of the buildings observed.

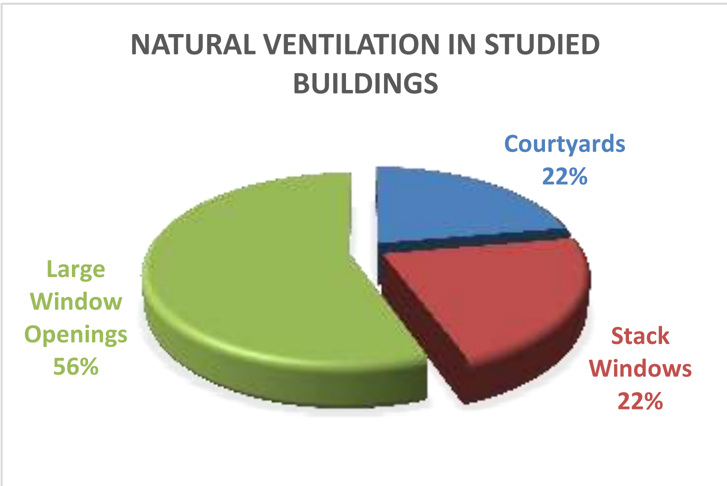



**Figure 4.6**: Natural ventilation in studied buildings
**Source:** Authors' work (2020)

The figure 4.6 shows the natural ventilation design elements observed in the office buildings. From the figure, it can be understood that only few of the office building made use of courtyard, they include the NCC building, the Bank of industry, and the NNPC Towers. Almost all the buildings make use of windows to ventilate the building except for the Church Gate Tower which does not have operable windows.

### 4.2.7 Daylighting building elements

Daylighting entails efficiently using natural light to illuminate spaces hence reducing dependence on artificial lighting means (Cuttle, 2013). This can be achieved through various means; roof lights, light wells, large windows and Curtain walls. According to Peter (2015), roof lights give wider and more distributed light into interior spaces. Large windows and curtain walls dominate the elements used at 36% and 29% respectively. 21% of them are roof lights while 14% of the buildings used none of the elements analysed.

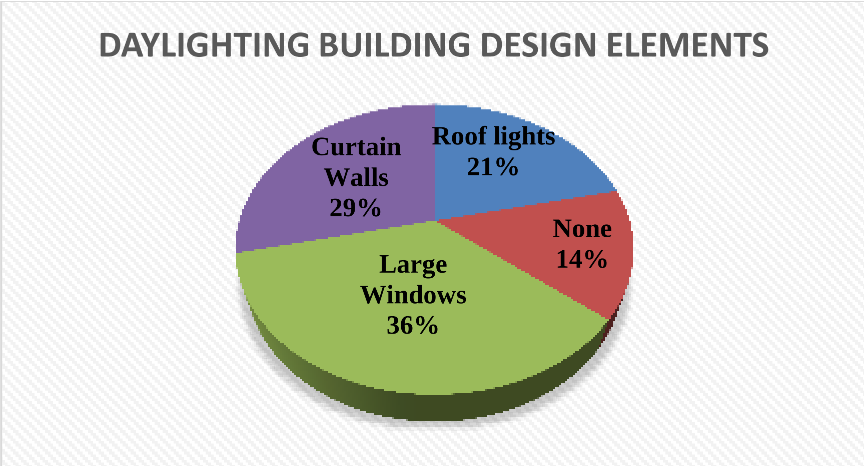



**Figure 4.7**: Daylighting design elements used in the case study buildings
**Source:** Authors' work (2020)

As indicated in the Figure 4.7, 36% of the buildings use large window as source of lighting the building. Curtain wall was used extensively in 39% of the building which include the Church Gate building, the Bank of Industry, and the World Trade Centre. Some other buildings like the Corporate Affairs Commission, Yakubu Gowon House, the NCC Towers, The NNPC Building, the Metro Plaza made use of small amount of curtain wall and operable windows to light the building. The corporate affairs commission also made of roof light to lit up the building.

## 4.3 Propose an Office Building Which Employs the Use of Energy Efficient Design Elements Towards Sustainable Office Building in Abuja, Nigeria.

### 4.3.1 Site analysis

In the design of any building, adequate analysis of the site is necessary. In designing for passive energy efficiency, it is among the most important preliminary design works. An adept knowledge of the characteristics of the site is required to generate a building that efficiently tackles energy demand and supply challenges of the building. Climatic elements such as temperature, rainfall, humidity and must be carefully studied in order for them to be properly harnessed. The vegetative nature of the site is also of prime importance. The availability and unavailability of natural vegetation as illustrated in the Figure 4.8 has an unswerving impact on the thermal condition of the site. The nature and characteristics of adjourning building were also studied before proposing a new building, this is necessary to ensure adequate form and orientation of the building.

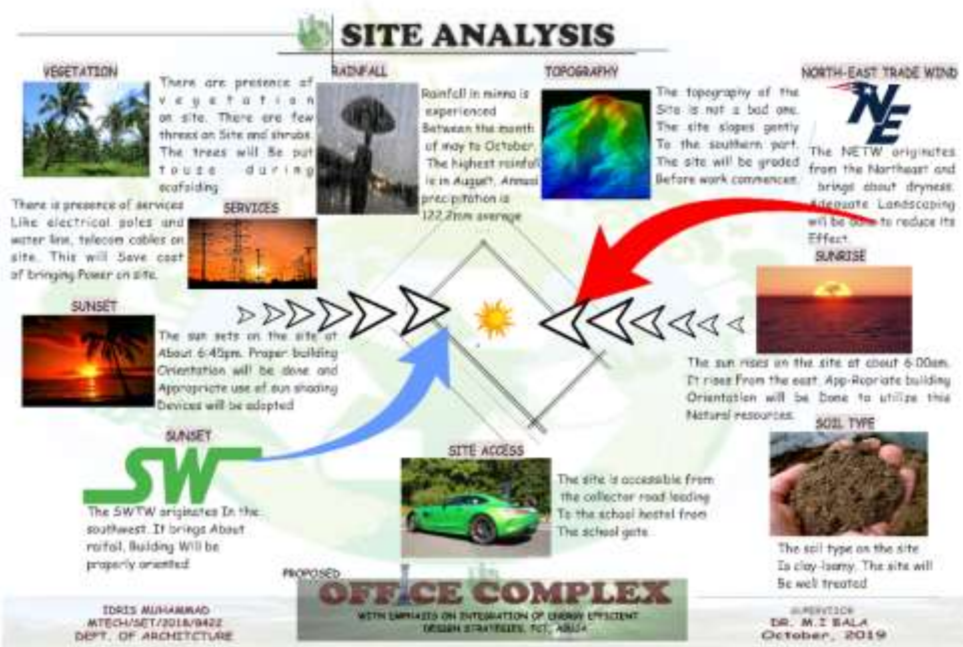



**Figure 4.8:** Site analysis for the proposed site
**Source:** Author’s work (2020)

#### 4.3.1.1 Temperature

Abuja is characterized with high temperatures for most of the year. The mean annual temperature is 28$^oC$. March which is the hottest month can have a temperature as high as 35$^oC$. The lowest temperature ranges occur in December with a value between 26$^oC$ and 22$^oC$. Due to this increased temperature experienced in the study area, a number of strategies have been put in place to prevent the building from absorbing the heat generated. These strategies include; application of insulation materials like wood and polystyrene as part of the interior finishing materials, use of light building envelope to radiate heat, a floor of the proposed building has been designed to be free to the building environment to allow air exchange with the building surrounding. More so, courtyard was designed to ventilate and cool the proposed building. Propose an office building design which employs the use of energy efficient design elements towards sustainable office buildings in Abuja, Nigeria.

#### 4.3.1.2 Rainfall

Rain usually falls between May and October with a short break in August. In some cases, early rains do fall in April. The average annual rainfall of the Federal Capital Territory is about 1200mm, including more than 100mm per month from May to October. Appropriate rain water harvesting measures have been designed in the proposed building to harness this natural, inexpensive source of water.

#### 4.3.1.3 Humidity and prevailing wind

The highest relative humidity occurs in July at 80%. Lowest occur in February at 30%. However, it is usually moderate during the *Harmattan* season in November and December. The air masses that are predominant are the tropical continental and tropical maritime and air masses. The tropical air mass brings rainfall while the tropical continental air mass which develops from the Sahara Desert brings the dry season.

#### 4.3.1.5 Vegetation

Abuja is situated within the Savannah vegetation zone of the West African sub-region. Patches of rain forest, however, occur in the Gwagwa plains, particularly in the gullied terrain to the south and the rocky south-eastern parts of the city. These areas of the Federal Capital Territory (FCT) make up one of the surviving existences of the developed forest vegetation in Nigeria. The most common vegetation of the FCT is, however, categorized into three (3) savannah types namely; the grassy or park savannah, the woodland savannah, and the shrub savannah. The city is also characterized with sparsely distributed trees and shrubs. This is prevalent in the proposed site. These vegetative cover can be utilized as part of the landscape elements to reduce the heat of the building environment.

### 4.3.2 Design philosophy

The design is driven from the need to gear towards environmental sustainability which is the watch word of today's architectural designs. The need to tackle the menace of pollution, depletion of natural resources and environmental degradation caused by the building industry cannot be overemphasized. Buildings have been identified as a major consumer of energy. The cost of cooling and lighting a building is on the high side. This design aims to minimize energy requirement through natural cooling and lighting. Applicable in an office building in the tropics, it adopts various passive energy design strategies and techniques to achieve energy efficiency. This is seen in the general design of the building as presented in the Figure 4.9.

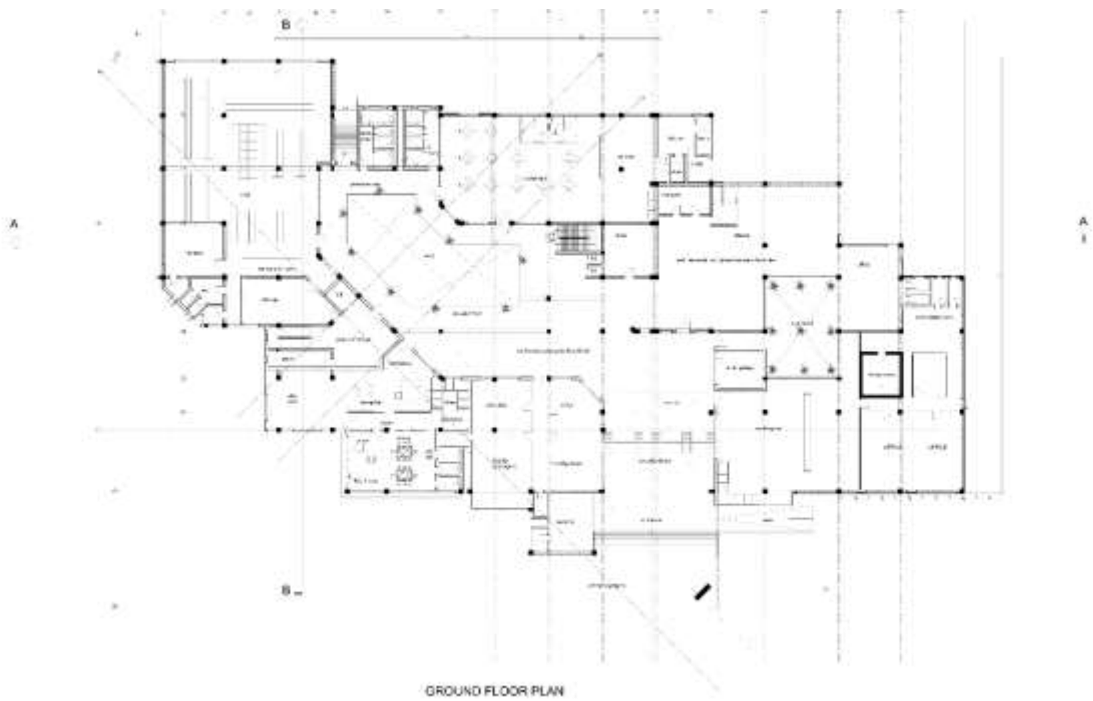
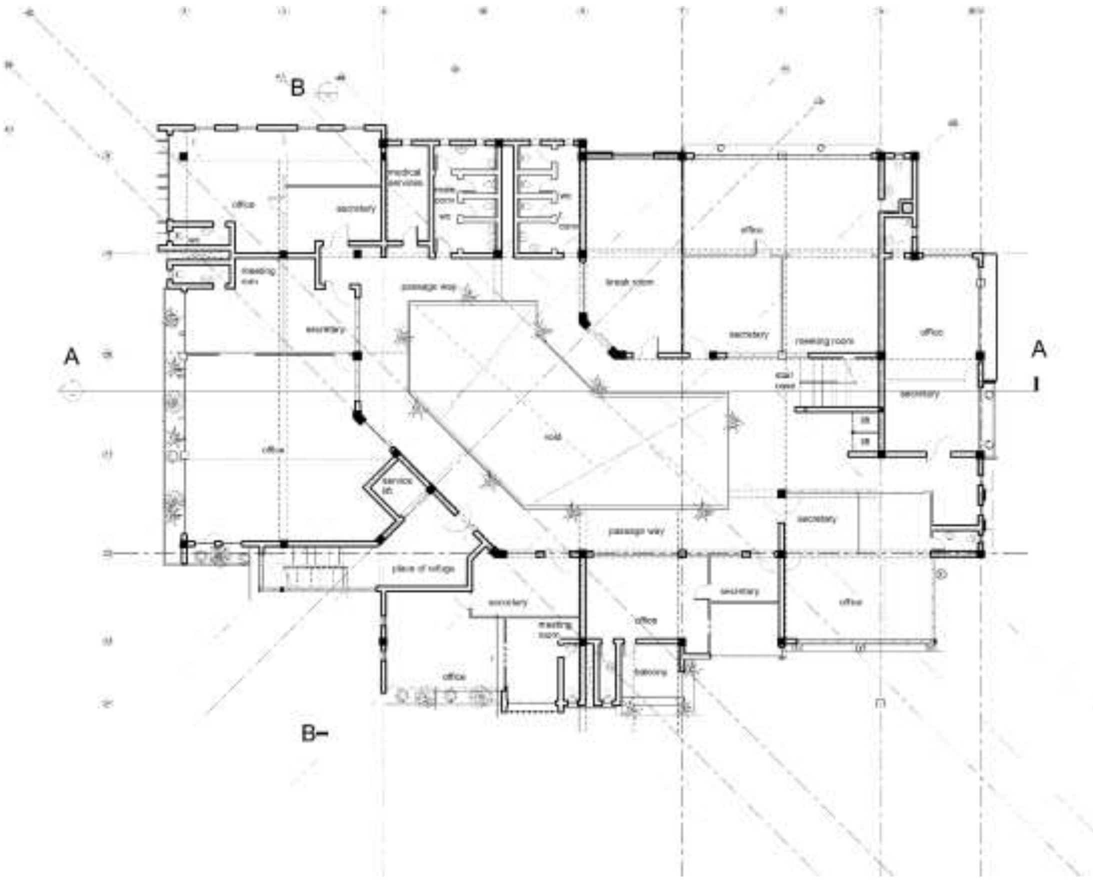



**Figure 4.9**: Proposed ground floor plan for office complex
**Source:** Authors' design (2020)

The proposed design shown in Figure 4.9 laid emphasis on energy efficient design elements through the use of passive elements such as courtyard to provide natural lighting and ventilation, the site landscape design also made use of trees to reduce the effect of sunlight on the occupants, water bodies were also included to enhance evaporative cooling thereby improving indoor quality. The proposed design also employed the use of overhangs and balconies, these prevent the action of direct sunlight on the occupants. Vegetation were also provided at the balconies; this vegetation helps to purify the indoor air. Through photosynthesis, these plants convert the carbon dioxide the occupants exhale into fresh oxygen, these plants which were carefully selected can also remove toxins from the air. Figure 4.91 showed the use of balconies and well as vegetation for energy efficiency.

### 4.3.3 Building form and orientation

As discussed in chapter two, the form of a building affects the energy requirement of the building. The amount of light into the building and circulation of air within the




building

**Figure 4.91**: Proposed 8th floor plan for office complex
**Source:** Authors' design (2020)

is influenced by the shape and volume of the building. The shape adopted for this design as indicated in the Figure 4.91is the rectangular form which allows for maximum daylighting and natural ventilation. Open plan system was also adopted. It allows natural light and ventilation into the building and helps improve air flow within the building. Orientation of buildings on site with respect to the position and path of the sun is another factor that affects the energy requirement of buildings. In tropical and humid regions like Abuja where the temperature of the sun is high throughout the year, there is the need to reduce the impact of direct sunlight on buildings. By orientation, the building's longer axis must not face the sun at any time of the day. As such, the building's longer axis is oriented to face the north and south since the sun rises from the east and sets in the west. This is evident in the proposed design shown in plate ix below. The longer sides of the proposed office building as shown in Figure 4.92 have been orientated away from east and west. As evident in Figure 4.92 also, rectangular form which is a suitable and efficient form for buildings in the tropic was adopted. Plantations was adequately designed in the proposed building to help freshen the air in the environment through photosynthesis and also reducing the effect of sunlight thereby keeping the office building environment cool and toxic free.

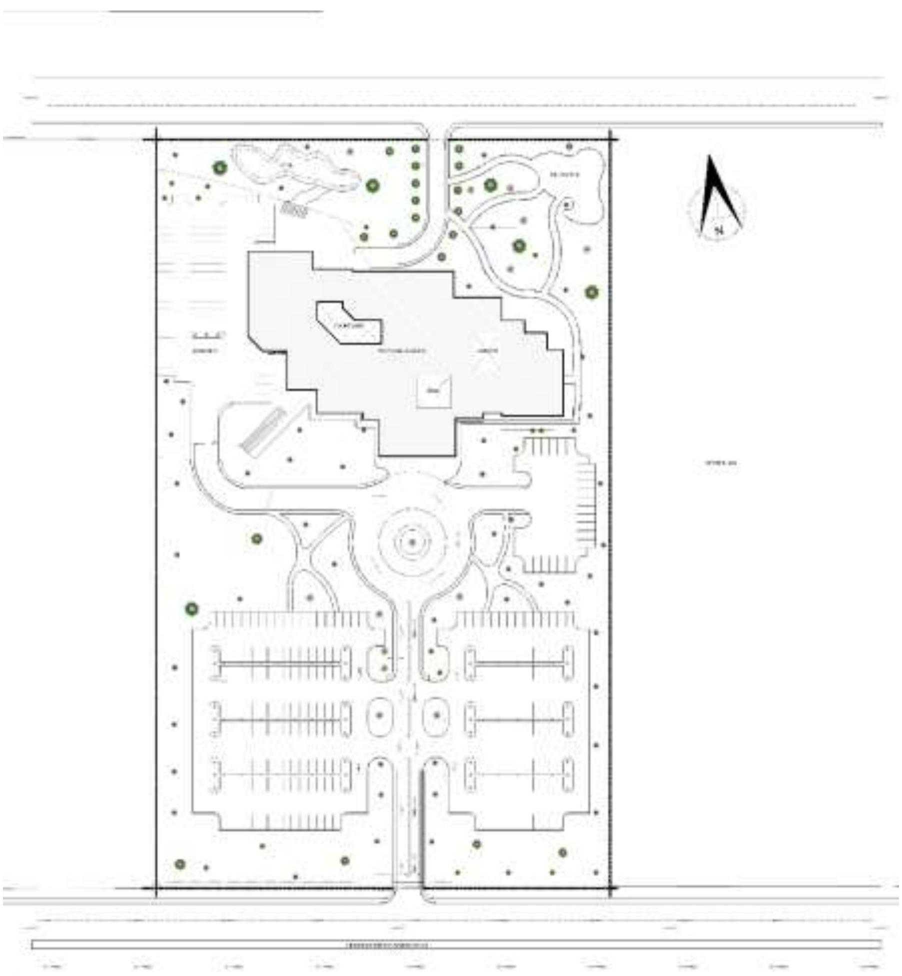


**Figure 4.92:** Proposed site plan for office complex

**Source:** Authors' design (2020)

#### 4.3.4 Passive energy efficient design elements adopted in the proposed design

Several design strategies were adopted to passively cool the building. They include designing for natural ventilation through the use of courtyards, large window sizes, appropriate windows positioning, building orientation, appropriate building envelope, proper thermal mass elements like tiles, evaporative cooling strategy through artificial water bodies on site, the use of airways which was achieved through creating relaxation floors which are free from partition walls, and the use of landscape design to achieve cooling. The building design in general, materials and finishes used are those that enhance the self-cooling capacity of the building and reduce its energy demand, these materials include low- emissive windows and glass panels, stucco internal partitioning, insulated aluminium panels, photovoltaic façade glass.

Rectangular building form was adopted for the proposed building. When considering energy efficiency for buildings in the tropics, the rectangular orientation is the best form of orientation for buildings (Abimaje & Akingbohungbe, 2013). The longer façade of the building was oriented to face the north and south direction to prevent the building from direct sunlight. The building façade facing the east and west directions have reduced windows and balconies were also created to prevent direct action of sunlight on the walls

Courtyard of appropriate design was designed for the proposed building to ensure that the building gets appropriate lighting and ventilation and to also reduce the need to air conditioning systems and lighting bulbs. More so, artificial water bodies have also been created to enhance the cooling of the proposed building through evaporative cooling.

The artificial water bodies created will help to cool the air entering the building to ensure occupants comfort.

# CHAPTER FIVE

## 5.0 CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

The construction industry has been identified as one of the major consumers of the world’s total energy. Combustion of fossil fuel gives off gasses that are harmful to human health. They contribute immensely to the depletion of natural resources and degradation of the environment. They are also a major cause of pollution which leads to global warming (Bernstein & Peter, 2007). In Abuja Nigeria, adequate consideration has not been taken to curb these negative impacts in the construction of office buildings. This menace can be reduced significantly by employing the use of energy efficient design elements in construction of office buildings and invariably reduce the effects of global warming. The concept of passive energy efficient design proposes using design elements to reduce dependence on artificial means of meeting the energy demand of buildings.

It was deduced from the office buildings observed that some passive energy efficient design elements like courtyard, balconies, shading devices, building orientation were used to reduce over dependence on mechanical means of lighting and cooling. The climate of the area under study is hot and humid, hence the building form adapted the use of courtyard, large fenestrations for windows and glazing to maximise natural ventilation and daylighting. Also, overhangs and shading was used to control incident rays of the sun reaching the interior spaces of the proposed building, thereby reducing heat and cooling costs. Landscape planning and design was provided for trees, shrubs, and ground cover to serve as wind breakers, provide shade from the sun as well as filter and refresh the surrounding air and reducing heat island effect.

## 5.2 Recommendations

To significantly reduce the energy demand of office buildings using energy efficient design elements within the study, the following are recommended based on the findings and the analysis of the data.

1. Designers and developers in the building industry should embrace energy efficient design elements in the design and construction of office buildings in order to achieve efficiency in energy use of office buildings. This will reduce dependence on mechanical cooling and lighting and provide a means of sustainable and conserved environment.
2. Statutory regulations should be geared towards ensuring that designers and developers adopt energy efficient design elements in the design of buildings. When these regulations are made, the law enforcement agencies should also ensure that they are critically followed and adhered to during the construction of these buildings. This will reduce the cost of governance and equally reduce emission of greenhouse gases, leading to a sustainable and eco-friendly environment.
3. Stakeholders (developers and designers) in the construction industry should provide inducements in the form of awards and recognitions for buildings built to achieve energy efficiency through passive design concepts. This will create some form of competition among building designers to develop more environmentally friendly buildings. Also, when buildings are built, the developers should be given green buildings certifications by the government to inform them of the level of their effort towards an energy efficient environment.

## CHAPTER SIX

## 6.0 PROPOSED OFFICE DESIGN

### 6.1 Integration of Passive Energy Efficient Elements in Office Buildings

The energy required for cooling, lighting and ventilating buildings, particularly office buildings has seen an increase over the past years. This cooling and lighting of buildings are mostly achieved through artificial means like the use of electric generators or through hydroelectricity, these means have proven to lack credibility in terms of economic and environmental sustainability. As such, there is need to reduce buildings energy consumption through the application of passive energy efficient design elements in the proposed office design.

**Table 6.1: Passive elements adopted in the proposed design**

| S/N | Passive Elements Adopted |
|---|---|
| 1 | Courtyard |
| 2 | Orientation and form of the building |
| 3 | Landscaping elements used |
| 4 | Air ways through free open floors |
| 5 | Overhangs and shading devices |
| 6 | Balconies |
| 7 | Daylighting strategies such as atrium |
| 8 | Use of operable windows |
| 9 | Overhangs and shading devices if any |
| 10 | Colour and insulation against heat |
| 11 | Air filtering indoor plants |
| 12 | Construction materials used |

**Source:** Author’s work (2020)

The proposed office design has adopted several energy saving strategies which can be seen in Table 6.1. these elements have been properly designed for in the proposed office building to ensure proper functioning and usage. The application of these passive design elements is further analysed below.

### 6.1.2 Integration of operable windows, courtyards and natural lighting strategies in the proposed design

To allow for natural lighting and ventilation in the proposed office design, courtyards, operable windows and atriums were introduced. The design adopted courtyards in two different areas of the building. These courtyards ensure that there are no dark spots and that every offices and spaces in the building is adequately lit up and ventilated.

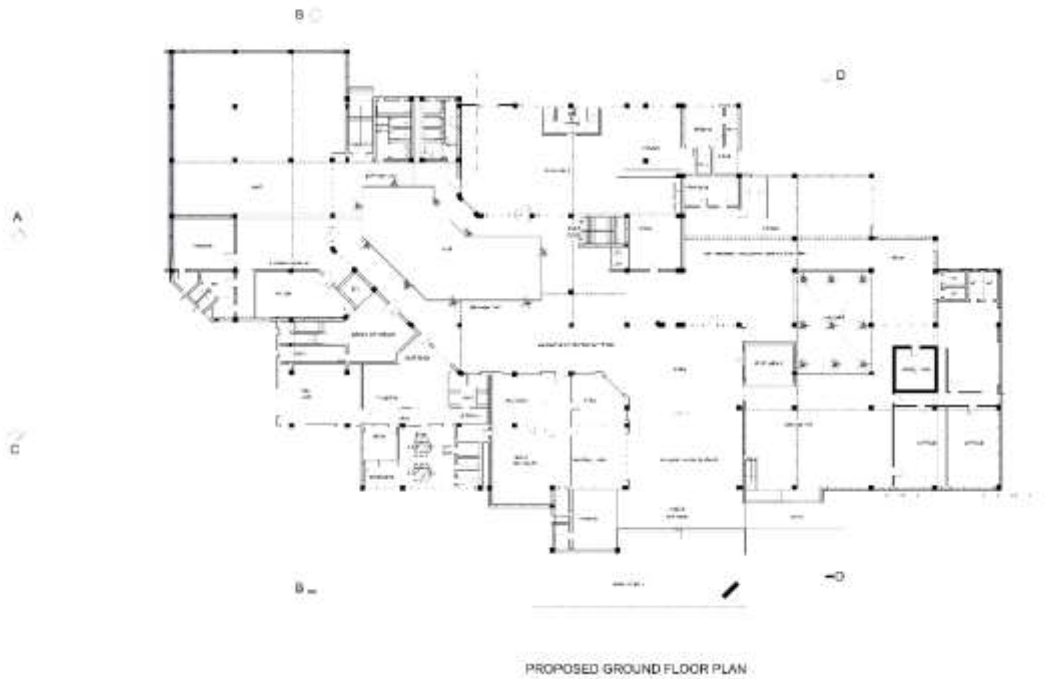



**Figure 6.1**: Proposed ground plan for office complex
**Source:** Authors' design (2020)

The Plate 6.1 showed how these courtyards were used and it can also be seen that the entrance and entrance lobby which might tend to lack natural lighting was also provided with an atrium. This atrium now allows for full lighting of the space without the need for more artificial lighting. Also, every spaces and offices in the building have been provided with operable windows to allow for ventilation. These windows are not just operable but appropriately sized to allow for sufficient air into the spaces.

### 6.1.3 Orientation, form and landscape elements used in the proposed building

As discussed above in the previous chapters, orientation and form of a building play important role in the energy savings of that building. For a sustainable building form, rectangular form which is suitable for reducing energy consumption for buildings in the tropic was adopted. As indicated in the Plate 6.2 below, the proposed office building was orientated on site such that is reduces the effect of sunlight on it, this is achieved by designing the building to make the longer side face away from the east and west direction which are the two orientations with the most sunlight for the day.

**Figure 6.2**: Proposed site plan for office complex
**Source:** Authors' design (2020)

The choice of vegetation was also considered in the design. To reduce the effect of sunlight on the building occupants, tall deciduous trees were used on the eastern and western sides to shade the building from the hot sunlight. On the northern and southern sides, evergreen trees were planted to reduce the effect of the wind and also act as wind breakers.

### 6.1.4 Integration of indoor air filtering plants and air ways (free open floors)

These are other passive concepts adopted in the design. In airway strategy, air ways in the form of free unoccupied and un-partitioned floors and provided in the design. As shown in Plate 6.3 and plate 6.4, the air way function as media through which used air from the courtyard is exchanged with the fresh air from outside the building. As this process is repeated, it keeps the air in the building fresh for the occupants of the building and also the air trapped within the courtyard do not have to go all the way to the top before it is discharged.

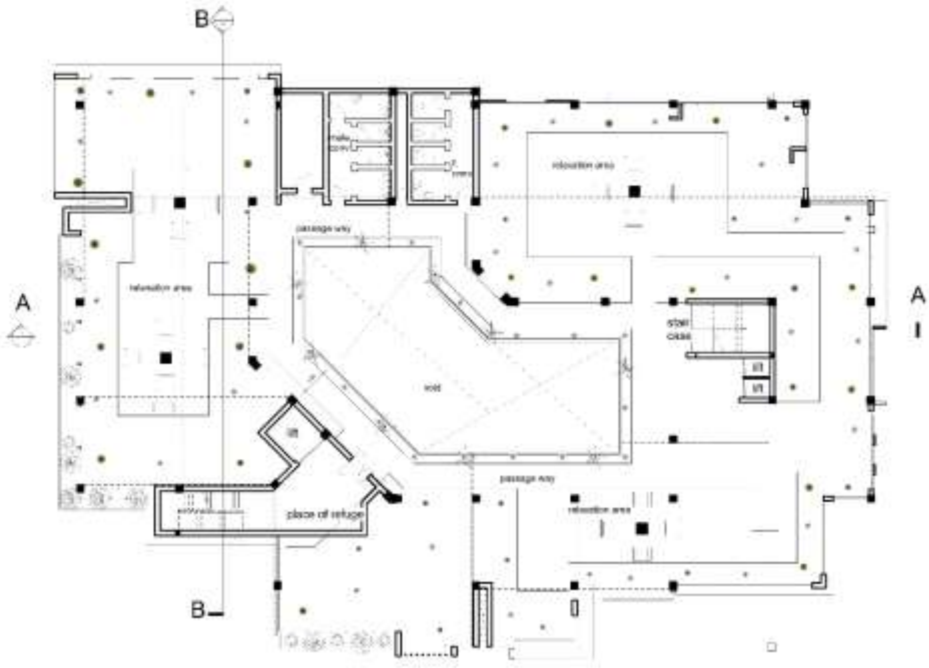



**Figure 6.3**: Proposed eight floor plan for office complex
**Source**: Authors' design (2020)

The floors created to be as airways were equally landscaped for relaxation and for air filtering purposes. These landscape elements were selected based on their abilities to convert used air into fresh air by removing the carbon from the air coming from or going into the building. The air that enters the courtyards and offices from the building environment is filtered and made pure by these plants. Some of the plants with these air filtering abilities were also used along the balconies and atop overhangs of the proposed office building.

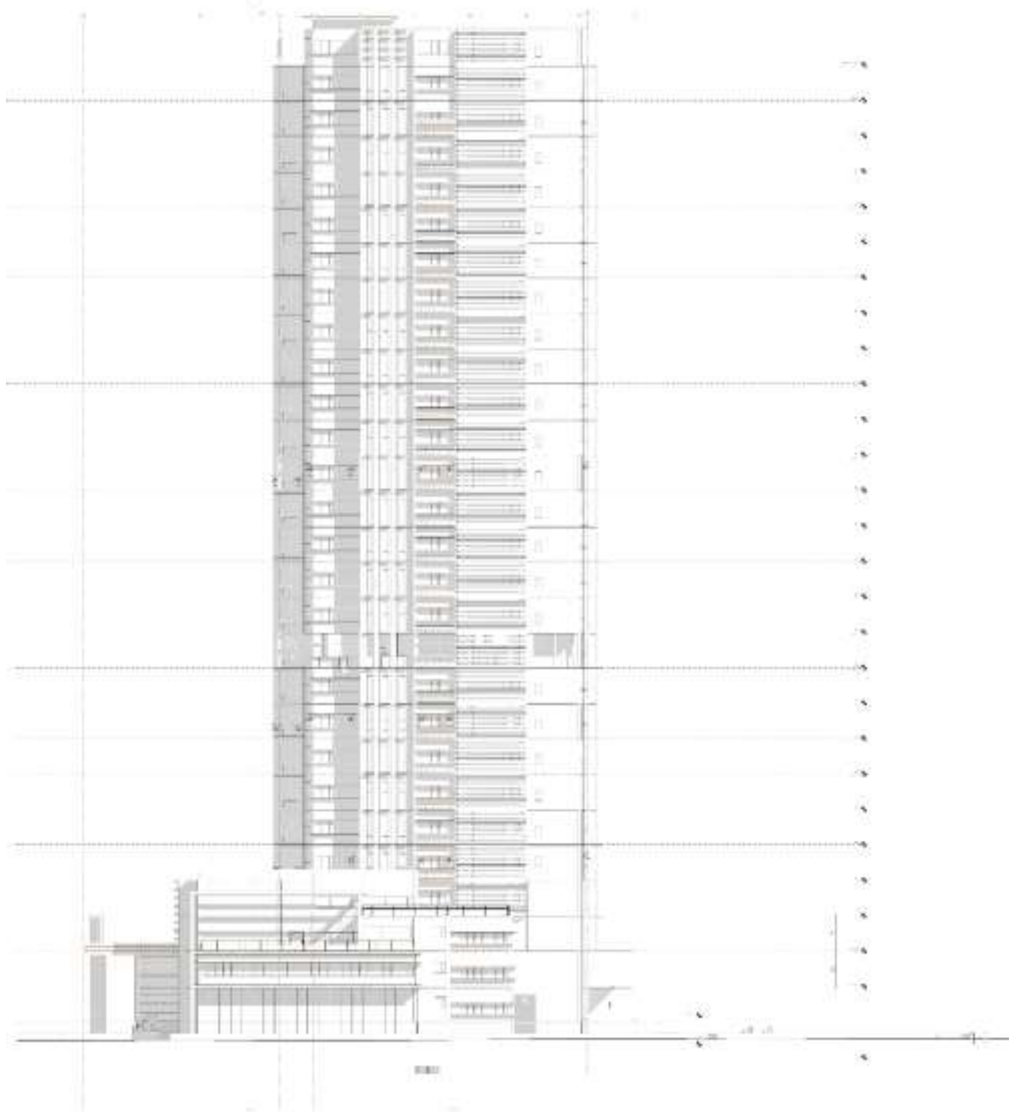


**Figure 6.4**: Proposed site plan for office complex
**Source**: Authors' design (2020)

The indoor air filtering plants used include Geranium plants, Jasmine, Gerbera daisy, Lavender flower, Mint flowers, Bamboo palm, Peace lily, and Aloe Vera. Some of these


plants were also used outside the buildings because of their importance to building sustainability. Detailed specifications and importance of these air filtering plants can also be seen in Figure 6.5.

**Figure 6.5**: Proposed site plan for office complex
**Source:** Authors' design (2020)

These indoor air filtering plants were adopted at different areas of the design where they are suitable. For example, the bamboo plants were planted mostly at the passage ways surrounding the courtyards because they thrive well in areas that are shaded away from sunlight. The geranium also can be planted along balconies because they are gorgeous when blooming and require very little care, they can live for up to two weeks without water during the colder, drier *harmattan*, the more sun they get, the more blooms they will have.

### 6.1.5 Integration of overhangs, balconies and other shading devices.

Overhangs and shading devices play important role in the energy consumption of a building as they tend to regulate the amount of sunlight that a building should receive. The proposed building adopted different types of shading devices on the different parts of the building. This is because in other to properly control the directions and angles at which sunlight hits a building, there are guides that must be followed to implementing these shadings and overhangs. These guides and specifications can be seen in Figure 6.6.


**Figure 6.6**: Passive energy efficient design elements
**Source:** Authors' design (2020)

Suitable shading devices have been used on the different orientations of the building. On the northern and southern sides for example, horizontal devices were majorly used in the form of canopies, long verandas, movable horizontal louvre blades or overhangs. Egg-crates and vertical elements were also used on the eastern and western sides of the building. These elements help to prevent direct sunlight from reaching the interior walls of the occupied spaces

**Figure 6.7**: Proposed design 3D view
**Source**: Authors' design (2020).

The Figure 6.7 shows how these different shading devices from vertical to horizontal devices have been adopted on the façade of the building. Also, in other to filter the air going into the building and reduce sunlight effects, plants were selected and planted on these shading elements and overhangs. The figure 6.7 also shows the use of egg-crate shading devices on the building façade. Climber plants were also specified for the side of the building with the egg-crate shadings to reduce sunlight effect on that part of the building.

## 6.2 Sustainable Materials and Techniques Adopted in the Proposed Office Building

Going further on the need for sustainable office design, the proposed building also adopted a number of techniques and materials to reduce energy consumption through improved occupants comfort. These materials and techniques include the use of double glazed heat reflecting glass, the use of power harvesting façade, the use of solar roofing panels, insulated façade cladding, sustainable or green roof techniques. Some of these techniques can be were represented in the roof plan shown in Figure 6.8.

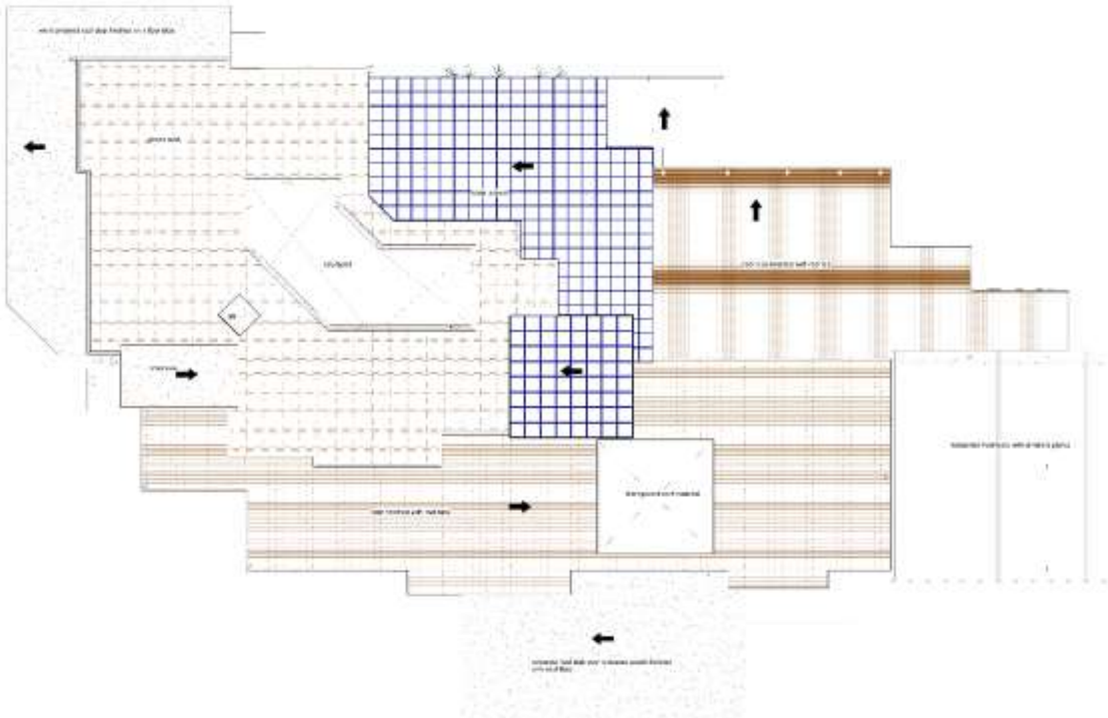


**Figure 6.8**: Proposed roof plan for office complex
**Source:** Authors' design (2020)

The pure harmless energy generated from these solar sources can be used to take care of other electrical needs of the building such as powering the elevators, the escalators, computers, and other machines that might be needed in the building. The green roof provide shade for relaxation, removes heat from the air, reduces temperature of the roof and the surrounding air. It can equally reduce heat island effect. Especially during the day. The concept of solar façade allows the glass used on the façade to be another energy source. Instead of just covering the building up with normal glasses, doubly glazed solar glass were used to reduce the effect of sunlight on the interiors and also generate electricity for the use of the building.

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