

**CLIMATE RESPONSIVE ARCHITECTURE
A CASE STUDY ON SOKOTO STATE, NIGERIA**

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ABSTRACT

CLIMATE RESPONSIVE ARCHITECTURE IN SOKOTO, NIGERIA

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The climate of a region has a significant effect on its architecture. In Sokoto state and some parts of Nigeria, most of the residential buildings are designed without considering the climate of the region and other core factors that ensure thermal comfort. Climate Responsive Architecture is the approach that tries to tackle this subject. Climate Responsive Architecture is aimed at achieving thermal comfort in buildings passively. This thesis used a survey method to achieve its main objectives of examining the Climate Responsive Architecture in the Sokoto State by focusing on thermal comfort in residential buildings. The sample size chosen for this survey is 100 household owners randomly selected using randomly sampling technique. Major findings from this survey revealed that the factors that limit the practice of Climate Responsive Architecture in Sokoto State include: Socio-cultural factors, clients' preference / choices, Poverty / high cost perception of choosing Climate Responsive Architecture principles, and neglect of vernacular architecture / traditional building materials while the common causes of thermal discomfort in residential buildings in the state are due to the lack of awareness on climate Responsive Architecture on the part of households' owners, lack of perception about local / traditional building materials and the non-engagement of professional architects for design and construction. As a measure to curb out this menace, there is need of more awareness programs on the importance of Climate Responsive Architecture and also the government and other relevant stakeholders in the building sector need to ensure that all design constructions are carried out strictly by professionals.

Key words: Climate Responsive Architecture, Thermal Comfort, Sokoto, Nigeria

ÖZET



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LIST OF ABBREVIATIONS

CRA	:	Climate Responsive Architecture
VA	:	Vernacular Architecture
LGA	:	Local Government Areas
SERPA	:	Sustainable Energy Regulations and Policymaking
GHG	:	Green Houses Gases
HVAC	:	Heating Ventilation and Air-condition
ASHRAE	:	American Society of Heating, Refrigerating and Air-conditioning Engineers
MAP	:	Metro-Area Population
AMS	:	American Metrological Society
HVAC	:	Heating, Ventilation and Air Conditioning

Chapter One

1. Introduction

The word “climate” is derived from the Greek word “*Klima*” – which means the slope of the earth in respect to the sun (Lechner, 2015). The climate of a region has a significant effect on its architecture. According to Olotuah (2015) climate is the average weather condition of an area over a period of time. The standard average period of time is usually 30 years. Lechner, (2015) added that climate is a primary function of the sun. According to the American Metrological Society (AMS), in its climate report (2021), climate is a measure of the average pattern of variation in elements such as temperature, humidity, solar radiation and wind over long periods of time. The climate of a location is affected by its latitude, terrain, altitude and water bodies (America Metrological Society, 2021).

Alkali, *et al.*, (2020) assert that the climate of any region is fundamental to the forms of architecture that propagate in that area. Therefore in designing buildings that will provide thermal comfort and healthy living conditions to occupants, the climate of the region where these buildings are to be designed need to be part of the design. Olotuah (2015), states that the design of buildings to ensure physiological and thermal comfort of users is achieved through the understanding of the climate system of the area the buildings are being designed.

According to the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) standard 55, thermal comfort is the condition of the mind that expresses satisfaction with the thermal environment (ASHRAE Standard 55, 2017).

Research by numerous scholars on climate and thermal comfort have shown that individuals are more proactive in comfortable environments, thus, thermal comfort in any building is of paramount importance and should not be debatable (Olotuah 2015; ASHRAE Standard 55, 2017). Today it is becoming increasingly difficult to achieve thermal comfort passively due to increasing temperatures as a result of climate change in the environment. Climate Responsive Architecture (CRA) principles provides a twofold effect to improving environments. It provides passive solutions to improve thermal comfort in interior spaces and environment while reducing energy requirements. Then it subsequently reduces Green Houses Gases (GHG) emission impacts on the built environment. It is pertinent to know that the climate of an area should always be considered during design. This enables architects

to take advantage of the climate of any particular area to provide passive design techniques which then improve physiological, physical comfort through thermal comfort in buildings without relying heavily on mechanical energy.

The scope of this study covers Climate Responsive Architecture in Sokoto state. It is limited to the thermal comfort in residential buildings types in Sokoto State. Studies have shown that common type of residential building types in Nigeria are Bungalows, Semi-detaches, Detached and Duplexes (Odediran *et al.*, 2013). Therefore these building types are synonymous to residential building types in Sokoto State.

The study is of immense significance to households because it creates awareness on Climate Responsive Architecture. It will emphasize on the role of architects and other related professionals in the delivery of a sustainable environment and thermal comfort in buildings.

The architects design; form, space, layout, opening, and building materials for construction through their designs and take advantage of the climate in a region to enhance thermal comfort in buildings (Boswell, 2013). They consider the climate of an area in designing buildings, thus helping to provide buildings that have a good relationship between their internal and external environment (Boswell, 2013).

The motivation for this study arose as a result of the following factors;

- i. The increasing rate of buildings constructed without consulting professionals in Sokoto state, Nigeria.
- ii. The need to reduce dependency on mechanically controlled systems as a result of the epileptic power supply and high cost of energy in the state
- iii. The personal drive to create awareness on Climate Responsive Architecture in Sokoto State, Nigeria.
- iv. Personal aspiration for thermal comfort in buildings while occupants are carrying out their various day by day activities
- v. The personal drive to raise awareness of upcoming architects and professionals in the built environment on the importance of considering the climate of a region before designing building, selecting building materials, orientation, solid-void on the façade etc.

1.1 Background

The biggest priority for indoor environmental evaluation of a building's thermal comfort is the physical and physiological comfort of the occupants (Sathi, 2021). In designing buildings, the climate of the region has a significant role to play in achieving this priority. Some countries, in developed and developing nations of the world in present, have been restricted in the quest of achieving this priority. This is due to the fact that some of the designs in these regions were done without considering the climate of the regions (Marro, 2018). Climate change, environmental conditions, poor construction techniques, choice of building materials, scarcity of natural and even financial resources have also limited the chance of achieving this priority in buildings (Osagie, 2017).

According to Olotuah, (2015), in understanding climate, the climatic conditions of an area and its environment is an important criterion to achieving healthy and comfortable buildings that will ensure physiological, physical and thermal comfort of users in buildings and the environment as a whole. Agboola (2011), states that the major environmental factors which directly affect building forms and designs in respect to provision of comfort are the climate and weather conditions of the area where the building is constructed.

In every region of the world, the major components that lead to the kind of architecture perpetuated include: culture, climate, technology, socio-economic and traditional building materials (Opoko, 2001). Alkali, *et al.*, (2020) agrees to this fact by asserting that the climate of any region and the local materials available for construction are fundamental to the forms of architecture that propagate in that area. This explains why architects and other relevant professionals in the built environment need to broadly understand Climate Responsive Architecture and Vernacular Architecture which is basically based on climate responsive architecture.

According to Malekafzali (2018) Climate Responsive Architecture refers to the design that reflects a particular region's specific weather conditions. It uses data of weather patterns and factors such as the sun, wind, rainfall, and humidity to enable architects to make decisions on construction techniques and building materials for designs. Yannas (2003) also defines Climate Responsive Architecture as the architecture that aims to achieve thermal and visual comfort of building occupants using little to no non-renewable energy sources by incorporating the elements of the

local climate in designs effectively. This architecture drives to achieve physiological and thermal comfort passively without reliance on mechanical energy.

According to Ghisleni (2020), vernacular architecture is a type of local or regional construction that uses predominantly traditional materials and resources available in the area where the building is located. Thus, this architecture is conscious of the specific geographical features and cultural aspects of its surroundings. As a result of this reason, vernacular architecture is unique to its location, becoming even a means of reaffirming the identity of a region. Architects therefore take into consideration the local or cultural aspects, climate and style to abundantly use available local materials and traditional construction techniques to achieve vernacular architecture. According to Bodach (2014), vernacular architecture enhances sustainability and is noted for being environmentally friendly. The idea of green architecture today has its route from vernacular architecture in terms of energy efficiency while utilizing locally accessible materials.

Presently, the focus of architects, builders and allied professionals in the building sector have increasingly shifted to creating structures that have less impact on the natural environment (Klein, 2013). Hence, climate-responsive architecture and vernacular architecture are design practices that can help attain this objective. In contemporary architectural examples, Climate Responsive Architecture and lessons learned from Vernacular Architecture have become a crucial step in achieving more sustainable buildings (Alkali, *et al.*, 2020). These design strategies have helped to produce energy efficient buildings that enhance physiological and thermal comfort. They have also helped in limiting the negative effect climate change has on buildings and occupants by providing measures that are vital in reducing Greenhouse Gases (GHG) emission and global warming (Mahdavi, *et al.*, 2015; SERPA, 2015).

1.2 Aim and Objectives

This thesis aim is to examine the Climate Responsive Architecture in Sokoto State, Nigeria. Its specific objectives are:

1. To determine the rate of indoor thermal comfort achieve in residential building types in Sokoto State.
2. To determine the factors that limits the rate of indoor thermal comfort in residential building types in Sokoto State.

3. To determine the impact the choices of building materials have on thermal comfort in residential building types in Sokoto State.
4. To determine the hindrances to the effective delivery of designs that enhances thermal comfort in buildings (passive and active) in Sokoto State.

1.3 Statement of the Problem and Research Questions

Climate responsive architecture is the design of buildings in a particular region with consideration on the local climate of that region. This architecture aims to achieve thermal comfort naturally (passively) in buildings without much reliance on mechanical energy (Chauhan, 2021). Studies have shown that the local climate of a region affects indoor heat and ventilation necessary for thermal comfort in buildings (Zainazlan, Mohammed, Shahrizam, 2007; Adegboyega, 2016).

In dry climates, like that of Sokoto State, which is often characterized by high temperature and excessive glare with an average daytime temperature of almost 40°C and 29°C at night all year round, buildings are often overheated during the day due to high solar heat gain and somewhat cool at night (Zainazlan *et al.*, 2007). The heat gains in these buildings during the day are often through the building envelope and solar penetration from windows and other openings in the building (Zainazlan *et al.*, 2007). The overheating of these buildings is often due to the extremely hot climate in the region comes with dryness and excessive indoor heat which becomes unfavourable to occupants, thereby causing thermal discomfort in indoor living spaces (Adegboyega, 2016).

Therefore, the level of thermal comfort experienced in indoor spaces in Sokoto State and some part of Nigeria as a whole is often limited due to the fact that most residential building types in Sokoto State are designed without considering the local climate of the region and other core factors that enhances indoor thermal comfort (Mamman, 1999). Most clients in this region rarely seek the services of professional architects with technical know-how to help them design their buildings. These clients often settle for unskilled masons that possess little or no knowledge / experience on climate responsive architecture.

Hence, the immense heat gain in buildings during the day due to the hot climate of the region coupled with the erratic power supply and poorly designed buildings by unskilled mason, in Sokoto State have proven to be the major problem that have impacted the level of indoor thermal comfort in buildings in the Sokoto

State. As a result of this, the quest to for thermal comfort in most buildings in Sokoto State has led to over reliance on mechanical energy for thermal comfort. Though majority of the populace in Sokoto State cannot afford mechanical source of energy for thermal comfort; and as such continue to suffer from thermal discomfort in their living spaces.

Conversely, this thesis will seek to proffer solutions to the problems impacting the level of thermal comfort experienced in living spaces in Sokoto State by raising awareness on the need to engage professionals who have climate responsive architecture and vernacular architecture knowledge paramount for achieving thermal comfort passively in building designs. Also, the information from this research will enable aspiring architects to see the reasons why the local climate of a region needs to be considered before designing or selecting building materials.

To attain the purpose of this study, the following research questions were formulated:

1. What is the rate of indoor thermal comfort in residential building types in Sokoto State?
2. What are the factors that limit the rate of indoor thermal comfort achieve in residential building types in Sokoto State.
3. What impacts do building materials choices have on achieving thermal comfort in residential building types in Sokoto State?
4. What are the hindrances to the effective delivery of designs that enhances thermal comfort in buildings (passive and active) in Sokoto State?

1.4 Research Methodology

The research adopts a survey methodology, with its main objectives being examining Climate Responsive Architecture in Sokoto State by focusing on the thermal comfort in residential buildings. According to Mills (2021), a survey research methodology refers to a particular type of research design where the primary method of data collection is by survey via qualitative and quantitative methods. Mills (2021) added that survey research design can be taken for a variety of reasons, but a common theme with survey is that they are an easily accessible way for respondents to share or demonstrate their knowledge or perspective about a particular topic.

Thus this survey research design proves appropriate for this thesis because the study tries to examine respondents' knowledge on Climate Responsive Architecture in Sokoto State, Nigeria. Hence, to efficiently carry out the aim of this study, the study will adopt both qualitative and quantitative techniques to glean adequate information from respondents on climate Responsive Architecture. These techniques will make the sequence for the workflow for this research.

Qualitative survey

According to Mills (2021), qualitative survey technique is a type of survey research that is typically administered during small scale research. This survey relies on open-ended questions usually in form of interviews to afford participants the leverage of expressing themselves more on answers or concepts which are more difficult to quantify. For instance answers that has to do with experience, attitude, perception or thoughts.

The qualitative survey technique for this survey design will involve conducting interviews with registered architects in Sokoto State. The key reason why only architects will be selected for this interview is because architects are those responsible for peddling first hand building decisions. Thus they have a great role to play in relaying this study's findings and teachings on Climate Responsive Architecture. The interviews will be conducted with the selected architects so as to also have a broader spectrum of the discourse on Climate Responsive Architecture in the area and how it affects thermal comfort in residential buildings.

The selected architects for the interview will be selected using random sampling technique method. According to Thomas (2022), random sampling technique method is a type of probability sampling in which the researcher randomly selects a subset of participants from a population. Thus, this probability sampling technique method was adopted to give every qualified architect in the study area equal chance of being selected for the research.

Thus twenty five (25) randomly selected architects in Sokoto State will be conducting this interview. The interview is limited to these twenty five (25) randomly selected architects due to the time frame available for the research and the financial implication of interviewing more architects. The selection criteria for selecting the architects will be based on years of working experience. The selected architects must registered and have at least a minimum of one year post-graduation

working experience. This is because at this stage they are regarded as professionals and are eligible to design and handle construction works. The interview questions are as thus:

1. What are the ways that can be used to create awareness on the need to consider climate before designing and choosing building materials in Sokoto state?
2. What beneficial impacts are there to gain as regards the consideration of the Climate in Sokoto State before using the right techniques / method to design buildings in Sokoto State?
3. What are the factors that limit the practice of Climate Responsive Architecture principles in Sokoto State in quest to maintain optimal thermal comfort?
4. What are the hindrances to effective delivery of thermal comfort in the design of buildings in Sokoto State?
5. What are the most widely used Climate Responsive Architecture techniques and passive design approach by architects for maintaining thermal comfort in Sokoto State?

The information gleaned from the interviews conducted with the five (5) selected architects provided the premise for structuring the research questionnaire for the quantitative survey methodology of the study.

Quantitative survey

According to Mills (2021), a quantitative survey design relies on closed ended questions and is often administered during large scale research. The data is numerical and is easily analyzed via numerous statistical tools. The data is often obtained via multiple choice or dichotomous answers which are always response to a survey questionnaire.

The quantitative survey design of this study is targeted towards residential household owners in Sokoto State, Nigeria. These categories of people are the core participants for this research and are the ones that require awareness on climate responsive architecture and thermal comfort in their living spaces.

The method of sampling technique that will be adopted for selecting these residential household owners will be random sampling technique method. According to Thomas (2022) random sampling technique is a method of selecting a subset of a population. Thomas added that in this sampling technique method, every member of the population has an exactly equal chance of being selected. Thus, this probability

sampling technique method will be adopted so as to give every participant in the study area within the selection criteria equal opportunity of being selected for the study.

The quantitative technique that will be adopted for this study will involve administering questionnaires to the selected residential household owners. The questionnaire will be the instrument for data collection from the selected household owners. The questionnaire will be structured in two sections. Section A will seek to collect demographic information on the building types in Sokoto State while section B will seek to collect information of Climate Responsive Architecture with focus on thermal comfort. The questionnaire comprises of closed ended and dichotomous questions. The questionnaire question is structured as follows:

Section A: Demographic Data of building Typology in Sokoto State

1. Type of residential building typology (a) bungalow ☐ (b) Duplex ☐ (c) story building ☐ (d) Mansion ☐
2. Building Form (a) Irregular ☐ (b) Rectangular ☐ (c) Square ☐
3. Status of occupants (a) Tenants ☐ (b) Owner ☐
4. Number of occupants (a) less than 5 ☐ (b) 5-8 ☐ (c) Above 8 ☐

Section B: Information on Thermal Comfort in Residential buildings in Sokoto State

This section of the questionnaires seeks information on the thermal comfort in residential buildings in Sokoto State. The questionnaire designed in line with the research question of the study is aimed at determining:

1. The extent of indoor thermal comfort in residential building types in Sokoto State
2. The factors that limit the rate of indoor thermal comfort achieve in residential building in Sokoto State
3. The impacts do building materials choices have on achieving thermal comfort in residential building in Sokoto State
4. The hindrances to the effective delivery of designs that enhances thermal comfort in buildings (passive and active) in Sokoto State?

Therefore to attain the aim of the questionnaire, the questionnaire questions are as follows:

1. At what time of the day do you feel more uncomfortable in your homes (a) 6am – 12pm 1pm – 6pm (c) 7pm -12am

2. At what time of the day do you feel slightly comfortable in your homes (a) 6am – 12pm 1pm – 6pm (c) 7pm -12am
3. How do you feel with your clothes on while performing an activity at home (a)slightly comfortable ☐ (b) comfortable ☐ (c) Uncomfortable☐
4. Do you feel comfortable in your homes without using fans and Air conditioners regularly (a)Yes ☐ (b) No☐
5. How would you rate the general thermal comfort in your homes (a) Excellent (b)good (c)fair (d) poor
6. Do you have idea about building orientation (a) yes ☐ (b) No
7. What is the pattern of orientation of your house (a) Length of building facing North-South direction (b) Length of building facing East-West direction (c) No idea
8. Are all bedrooms and living room windows in your house cross ventilated (a) yes ☐ (b) No☐
9. Are external shading devices incorporated in your house designs (a) yes ☐ (b) No☐
10. Do you think the functional areas in your building are properly zoned (a) yes ☐ (b) No☐
11. Type of building wall materials in your house (a) concrete blocks (d) burnt bricks (c) clay (d) bamboo
12. Are the walls of your building finished with bright color (a) yes ☐ (b) No☐
13. Type of Roofing materials (a) Long span aluminum with ceiling (b) Long span aluminum without ceiling (c) Corrugated zinc with ceiling (d) Corrugated zinc without ceiling (e) thatch roof
14. What color is your roofing sheet (a) black☐ (b) silver☐ (c) others specify_____
15. Type of landscape provided in your building (a) No landscape is provided ☐ (b) landscape is provided with trees, short grasses and concrete interlocks
16. The Sizes / position of door and windows in your house is adequate (a) yes ☐ (b) No☐
17. There is adequate power supply to run appliance needed for thermal comfort (a) yes ☐ (b) No
18. Type of mechanical ventilation in your house (a) None ☐ (b) Electric fans only ☐ (c) Air conditioners only ☐ (d) Electric fans and conditioners.

The reliability and validity of the questionnaire will be tested. According to Oladimeji (2015) the reliability of a questionnaire measures the consistency of the questionnaire; it refers to the degree to which the results obtained by the questionnaire can be replicated when the survey is repeated under same condition. Hence, the reliability of the questionnaire for this study will be tested by conducting a pilot study on residential household owners' in Sokoto State. The pilot survey is aimed at examining respondents' awareness on Climate Responsive Architecture in Sokoto State using a sample size of 10 participants. However, if any question is not valid during the course of the pilot study revision will be made accordingly. The pilot study will determine if the questionnaire will address the objectives of the study.

According to Oladimeji (2015) the validity of a questionnaire determines the accuracy of the questionnaire. Oladimeji added further that the validity of a questionnaire expresses the degree to which the instrument really measures what it supposed to measure. Thus, the validity of the questionnaire for this study will be tested using face and content validity. According to Morrison (2022), a questionnaire has face validity if in the view of the respondents the questions in the questionnaire measures what they intended to measure while a questionnaire has a content validity if in the view of an expert (for example a professional and registered architect) the questionnaire contains questions which cover an aspect of the construct being measured. The face validity of this study's questionnaire is tested with the 10 randomly selected participants for the pilot study to determine if the questions measure its intended target. While the content validity is tested by presenting the drafted questionnaire after conducting interviews with some professional architects for perusal before distributing the sample in the study area.

The total questionnaire samples distributed in the study area is 100. This questionnaire samples is distributed amongst the 100 randomly selected residential household owners selected from the target population of the study area. The total population of residential household owners in the study area is estimated to be approximately over 1000 household owners thus 10% of this population is being targeted for this survey.

The data that will be obtained from the distributed questionnaires is subjected to quantitative data analysis. The data is analyzed using a statistical data analysis method of simple percentages to determine the percentage of each participant's response to every statement in the survey using Microsoft Excel before drawing

inference in relation to the percentage of modal frequency in each question of the survey. The percentage (%) of each response is displayed using bar charts.

The information that is obtained from personal observations; interview conducted with the professional architects along with the survey questionnaire serves as the primary source of data evaluation for this research case study.



Chapter Two

2. Thermal Comfort in Residential Buildings

One of the primary requirements for functionality and performance in residential buildings is thermal comfort. Building type, climate and human parameters influence the level of thermal comfort (Adunola and Ajobola, 2016). Numerous studies have shown that the thermal comfort often varies in residential buildings than public and commercial buildings (Marro, 2018; Sathi, 2021). This is often attributed to their smaller sizes, the variations in building skin and different uses of each room (Sathi, 2020).

In residential buildings, the main rooms are the living room, bedrooms, bathrooms and kitchen (Vallabhaneni, 2014). Thus, the temperature level and thermal comfort in these rooms are very important. Numerous studies have shown that humans tend to spend more time in living rooms than other rooms in the building (United nation Environmental Protection Agency, 1989; Peters *et al.*, 2009). Therefore, the thermal comfort in living rooms is more important in residential building. According to Peters, *et al.*, (2009), the thermal comfort in bathroom is also important because bathrooms need to be at temperatures comfortable for humans with or without clothing. Peter *et al.*, (2009) continued that the thermal comfort in bedrooms is also of utmost importance because the bedrooms often accommodate different levels of clothing and also different metabolic rates of people asleep or awake. Thermal comfort in kitchens too is not left out because the kitchens are susceptible to different temperature for cooling and heating. Thus it pertinent to know that to have an equality of temperature in the whole building is the best so as to achieve a better thermal comfort level in the whole building (United States Department of Energy, 2015; Sathi, 2021).

Generally, thermal comfort in any building is of paramount importance. In an attempt for a building to attain optimum thermal comfort, it has to be designed to adjust to the climate of the region and it must offer a relationship and integration between the internal and external environment. This helps to generate a comfortable and conducive lifestyle for the occupants. According to American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 55, (2020), it is important for buildings to be designed to create an optimal thermal environment that will satisfy all occupants. Thus the Health and Safety Executive

(HSE) suggest that “a building can be said to achieve reasonable comfort when at least 80% of its occupants are thermally comfortable”.

According to Neupane (2022), a well-designed building should ensure that it satisfies the functional requirement of its occupants. Thus the optimal thermal comfort of a building can be determined through the physiological and psychological satisfaction derived by the occupants. However, individual variations in respect to physiological and psychological satisfaction have rendered it difficult to find an optimum temperature at the same time for everyone in a given space (Sathi, 2021). According to Akaat (2021), the specific thermal comfort in buildings is often challenging to define due to the fact that a wide range of environmental and person factors need to be considered when determining the temperatures and ventilation which makes individual comfy in buildings.

Hence, Serv (2018) opined that in terms of temperature and thermal comfort, the ideal temperature for optimum thermal comfort in a room should help maintain the body temperature at 37⁰C. Serv (2018) added that depending on the season, the ideal house temperature for both comfort and efficiency is between 20⁰C to 25⁰C. Alozie (2014) added that achieving thermal comfort in residential buildings has proven to be difficult as a result of climate change and poor architectural design practices. In the quest for achieving thermal comfort, most building occupants have resulted to mechanically controlled system in their buildings (active designs) to achieve thermal comfort. However, the cost of running these systems for HVAC in order to maintain thermal comfort have made most low income earners practically unable to achieve thermal comfort in their homes. Thus, the significance of thermal comfort in residential building cannot be underestimated. Akaat (2021), stated that thermal comfort is important in all buildings, especially in dry climate regions where the temperature are extreme and there is need for intensive cooling capacities.

Thus, residential buildings need to be designed with the objectives of minimizing heat gain and promoting heat loss where possible. It is pertinent to know that when thermal comfort is managed in buildings, users tend to have improved morale and productivity as well as improved health and safety. However, people working in uncomfortably hot and cold environments are more likely to behave unsafely due to the uncomfortable condition in their working environment which affects their ability to make decisions and/or perform manual tasks (SERPA, 2015).

In building science studies, thermal comfort has a direct relationship with productivity and health. Numerous surveys by scholars in this field have proven that residential occupants and office workers who are more productive and healthy are those satisfied with their thermal environment (Olotuah 2015; ASHRAE Standard 55, 2017). According to Fang *et al.*, (2004), thermal discomfort is often linked with sick building syndrome symptoms. In their study in the United States, Fang *et al.*, (2004), discovered that the higher indoor temperature, even within recommended comfort range often increases sick building syndrome. This syndrome often increases more in raining seasons when indoor temperature is raised than in the dry season as a result of the larger differences created by indoor and outdoor temperatures. Thus, enhancing thermal comfort satisfaction is a paramount necessity in buildings.

According to Axelrod and Diringer (2018), thermal satisfaction with the environment is important in buildings and also to humans due to the fact that harsh thermal environmental conditions poise potential life-threatening conditions to humans when the essential body temperatures reaches a condition of hyperthermia, above 37.5–38.3 °C, or hypothermia below 35.0 °C. Thus, buildings play a great role in modifying this adverse thermal environment condition by maintaining interaction between external thermal environment and indoor thermal environment. This reduces the effort that the human body needs for stability and comfort a normal body temperature vital for the right functioning of its physiological processes. Therefore, maintaining standard thermal comfort in residential buildings or other enclosures for occupants as regards HVAC is one of the major drive push of architecture globally as affirmed by the Roman writer – Vitruvius who actually linked this purpose to the birth of Architecture (Vitruvius, 2001).

Presently, architects are tasked with the responsibility of providing thermal comfort naturally in buildings (Sarathi, 2021). This will result in more energy efficient buildings and more ecofriendly environments with less GHG emissions. Architects have however resulted to Climate Responsive Architecture and Vernacular Architecture strategies to produce passive design techniques that will naturally improve thermal comfort in buildings. Although, in some developed and most developing countries, it is becoming increasingly difficult to improve thermal comfort passively due to increasing temperatures as a result of climate change, poorly designed buildings and lack of awareness on Climate Responsive Architecture etc.

2.1 Thermal Comfort Factors

Thermal comfort factors in buildings are those elements that influence internal climate quality in buildings. The design criteria that improve thermal comfort in buildings have a direct relation with the factors that influence thermal comfort. According to ASHRAE 55 standard, due to the complexity of design for thermal comfort, standard design criteria (guidelines) have been developed to help building professional achieve thermal comfort within occupied building spaces. These criteria provide analytical method of evaluating the interaction between the factors that affect thermal comfort (ASHRAE 55 standard, 2020). According to (Lohrey, 2017) analytical method of evaluation is aimed at establishing relationships between actual and benchmark data to determine if variations exist. They provide the yardstick for determining the variation between actual thermal comfort factors in buildings and already established and acceptable standards for measuring thermal comfort in buildings.

According to Alozie (2014) the major factors that directly affect thermal comfort can be categorized as environmental and human factors. Alozie further added that other contributing factors are acclimatization device, wetness of skin, health status of individuals, drinks, food etc. It is pertinent to know that though these factors may vary with time, but acceptable standards in measuring their effect in relation to thermal comfort in building are usually in a steady state (ASHRAE standard 55 (2020)).

2.1.1 Environmental factors.

Environmental factors for thermal comfort are those environmental conditions that influence thermal comfort. According to Lechner (2015), they are factors required to allow heat to be lost in in order to achieve thermal comfort. These factors include: Air Temperature (AT), Radiant Temperature (RT), Air Velocity (AV) and Relative Humidity (RH) (ASHRAE 55 standard, 2020).

2.1.1.1 Air Temperature: According to ASHRAE 55 standard (2022), Air Temperature is the average temperature of the air surrounding an occupant, with respect to location and time. It is measured using a dry-bulb thermometer. Air temperature is known as dry-bulb temperature (ASHRAE 55 standard, 2020). Air Temperature determines the rate at which heat is lost to the air (Lechner, 2015).

2.1.1.2 Radiant Temperature. This is an important component of thermal comfort in buildings. Radiant Temperature is the amount of heat transferred from a building surface. The amount of radiant temperature heat loss in a building surrounding depends on the building components emissivity and absorption ability. The average of a Radiant Temperature is known as Mean Radiant Temperature (MRT) which is measured with a MRT globe thermometer. It is pertinent to know that Mean Radiant Temperature doesn't not only depend on temperature and emissivity of the surrounding surface, it also depends on the view factor / degree of exposure of the building to sun rays. According to Lechner (2015), in a well-insulated and shaded building, the Mean Radiant Temperature is usually close to that of the indoor air temperature. This enables the building to achieve thermal comfort. However when there is a great difference between Mean Radiant Temperature from Air temperature, thermal comfort in the building tends to become harsh and difficult to achieve (Lechner (2015)).

2.1.1.3 Air Velocity. This is a very important environmental factor that directly affects thermal comfort in buildings. Air velocity simply refers to the rate at which air moves from a point without respect to direction and is measured in m/s. According to the ASHRAE 55, standard (2020), Air Velocity is the average air speed surrounding an occupant in a building space with respect to location and time. It has direct relationship with natural ventilation in buildings. Its spatial average is defined as average air temperature. According to Lechner (2015), like air movement, air velocity also affects heat loss in buildings by convection and evaporation. In the summer air velocity is great while during the winter period it becomes liability. The comfortable range for air velocity as recorded by Lechner (2015) is from 20 to about 60feet/minute (fpm) (0.1 to 0.3ms) and above about 200fpm air velocity can be slightly unpleasant.

2.1.1.4 Relative Humidity. This is another environmental factor that determines thermal comfort in buildings. Relative Humidity is the ratio of the amount of water vapour in the air to the amount of water vapour that the air could hold at a specific temperature and pressure. It is usually expressed in percentage. Numerous researches have proven that the combination of high temperature coupled with and increased Relative Humidity often reduces thermal comfort and indoor air quality (Lechner, 2015; ASHRAE standard 55, 2020).

Lechner (2015) added that when relative humidity reaches 100 percent, it means that air is holding all the water vapor it can and then cooling by evaporation stop. However, for comfort to be attained, Relative Humidity needs to be above 20 percent all year but below 60 percent and 80 percent in the summer and winter respectively. Therefore a dry environment with RH as low as <20-30% is uncomfortable. According to Balaras, *et al.*, (2007), “the recommended level of indoor humidity is in the range of 30-60% in air conditioned buildings”. But new standards such as the adaptive model allow lower and higher humidity, depending on the other factors involved in thermal comfort (ASHRAE standard 55, 2020).

Hence, the way a building is designed determines the impact environmental climatic conditions such as Air Temperature, Radiant Temperature, Air Velocity and Relative Humidity that determines thermal comfort have on the building and its occupants. Numerous studies have proven that traditional building designed with vernacular architecture techniques and modern buildings designed after properly considering the climate of a region have tendencies to adjust to climatic conditions so as to provide optimum temperature in buildings (Alkali *et al.*, 2021)

Conversely, in Sokoto State research has shown that traditional buildings types designed with vernacular architectural techniques adjusting to the climatic conditions (Air Temperature, Radiant Temperature, Air Velocity and Relative Humidity) required for thermal comfort in buildings (Alkali, *et al.*, (2020). Also modern building designed by architects’ who carry out proper site climatic analysis and design building to take advantage of the information from their analysis also adjust to these environmental climatic condition. Therefore in order to provide thermal comfort in winter and summer seasons to occupants in Sokoto state, rigorous climatic site analysis and the use of the right techniques for design are necessary to easily provide thermal comfort.

Therefore, the tendency of the traditional building types in Sockoto to adjust to the different environmental climatic conditions (Air Temperature, Radiant Temperature, Air Velocity and Relative Humidity) required for thermal comfort at different times of the day; is attributed to not just their design techniques but also the compatibility and adaptive ability of the local materials for construction. This agrees with Alkali *et al.*, (2021), findings that locally sourced building materials for traditional building construction are more compatible and adaptive to the climate of an area (Alkali *et al.*, 2021).

2.1.2 Human factors.

Human factors are the personal characteristics of the occupants. These factors vary in different humans, (which mean they are subjective in nature), because humans are built differently and attain thermal comfort at a different level. According to ASHRAE standard 55 (2020) the personal factors which significantly influences thermal comfort in humans and buildings are as thus:

2.1.2.1 Metabolic rate. This is related directly to metabolic heat. According to Lechner (2015), the heat produced during metabolism is partly a function of outside temperature but mostly a function of activity. Metabolic rate is this heat produced by a person carrying out work, any physical activity or even when our body is at metabolism. The metabolic rate during an activity is presumed to be higher than during metabolism. This explains why people on motion feel hotter than those who are in a stagnant position. Lechner (2015) elaborated by adding that a very active person generates heat at a rate which is more than 8times a resting/reclining person. It is pertinent to understand that each individual has different metabolic rate. Hence individual metabolism depend on the activity level, environment condition at a particular time, age, health condition etc., (Toftum, 2005). However, to maintain vital thermal equilibrium human bodies need to lose heat at the same rate at which it produces it through any metabolic rate (Lechner, 2015).

2.1.2.2 Clothing insulation. Clothing insulation is measured in clo units. The ASHRAE standard 55, for thermal comfort records that 1 clo is equal to 0.155 m²·K/W. This corresponds to trousers, a long sleeved shirt, and a jacket as well as the textile type.

2.2 Heat Transfer and Thermal Comfort in Buildings

Heat transfer and thermal comfort in buildings go in hand. Energy movement either by one or a combination of the following processes: conduction, convention, radiation and evaporation, is referred to as heat transfer. Buildings use these processes to achieve thermal equilibrium (Arup, 2016).

Numerous studies have shown that heat transfer in buildings specifically determines heat gain or heat loss in the building (Lechner, 2015; Design Building wiki, 2021). The study of heat transfer (conduction, convention, radiation and evaporation) in buildings is particularly important for determining the appropriate building fabrics and the best design strategies (including passive and active systems) for achieving optimum thermal comfort in the building (figure 1). Fanger, (2008) added that in order to attain optimum thermal comfort level within a building, the processes of heat transfer must be considered, since these process of heating gain or heat loss implies a transfer of thermal energy from one region to another by virtue of the existing temperature difference. Figure 1 shows the movement of heat in and out of a building.

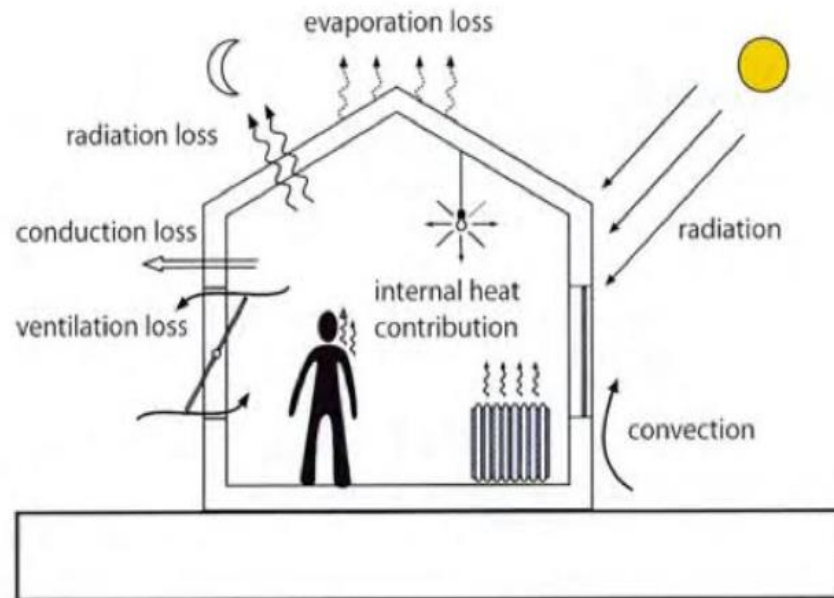


Figure 1: An illustration of the process of heat transfer in buildings,
(Arup, 2022; Dekorne, 2022)

2.2.1 Conduction

Conduction is the molecular movement of heat energy through solid materials (Dekorne, 2022). For building materials, conduction takes place at different rates

depending on the materials. The rate of conductive heat flow is measured as U-value, and resistance to heat flow is measured by its reciprocal, R-value. In building terminology, the property of how well a building conducts heat per unit area across a temperature gradient is U-value while R-value is a measure of how well a two-dimensional barrier such as layer of insulation, a window or a complete wall or ceiling resists the conductive flow of heat (Rathore *et al.*, 2011). This simply means R-value is thermal resistance per unit area (Rabi *et al.*, 2005). It is pertinent to know that the lower a given material's U-value, the less conductive it is. The higher the U-value of a material, the more conductive it is (Dekorne, 2022).

In building assembly, materials with poor conductors are often used as insulators. They are often used in between more conductive materials in the building assembly such as the walls or roof. According to Dekorne, (2022) the principle behind most insulation materials are the air pockets that interrupts conductive heat flow through a material.

In terms of thermal comfort in buildings, conduction is the diffusion of internal heat energy within the building due to temperature difference within the building and its surrounding (Rathore *et al.*, 2011). Thus, as a way to maintain thermal comfort in buildings, conduction is often inhibited by materials that are good insulators with high thermal resistance.

2.2.2 Convection

This is the flow of heat within a fluid. These fluids are used to transfer heat within a building by 'mass transfer'; for instance, the flow of a refrigerant, chilled or hot water around a building to provide heating or cooling. Convection is the heat transfer mechanism, resulting from the movement of air of different temperatures. This air is also known as “stack effect” (Dekorne, 2022).

Convection is a very important mechanism in the design of buildings because air movement is necessary to:

- i. Moderate internal temperature
- ii. Reduce the accumulation of moisture, odour and other gases that can build up during occupied periods
- iii. Improve the comfort of occupants

These air movement in buildings can be 'forced' (for example driven by fans), or 'natural' resulting from pressure differences from one part of a building to another. Natural air movement can be either wind driven, or resistance driven.

2.2.3 Radiation

Radiation in buildings has to do with heat movement often as electromagnetic waves through spaces. Radiation is often not linked with air because air doesn't affect it. It has to do with mostly sun rays. Therefore, it is pertinent to note sun rays reaches buildings via radiation. This sun rays causes the buildings components to absorb energy into it (Lechner, 2015). This means that for a building to absorb radiant energy the waves have to be in direct contact with the building.

Therefore for thermal comfort to be attained in buildings from radiant energy in extremely hot climate, it is important for shading devices and insulators to be employed in building design because shading devices and insulators play a vital role in improving optimum thermal comfort in buildings. In terms of using shading devices to improve thermal comfort, building can be designed to put an overhand or an awning between the sun and a window to reduce radiant heat flow into the building. This makes the solar radiation from the sun warm the overhangs or the awning as the case maybe absorbing energy into these materials rather than the building makes the building to be in optimum thermal comfort. Although in winters when a building is to be heated the radiant energy becomes important for this process while for insulators cladding materials can be used for wall finishes to absorb heat during the day when the temperature is extreme.

2.2.4 Evaporation

Evaporation is known as heat transfer in buildings through phase change. The change of phase of substances allows heat to be absorbed or released depending on the type of phase change. In building constructions, phase changes are used to reduce internal temperature. The basic principle of evaporation in building in terms of thermal comfort is centered on the concept of water evaporation. This principle is based on the idea that when water evaporates it absorbs heat which later produces cooling effect and then when it condenses it releases heat (Dekorne, 2022).

The principle is employed in evaporative cooling in building to attain thermal comfort. This process has to do with the use of water features such as fountains in

courtyards, pools, pond near a buildings etc. This process is also employed in the design of air conditioners. However, it is pertinent to know that the use of evaporative cooling techniques in Sokoto state is quite limited due to the erratic rainfall and power experience in the state.

According to Dekorne, (2022), the process of heat transfer is applicable in all materials and layers that make up a building assembly have some resistance and conductance to heat flow so as that thermal equilibrium can be reach in a building. Materials with good resistance value are good thermal insulators because of their ability to retard the flow of heat while materials that allow the passage of heat are good conductors. Figure 2 shows a cross section of how materials use for a building assembly work in equilibrium so that optimum thermal comfort can be attained in a building.

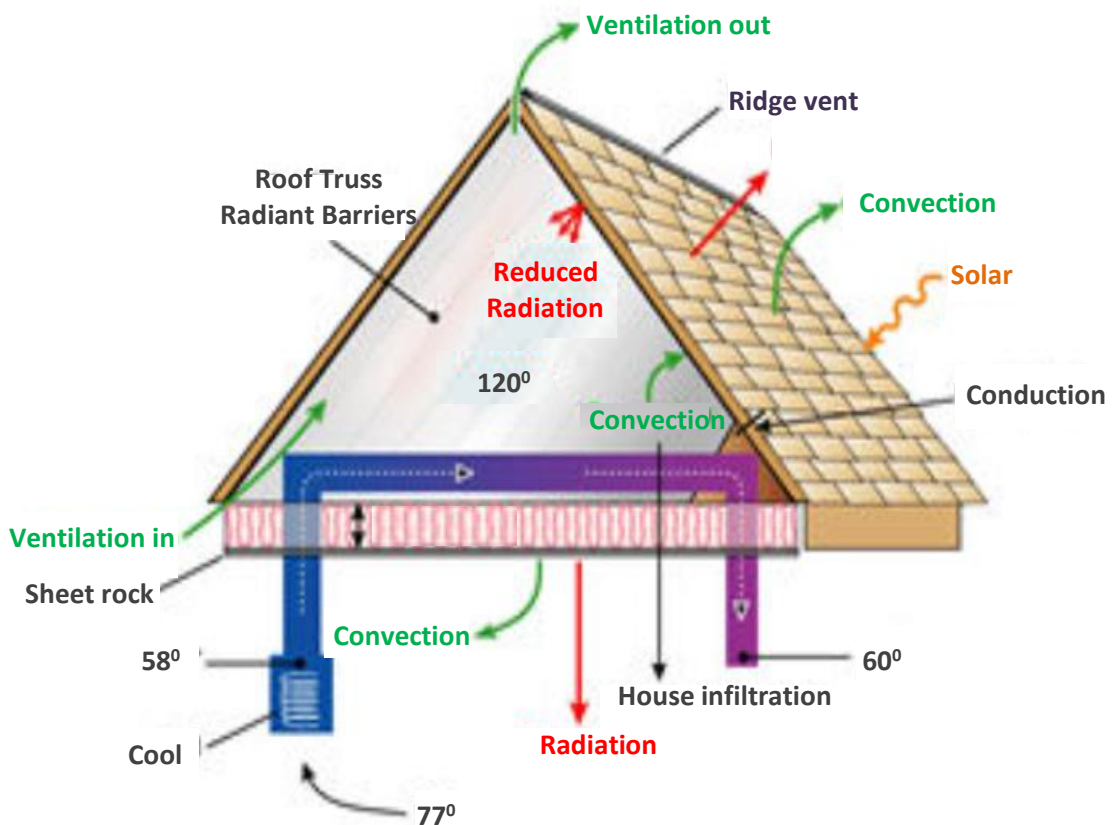


Figure 2: An illustration of cross section of heat flow in a building
(Sherwin et al., 2001)

Figure 2 shows the four heat transfer methods in a section of a roof work in equilibrium to attain thermal comfort. Radiant energy is radiated from the sun via the roofing material as the material heat up. This radiates the heat into the attic section warming the attic air its frames that are exposed to the environment. The insulation

of the wood limits the flow of heat into the building by conduction across the ceiling. The attic is cooled by convection and evaporative energy in form of ventilation when moving air through the soffits and ridge vents. The air pressure in these roof flows through tiny holes in the ceiling, hence maintain thermal comfort in the building (Dekome, 2022).

2.3 Impact of Climate Change on Thermal Comfort

The United States Environmental Protection Agency (EPA, (2007), defines climate change as any significant change in the action of weather elements like temperature, precipitation, or wind etc., lasting for an extended period of a decade or longer. Climate change may result from human impacts (through burning of fossil fuels, deforestation, reforestation, urbanization etc.), natural factors (such as changes in the sun's intensity), or processes internal to the earth (such as changes in ocean circulation, volcanic eruptions, desertification etc.).

One of the known effects of climate change is global warming. Global warming is an average increase in the temperature of the atmosphere near the earth's surface which can contribute to changes in global climate patterns (EPA, (2007). According to Intergovernmental Panel on Climate Change (2001), global warming can occur from a variety of causes, both natural and human induced. It is largely attributed to human impacts of emission of green-house gases from burning fossil fuels and other source of energy.

Climate change has a significant impact on the level of thermal comfort. According to Dodoo, *et al.*, (2014), the increases in global air temperatures (global warming) and solar radiation due to climate change have intensified the problem of ensuring human thermal comfort in buildings in both dry and temperate regions of the world globally. A significant amount of the energy produced in the world is used for the thermal comfort of the occupants (Ngarambe, *et al.*, 2020).

According to Ferdyn-Grygierek, *et al.*, (2021), in most temperate regions of the world, more energy is mostly considered for heating and cooling as well. As a result of this, architects and engineers' are focused on reducing this energy so as to limit the harmful effect of climate change (global warming). They now look to increase thermal insulation of external walls of the designed buildings. These operations, apart from the expected reduction in heat demand, also have negative effects, for example overheating building in the warm season. The heat and mass

transfer between outdoor and indoor environment is limited. Therefore, finding the right balance between reducing a building's energy consumption and ensuring an adequate level of thermal comfort poses a major challenge (Ferdyn-Grygierek *et al.*, 2021).

According to Sarkingobir (2018) being that Sokoto State in the semi-arid region. The state is prone to climate change repercussion such, lengthy periods of rainfall, occurrence of flood etc., that could affect the architecture of the region, Although this may exhibit positive impact as it could increase relative humidity, air temperature thereby reducing the heat in the region but could significantly affect the existing architectural design pattern who were designed in relation to the original hot climate of the region. For instance the flat roof which was favorable for low rainfall and tall wall massing for thermal comfort could soon become a problem and also the traditional vernacular building that comprises of mud could ware up easily, therefore affecting the durability of building materials for vernacular designs as a result of the roofing pattern (Sarkingobir 2018).

Chapter Three

3. Climate Responsive Vernacular Architecture

According to Yanas (2003), climate responsive architecture is the architecture that aims to achieve thermal and visual comfort of building occupants using little to no non-renewable energy sources by incorporating the elements of the local climate in design effectively. Malekafzali (2022) added that climate-responsive architecture's goal is centered on naturally creating a comfortable indoor environment by reducing buildings reliance on artificial energy.

Malekafzali (2022) added that a climate-responsive building design reflects the weather conditions in the precise area where the building is constructed (Malekafzali, 2022). According to Lechner (2015) climatic responsive architecture design priorities is to keep heat in and cold temperature out during the winter; protect from cold winter winds; let the winter sun in; protect from summer sun and use natural ventilation for summer cooling. The design utilizes data on the region's weather patterns that accounts for factors like seasonality, intensity of the sun, wind, rainfall and humidity etc. while designing to attain the climate design priorities (Lechner, 2015).

The information from this data enables architects to incorporate the best vernacular architecture practices to the designs, and also enables them choose the best locally sourced building materials that will positively impact the building in relation to thermal comfort. The influence of climate on vernacular architecture has been widely recognized. Thus, it is relevant to study how climatic factors such as sun, wind, rainfall and humidity, etc. have impacted vernacular architecture. It is pertinent to know that true climate-responsive architecture goes well beyond adherence to code it entails incorporating vernacular architecture strategies to design.

According to Bodach, *et al.*, (2014), vernacular houses use most of the identified climate responsive strategies. This simply means traditional houses are designed according to local climate. Thus by implementing vernacular architecture and organic urban design practices, proactive designs and changes for designing suitable cities can be made. Bodach *et al.*, (2014) elaborated that vernacular architecture is the result of hundreds of years of optimization to provide a comfortable shelter in a local climate using available materials and known local construction strategies.

The word “Vernacular” is from the Latin word ‘*vernaculus*’, which translates as ‘domestic, indigenous or native’. According to Fernandes *et al.*, (2014), “vernacular architecture is the building methodology which employs the usage of available local materials and tradition to respond to the local needs”. Lawrence (2006) stated that “vernacular buildings can be seen as those constructions by man that results from interactions with certain stimulators such as the ecology, culture, climate, material, economy and social factors”. From these definitions, it is safe to say vernacular architecture is developed mainly from predominantly available local materials, locally skilled artisans and prevailing environmental conditions. Arome, and Çağnan, (2021) added that Vernacular Architecture is architecture which is indigenous to and specific to a particular place and is often carried out by untrained artisans.

Rudofsky, (1964), stated that vernacular architecture is largely the art of constructing shelter for safety and comfort using locally sourced materials. It is a community based and environmentally oriented architectural practice that have evolved over time with repetition and efforts of indigenous people’s technologies and cultural values (Rudofsky, 1964). Vernacular buildings use a design approach that works towards reducing energy consumption with the use of natural resource for creating a sustainable living space which is comfortable and healthy and due to the absence of mechanical means, traditional buildings use solar passive measures to achieve thermal comfort conditions, thus achieving the aims of climate responsive sustainable building design.

According to Lechner (2015) solar passive measures has to do with a system of collecting, storing and redistributing solar energy without the use of fans, pumps or complex controllers. Lechner (2015) added that solar passive systems functions by relying on the idea of integrated approach in building designs where the basic elements of buildings such as windows, walls and floor have many different possible functions. It pertinent to understand that every solar passive heating system has at least two elements: a collector consisting of south-facing glazing and an energy-storage element that usually consists of thermal mass, such as rock (wall) or water (Lechner (2015)).

Evans (2019) added that climate responsive architecture often considers seasonality, the direction of the sun (sun path and solar position), natural shade provided by the surrounding topography, environmental factors (such as wind,

rainfall, humidity) and climate data (temperature, historical weather patterns, etc.) to design comfortable and energy-efficient buildings. This explains why architects / designer are interested in the aspects of climate that affect human comfort in buildings by employing climate responsive strategies. Hence, climate responsive strategies are measures harnessed to effectively employ climate responsive architecture vernacular architecture characteristics in the built environment. They include: Passive Design Approaches and Bioclimatic Design Approaches.

3.1 Passive Design Approaches

Passive design approaches provide solutions to the problem of thermal comfort in buildings. According to Lechner, (2015), the general idea of passive design approaches is based on optimizing the building envelope in respect to the climate of a region so as to substantially reduce the size and reliance on mechanical system for thermal comfort (Lechner, 2015). Passive design uses layout, fabric and form to reduce or remove mechanical cooling, heating, ventilation and lighting demand (Harbour, 2021). Lawal and Makinde (2007) define passive designs as the design of building built in tune with indigenous resources symbolized and exemplified by the sun and the climate. Therefore, passive design approach is one of the main strategies of climate responsive architecture. Passive designs are self-sufficient buildings which rely on natural principles instead of mechanical systems to provide a non-polluting source of HVAC. Examples of passive design strategies include optimizing spatial planning and orientation to control solar gains and maximize day-lighting, manipulating the building form and fabric to facilitate natural ventilation strategies and making effective use of thermal mass to help reduce peak internal temperature.

The concepts of solar passive measures are of three (3) types which include: (i) Direct gain, (ii) Trombe wall (indirect gain) and (iii) Sunspace (isolated gain).

i. *Direct gain:* In direct gain solar passive measures, south facing windows are designed to create a direct solar-gain system, while window facing the east, west and especially the north are designed to lose more heat than they gain during winter and vice versa. It is important to have a proper ratio of mass to the south-facing glazing because in this system, the greenhouse effect collects and traps solar radiation during the day while the thermal mass inside the building stores the heat for nighttime use in the while preventing overheating during the day (Figure 3)

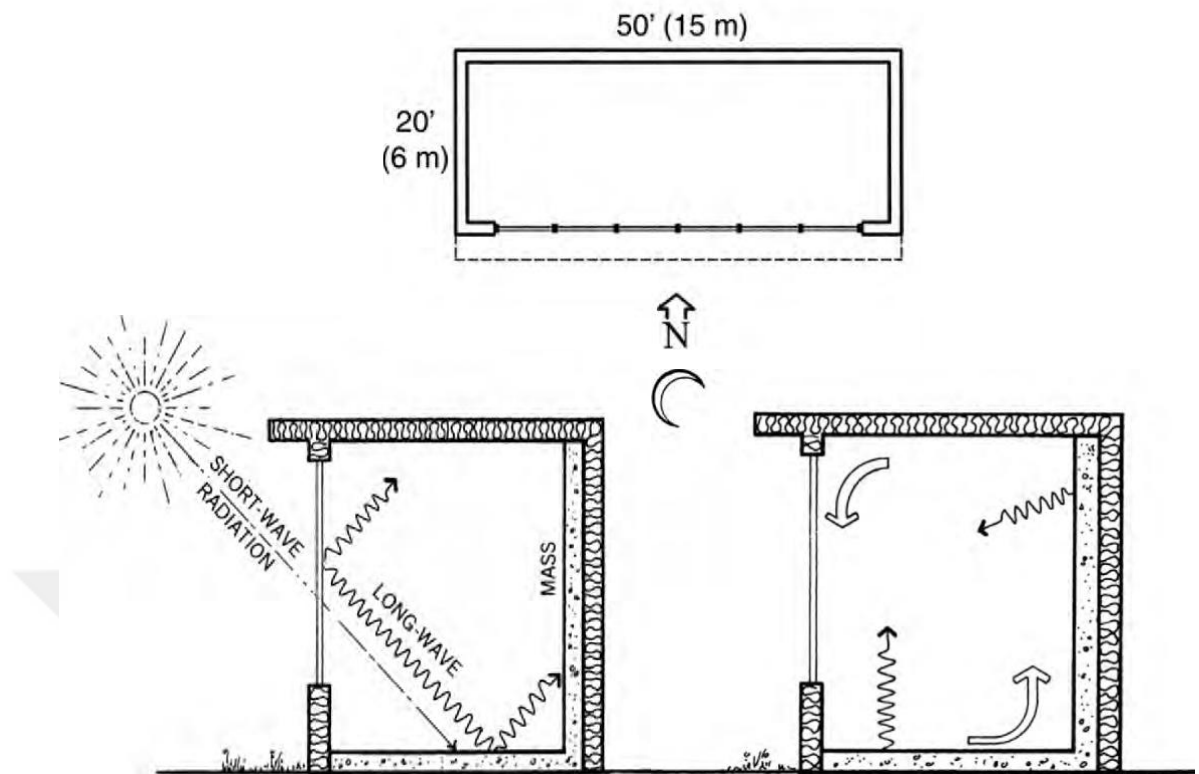


Figure 3: An illustration of solar passive system direct gain (Lechner, 2015)

ii. *Trombe wall (indirect gain)*: The Trombe wall solar passive measure is also referred to as indirect gain. This system was named after Professor Felix Trombe, who developed the technique in France in 1966. This method is similar to the direct gain but in this passive system, heat is collected with light entering the building because the thermal mass consists of a wall which is often about 30cm thick just inside the south facing glazing. The surface of the wall facing the sun is often covered with a selective coating or painted with a dark colour. These coating materials allow for the solar radiation trapped from greenhouse effect to be trapped during the day as it gets hot causing heat to flow into the wall; and since the wall is thick, the time lag for the heat entering the building wall becomes quite long (Lechner, 2015). Therefore, heat does not reach the interior surface during the day until evening when it gets cold so as to maintain thermal comfort (Figure 4). It is worthy to mention that in In hot climates, a shade screen can be draped over the Trombe wall glazing during the summer while a radiant barrier should be in place during winter nights and summer days.

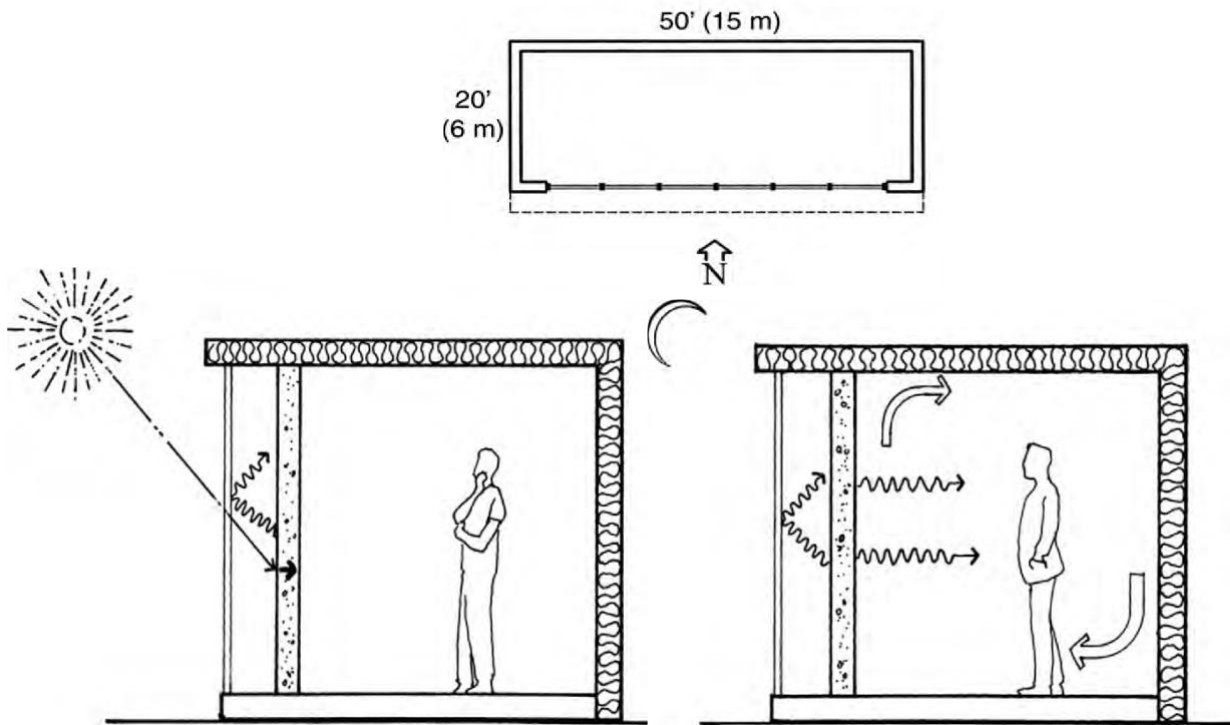


Figure 4: An illustration of solar passive system Trombe wall (Lechner, 2015)

iii. *Sunspace (isolated gain)*. Sunspaces solar passive measure is also referred to as isolated or remote gain. According to (Lechner 2015), a sunspace is a solar collector that can also be used as an attractive living space in most cases, but not all, of the time. This solar passive measure system is designed to collect heat from the main part of the building while serving as a secondary living area. They are also designed in a separate thermal zone isolated from the rest of the building. Lechner 2015 added that sunspaces are one of the most popular passive systems, not because of their heating efficiency but because of the amenities that they offer as a secondary living space or relaxation spots in buildings. Most people find the semi-outdoor aspect of sunspaces extremely attractive. Lechner (2015) continued that almost everyone finds it pleasurable to be in a warm, sunny space on a cold winter day. Thus, sunspaces are considered adjunct living spaces because the temperature is allowed to swing widely. On a sunny, cold day, the temperature can go as high as 32°C during the day and cool down to 10°C just before sunrise. In terms of thermal comfort, during the day, the sunspace collects solar radiation and distributes much of the heat to the rest of the building (Lechner 2015). The thermal mass stores the heat for nighttime use. It is

important to understand that at night sunspaces must be sealed from the main building to prevent them from acting as means for energy drain to the main building (Figure 5).

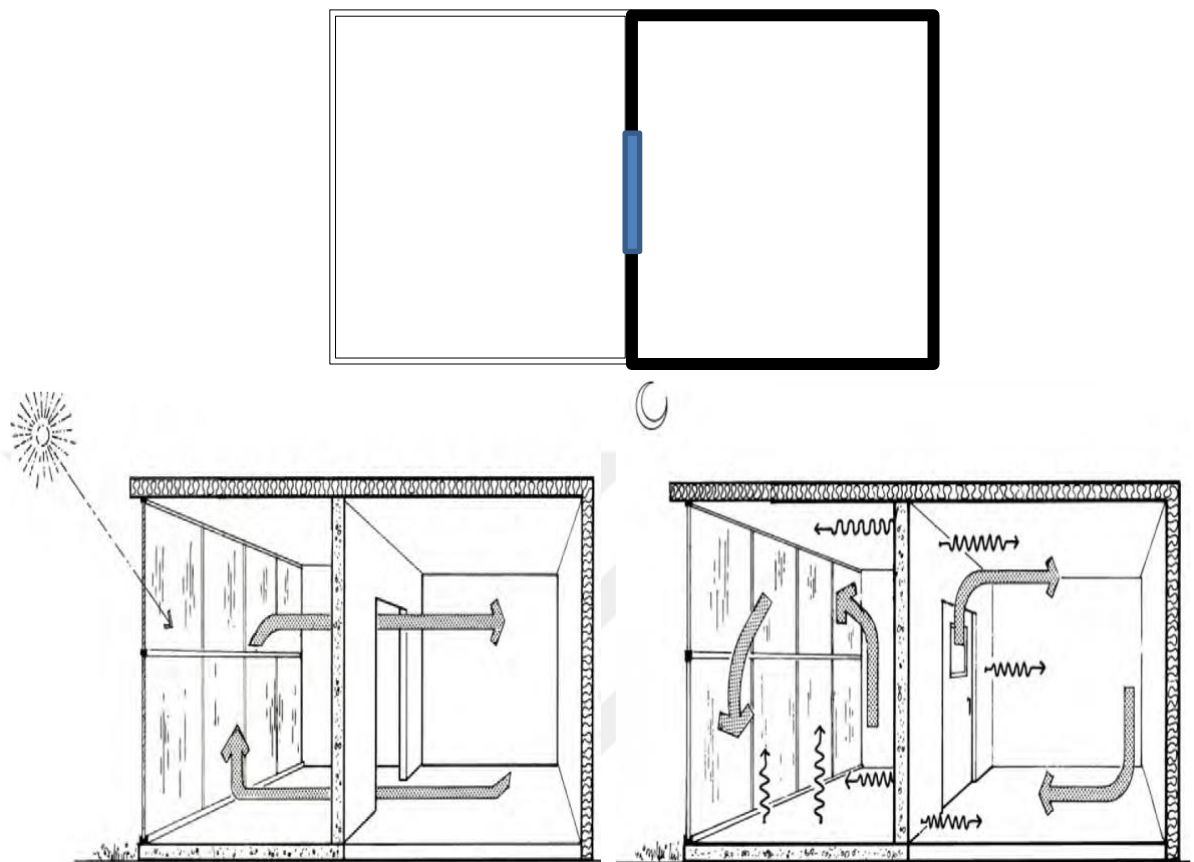


Figure 5: An illustration of solar passive systems – Sunspace (Lechner, 2015)

The origin of this concept is derived from the conservatories that were popular in the eighteenth and nineteenth centuries (Lechner 2015). It is pertinent to know that sunspaces in building are designed in three different ways. They are either: attached, semi-closed or enclosed to the building (Figure 6)

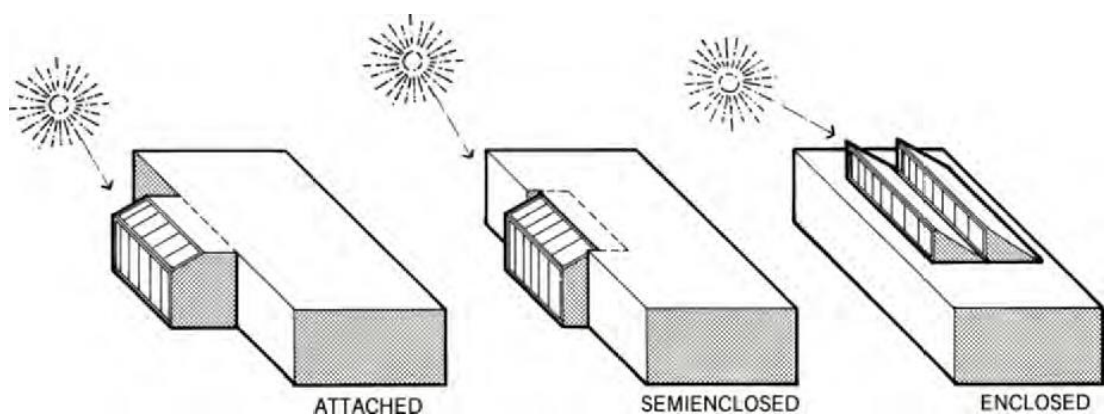


Figure 6: An illustration of possible design concepts of sunspace to main buildings (Lechner, 2015)

According to Lawal and Makinde (2007) some of the advantages of passively design buildings include:

- a) The Buildings are used to provide shelter and maintain the environmental conditions that determine the quality of life required for human existence.
- b) The Buildings are used to provide the micro climate required for human existence.
- c) The Buildings respond to passive energy and minimize the use of active energy for human comfort.

Ortner (2001), further describes passive design as architectural means of constructing comfortable interior environments by building with natural equipment, without the use of mechanical equipment. Lawal and Makinde (2007) stated that it is advisable for all building to be passive to the extent that without the use of mechanical driven system energy sources, the building should still produce comfortable interior climate. Thus, there are a lot of passive strategies which will help achieve these passive building designs. The main ones are building orientation, floor plan zoning, natural ventilation / day-lighting, landscaping, shading and building materials.

i. *Building orientation.* Building orientation is the position of a building in relation to seasonal variations in the sun paths as well as prevailing wind pattern (Akande, 2010). Figure 6 shows the three (3) seasonal variations in sun-path: summer solstice Equinox, and winter solstice

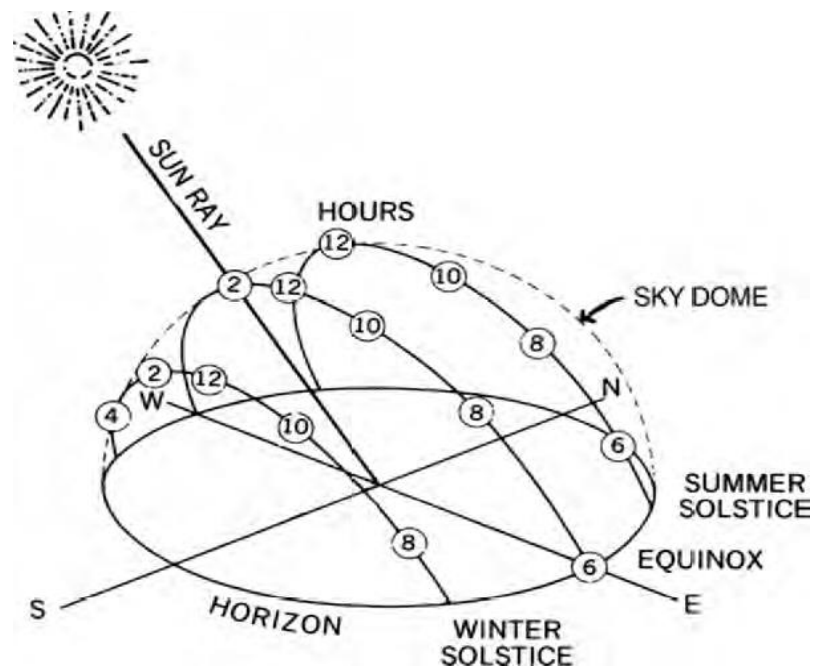


Figure 7: Seasonal variation in sun-path variations (Architectural Graphic Standards, 1988; Lechner, 2015)

It is vital to note that seasonal variation in sun-path is a consequence of tilting of earth's axis of rotation. These variations happen at different times all year round. It is generally accepted that summer solstice becomes extreme in June 21 when the sun is directly overhead at the tropic of cancer which is at latitude 23.5° N while the winter solstice period is around December 21. During the winter solstice the sun is directly overhead on the tropic of Capricorn at 23.5° S latitude. The equinox is the period for equal day of nighttime and daytime hours and during this period the sun is directly overhead on the equator. This occurs twice in a year with March 21 being the spring equinox and September 21 the fall equinox (Lechner, 2015).

Lechner (2015) elaborated that due to the fixed nature of the earth's tilt is why the Northern Hemisphere faces the sun in June and the Southern Hemisphere faces the sun in December thus causing summer solstice when the North pole is pointing most towards the sun with extreme condition at June 21 and winter solstice when the North pole is pointing farthest away from the sun with extreme conditions at December 21. The summer and winter solstice is characterized with longer and shorter days of the year respectively. Lechner (2015) added that at halfway between summer solstice winter solstice is the equinox characterized by equal night and day. The equinox occurs twice as earlier stated around March 21 and September 21. During the sun is directly overhead on the equator.

Therefore, buildings that are properly oriented take advantage of these sun path variations (solar radiation) and prevailing wind to benefit the building. Gronicko (2006) added that building orientation is the practice of facing a building on site so as to maximize certain aspects of its surroundings. This takes into consideration sun path and climate of the area.

However it is important to know that it is the region where a building is located that determines the best orientation for the building. In Africa buildings need to be oriented in such a way that the shorter side faces the East and West (Ochedi *et al.*, 2022). This orientation positions the façade of the building to the North and south. This ensures that when the sun rises in the façade of the building are protected from overheating in the summer and also are properly warm in the winter.

According to Gronicko, (2006), with the rising energy costs and climate change, it is becoming increasingly important for builders to orient buildings to capitalize on the Sun's free energy. However, in Sokoto State, this is not the case as most existing building projects and even new buildings are being designed without

proper orientation because client don't consent professionals who are knowledgeable about how to orient a building on site. Figure 8 shows an illustration of a building orientation on site.

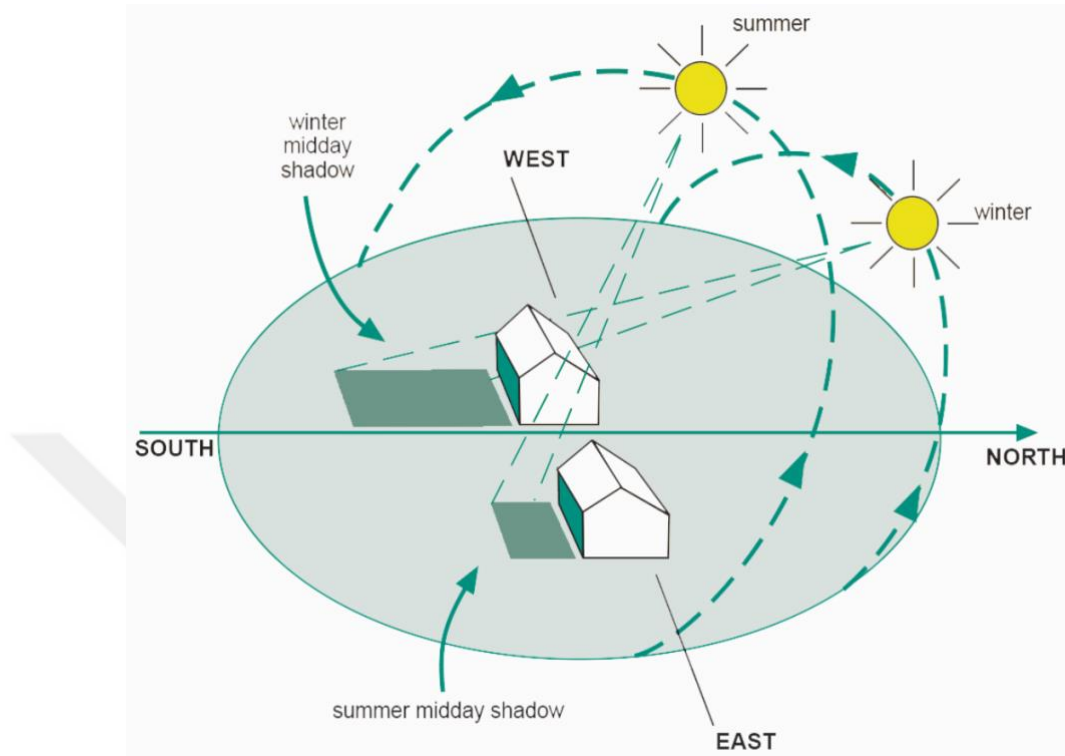


Figure 8: An illustration on optimum building orientation on a North-South pole (Gronicko, 2006)

According to Steepen (2018), to orient a building to accept the sun's warmth in winter while avoiding excessive solar heat in summer is a good form of building orientation. It is important to understand that the amount of sunlight directed at a window varies according to the year and orientation of the building (Gordon, 2005).

In the Northern Hemisphere, the winter sun (November, December, January) rises in the southeast, transits celestial meridian at a low angle in the south (more than 43° above the southern horizon in the tropics), and then sets in the southwest (Khavrus *et al.*, 2010). And in the summer of the Northern Hemisphere (May, June, July), the Sun rises in the northeast, peaks out slightly south of overhead point (lower in the south at higher latitude), and then sets in the northwest.

According to Steepen (2018) for optimum building orientation in this region, face the long, front side of the building within 15-20 degrees either side of true south. This positions south-facing windows to act as solar collectors that bring heat into the building in winter and summer shading. This allows the East and West

facing ends of the building to be shorter than the North/South dimension. It is important to understand that the lesser utilized parts of the building such as laundry rooms and garages should be at the short ends of the building to provide a thermal buffer zone against infiltration by cold east/west winds while the most frequently used rooms should front the longer, south-facing side. This will offer greater solar warmth in winter to these rooms and shade during summer. It will also allow the rooms to be more consistently lit by sunlight because sun stays more on the south (equator) side of the building all day long (Steepen, 2018). This can help reduce lighting costs.

In contrast, in Southern Hemisphere (May, June, July) the winter sun rises in the northeast, peaks out at a low angle in the north (more than halfway up from the horizon in the tropics), and then sets in the northwest; in the summer (November, December, January), the Sun rises in the southeast, peaks out slightly north of overhead point (lower in the north at higher latitude), and then sets in the southwest (Khavrus, 2010). For proper building orientation in these regions, the building needs to be oriented to the North since the path of the sun is north (Beagley, 2011). Therefore orientation of up to 15° west of North and 25° east of north allow for good passive sun access (Cole, 2011). This allows the north-facing windows let plenty of solar thermal energy into the building in the winter and are easily shaded by the eaves of the roof in the summer (Beagley, 2011). Steepen (2018) added that this positions North-facing windows to receive twice the winter sun than east and west facing windows, allowing light and warmth into the home. They can be easily shaded from the high summer sun to help keep the house cool. Ideally, the glazing area should be between 10-25% of the floor area of the room. In terms of zoning of function in these regions, locate common rooms such as the living, dining and kitchen to the north to keep building warm and keep the eaves of the building at a depth of 600mm so they don't block winter sun.

Hence architects and builders, orienting a new building need to always take advantage of the Sun movement for the best orientation depending on the region. For building users, it will increase their indoor comfort and reduce their energy bills. This is in line with Steepen (2018) findings that proper orientation of a new building allows the building users to take advantage of solar energy to attain a power source at lower utility costs.

However, it is important to understand that the shape of a building, orientation, solid-void, materials etc. determines how much area is exposed to outdoors energy through exterior walls and ceilings. This has a direct relationship with achieving thermal comfort in buildings. Studies by numerous scholars has shown that orientating building designs with simple square or rectangle floor plans is relatively easy compared to irregular shaped plans(Akande, 2010; Akaat, 2021;). Therefore, building with complex shapes is difficult due their complex shape. According to Akande, (2010), the solar orientation of a building is done for the following purposes:

- i. To give the correct direction to the building according to the surroundings.
The correct direction to orient a building is to longer part facing the North or the south. This orientation gives the best results for both winter heating and summer shading (Lechner, 2015).
- ii. To provide natural light and air to the inhabitants.
- iii. To shield the inhabitants from dust and smoke.
- iv. To shield the inhabitants from noise.
- v. To provide privacy to the inhabitants.
- vi. To shield the building from damages due to rain.
- vii. To shield the inhabitants from the bad effects of the worst weather.
- viii. To add beauty to the building

ii. Floor plan zoning. Gut and Ackerknecht (1997) stated that the spatial layout of rooms depends on the function they serve and according to the time of the day they are in use. Zoning of floor plan zoning is an important passive design approach. According to Akande (2010), different rooms of a building require suitable natural light. Some room needs much sunlight while the other needs less of it. For example, the drawing room and the common room need much light whereas the store does not need much light.

Thus, in this case, the rotation of the sun has much importance in determining floor plan zoning. The rooms which need much light are arranged to the east and south direction like the kitchen, bathroom, drawing room, etc. Akande (2010) further stated that the following things should be kept in mind while arranging the rooms and designing the floor plan:

- (i) The kitchen is suitable in the direction between North East and South East.

- (ii) The drawing room is suitable in the direction between South East and South West.
- (iii) The drawing room and the T. V. Lounge should be in the extreme of South East direction because much light is available there.
- (iv) The bed room should be given the direction between South East and North West.
- (v) The suitable place for store and staircase is between North-East and North-West because less time is spent there and they need less light.
- (vi) The verandas are constructed in the direction of South West because the Sunlight is severe in summer in this direction.

The coordination functions in zoning of floor plan are also important.

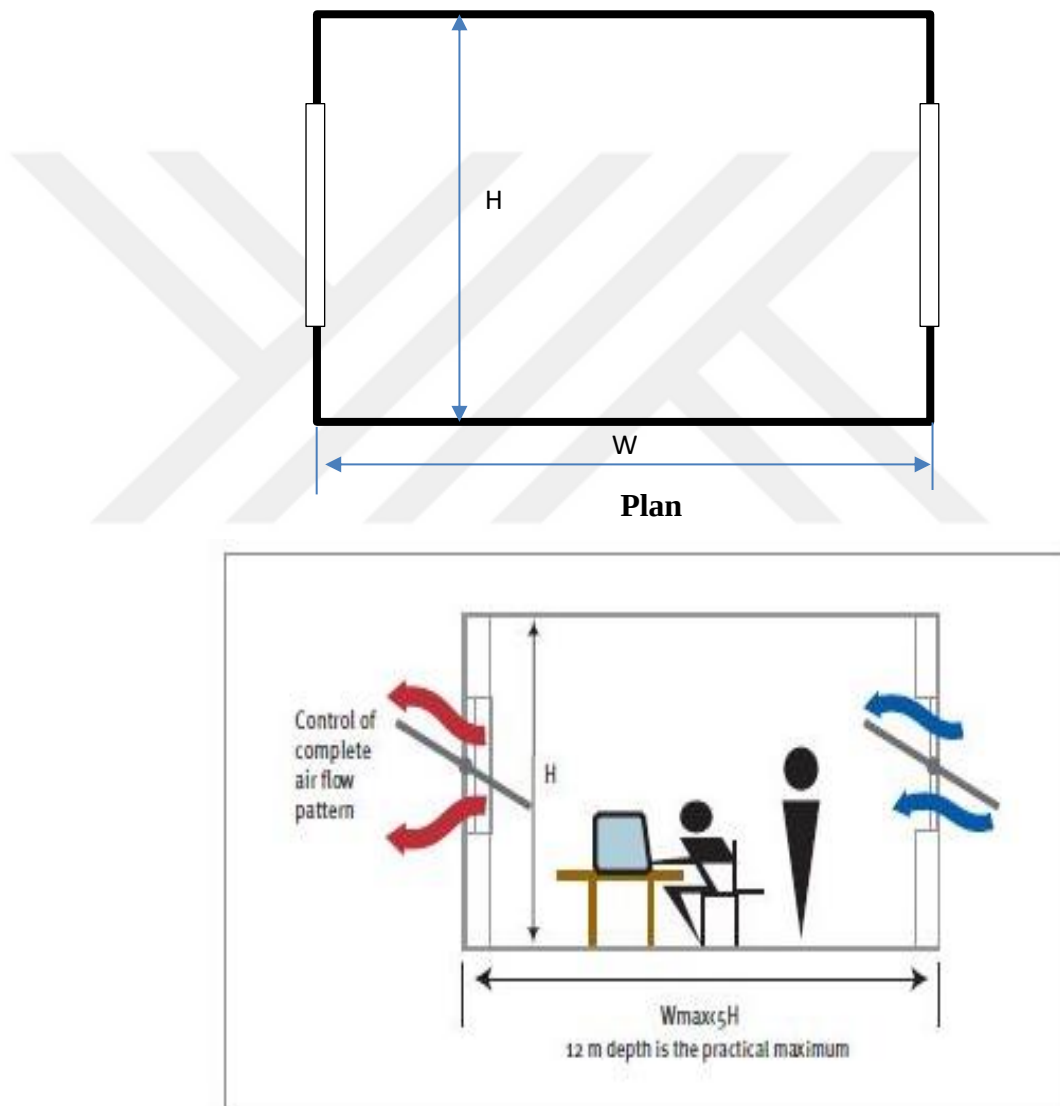
According to Akande (2010), there need for a connection between the various parts of the building to facilitate the residents. In this connection the following parts need to be immensely related with one another:

- (i) There is need for a suitable relationship between drawing room, dining room, kitchen, and pantry.
- (ii) There is also need for a suitable relationship between the bedroom, bathroom, dressing room, and study room.
- (iii) All the parts of a building need to be covered through a passage like a veranda.

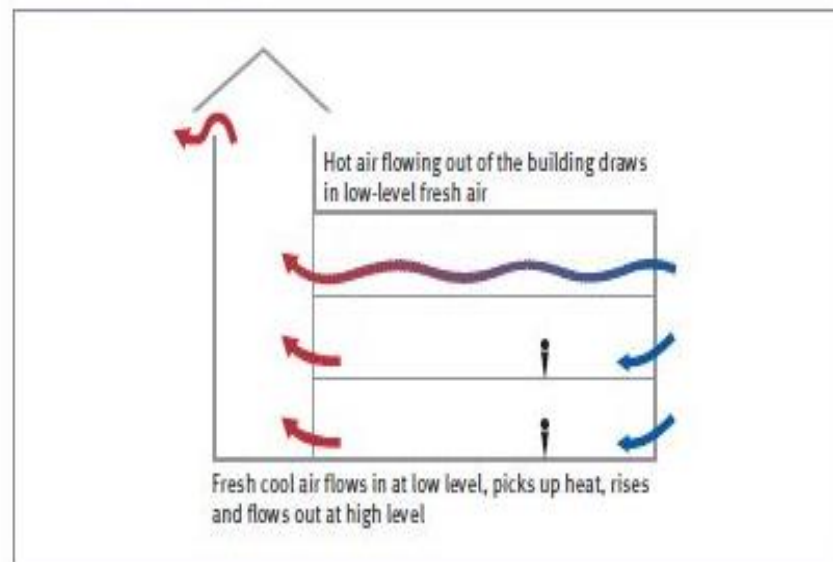
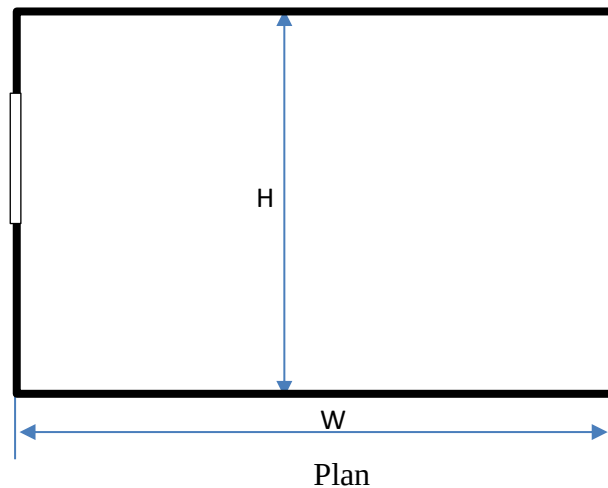
This will facilitate to move from one part to the other part of the building safely in the case of severe rain or hot sunlight.

iii. Natural ventilation / lighting. Natural ventilation and day-lighting is a passive design measure for achieving thermal comfort and energy efficiency in buildings. This is because less mechanical energy is spent to ventilate or light the building. Natural ventilation and day-lighting are proven measures for improving energy efficiency in buildings. The positioning of openings in buildings is paramount in the quest for natural ventilation and day lighting in buildings. Natural ventilation and day-lighting tend to cohabit in building designs. Buildings designed to have satisfactory natural ventilation are also good in terms of achieving day-lighting too. According to Gronicko (2006), cross ventilation and stack ventilation are important types of natural ventilation that must be considered in building designs.

Cross ventilation allows for air to pass from one side of a building to the other side of the building. According to the Sustainable Energy Regulations and Policymaking (SERPA, 2015) the minimum width a building must not be more than for cross ventilation to be effective is 12-15m. While Stack ventilation or stack effect on the other hand is the practice of introducing central atria to draw air from outer perimeter and bring them up through the center of a building. In deeper spaces, Natural ventilation is achieved by stack effect. Figure 9 shows a practical illustration of natural cross ventilation and stack ventilation.



1. Cross ventilation



2. Stack effect

*Figure 9: An illustration depicting types of Natural ventilation
(SERPA, 2015)*

iv. *Landscaping.* The use of landscaping is another important passive design technique. According to Akande (2010), Landscaping is an under-utilized element of domestic architecture despite its relative cheap cost and effective results in the improvement of year-round comfort and energy efficiency. A study by Raeissi (1999) revealed that cooling loads can be reduced by 10-40% through tree plantation. According to Akande (2010) in Nigeria, the rapid growth of vegetation can be harnessed for passive design element either vertically or horizontally as patios, pergolas, screens, atriiums, flowers pots, etc. in order to create cooling microclimates. Other methods of passive cooling that can be employed in passive design to provide

suitable thermal comfort without resorting to mechanical methods include enclosed courtyards, cooling pools and wind catchers.

v. *Shading*. According to Odimegwu (2019), solar gains through openings such as windows and doors, as well as on the opaque walling fabrics increase the surface temperature of the building envelope and contribute to the heating of the interior environment. A study by *Danja et al.*, (2020) indicated that shading devices on building can help reduce heat gain. According to Akande (2010), shading devices are those devices that can be used to control the amount of solar heat gain and visible light that is admitted into a building. They are devices that intercept or block sunlight before it reaches the walls and glazing of a building.

Generally, shading devices are classified into fixed shading devices (external) and moveable (internal) shading device.

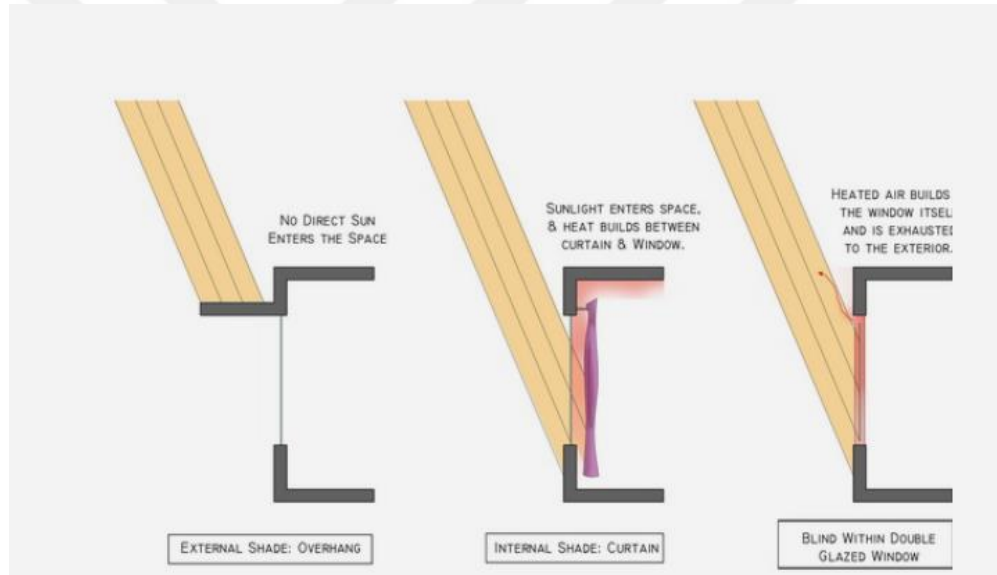


Figure 10: An illustration depicting external and internal shading device (*Danja et al.*, (2020))

According to Don (2016) fixed or external shading device are effective for reducing solar heat gain into buildings by 80%. They include eaves, awnings, canopy, window hoods, overhangs, pergolas, vegetation and tress, projecting horizontal or vertical fins, balconies etc. Don (2016) added that the moveable shading devices (internal) such as internal blinds, curtains, internal or external shutters allows occupants to control the amount of daylight and energy allowed into a building.

vi. *Building materials*. The choice of building material adopted for a design can add to the passiveness of the design. Numerous studies have shown that traditional / locally sourced Building materials are good for passive designs against modern building materials (Agboola, 2011, Auwal, 2019). Traditional materials such as earth, bamboo, timber, thatch/ grasses etc. are commonly used in vernacular architecture. According to Akande (2010), materials used in modern buildings tend to obstruct the flow of air, necessitating the use of mechanical ventilation.

3.2 Bioclimatic Design Approaches

Bioclimatic design; a combination of “biology” and “climate” – is an approach to the design of buildings and landscape that is based on local climate. According to Nnaemeka-Okeke, *et al.*, (2019), bioclimatic architecture is design that has a connection with nature. Liebard and Traité (2005) stated that bioclimatic approach to climate responsive and vernacular architecture, considers the climate and environmental conditions to favor the thermal comfort of the users. It emphasizes on the importance of the interactions of living organisms and the local climate through the form and fabric of the building to gain thermal comfort (Akande 2010). Nnaemeka-Okeke *et al.*, (2019) added that bioclimatic architecture tries to create integration between the design and natural elements such as the sun, wind, rain and vegetation, which optimizes resources. In other words, bioclimatic design considers the climate and environmental conditions to help achieve optimal thermal comfort indoors (Chayaamor-Heil, &Hannachi-Belkadi, 2017). According to Odimegwu (2019) many variables come into play when considering bioclimatic architecture and how it will affect a building’s comfort and energy use. However, the most effective variables to consider are the environment, local weather data and the building fabric materials. The environmental analysis looks at historical temperature average, humidity level, solar radiation and sky condition to inform decisions made during the schematic design phase and to improve the climate responsive features of the building (Odimegwu, 2019). According to Nnaemeka-Okeke *et al.*, (2019), a bioclimatic designed building responds to the climatic conditions within its environment and is modified with appropriate design strategies to create conducive environment that provides thermal and visual comforts to its users at the lowest energy consumption.

According to Manzano-Agugliaro *et al*, 2015, bioclimatic buildings are constructed in such a way that, during winter months, exposure to cold temperatures is minimized and solar gains are maximized; during the summer, bioclimatic structures are shaded from the sun and various cooling techniques such as louver shading device, double glazing, insulation, evaporative cooling (fountain), natural ventilating etc. are employed, often with the aid of renewable energy sources.

In a study on by Nnaemeka-Okeke *et al.*, (2019), on the review of bioclimatic design strategies for residential buildings in a warm humid climate using the Psychometric chart adapted from Giovani (1992) to analyze the climate of the study area and identify the bioclimatic design strategy that will aid energy efficiency. This study concluded that some bioclimatic design strategies can be used in countries with similar climates and therefore, advocates for more incorporation of bioclimatic design strategies for energy-efficient buildings.

Nowadays, Architects design buildings using the principles of sustainable architecture and Bioclimatic Design Strategies to maintain thermal comfort in buildings. Some notable bioclimatic design approaches include (Okeke *et al.*, 2019):

i. Natural lighting strategy. According to ChayaamorHeil and Hannachi-Belkadi, (2017) natural lighting strategy is an important bioclimatic design strategy which is aimed at improving the inflow of natural light in buildings. This strategy allow for effective capturing and penetration of natural light into a building. In buildings, when natural lightning is controlled and maximized, it reduces visual discomfort. Floor plan zoning has a direct relationship with natural lightning. There are a number of ways that can be used to control the amount of natural lightning entering a building. Some of these include the use of shading canopies, overhangs, reflectors, glass windows, blinds etc. Figure 11 illustrates how natural light can be controlled in a building.

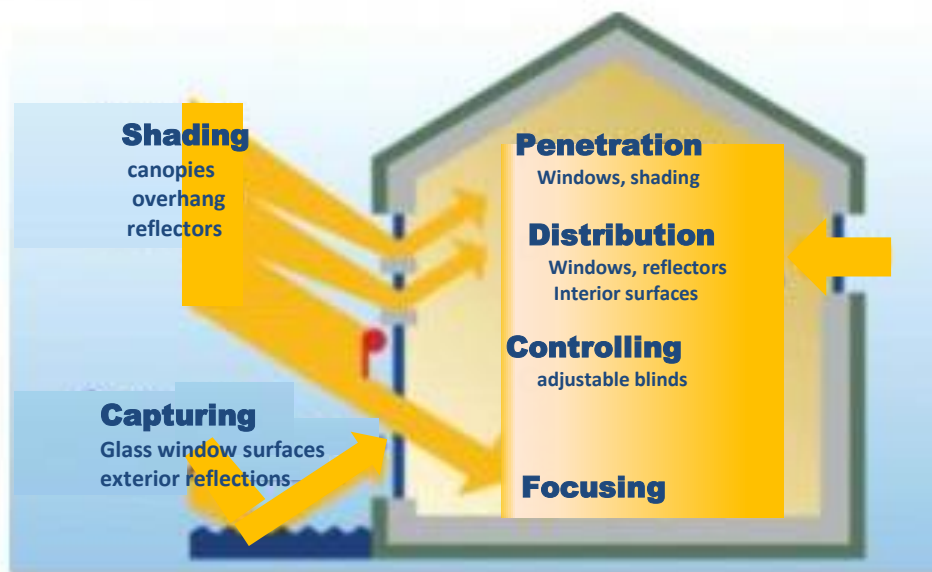


Figure 11: An illustration of for bioclimatic strategy for natural lightning control in a building (Liebard *et al*, 2005.)

This figure (figure 11) illustrates the bioclimatic strategy for controlling natural lightning into a building. From the figure, the rays of the natural light from solar radiation are controlled by the glass windows.

ii. *Cooling Strategy*. This is another bioclimatic design strategy that is important in design decision. According to Nnaemeka-Okeke *et al.*, (2019), minimizing the amount of heat entering a building is known as cooling strategy. The ultimate purpose of this strategy is for thermal comfort to be achieved in buildings. This can be achieved by shading from solar radiation and heat gain, minimizing internal heat sources, dissipating excess heat and cooling down naturally. Minimizing of internal heat sources is aimed at avoiding excessive heat in buildings due to the occupants and their equipment. There are a number of bioclimatic cooling strategies; some notable mentions include landscaping, shading, cooling pools, etc. Figure 12 shows an illustration of how cooling takes place in a building by shading.



Figure 12: An illustration of Bioclimatic strategies for cooling in buildings
(Liebard et al, 2005.)

From figure 12, the bioclimatic strategy employs a cooling pool just opposite the building. Water evaporates from the pool due to the effect of solar radiation. The evaporated water condenses in the atmosphere to produce a cooling effect in the building.

iii. Heating strategy. The heating strategy is also a vital bioclimatic design strategy that involves heating up living spaces when the surrounding temperature is cold. This strategy is often employed during winter to attain comfort in indoor spaces. In this strategy, the heat captured from solar radiation are stored in the thermal mass of the building design then distributed around it (Nnaemeka-Okeke *et al.*, 2019). The orientation of the building, daily and season variations in climate, nature of the surface material used, building material, topography of the site has a direct relationship with heating strategy. Figure 13 illustrates how heat is stored and distributed in a building.



*Figure 13: An illustration of Bioclimatic strategies for Heating in buildings
(Liebard et al, 2005.)*

Figure 13 shows an illustration of bioclimatic strategy for heating. Solar radiation from the sun enters the building during the day through the windows and other openings in the building. The heat from the radiation is stored in the floor and wall of the building which serve as the thermal mass during the day. At night, when the weather becomes cold, the energy is then distributed in the building to heat up spaces at night, thus providing thermal comfort in the building.

In line with the discourse in this chapter of the thesis, it is a known fact that that climate of Sokoto is extremely hot and characterized erratic rainfall and dusty storms (Ekoh, 2020). This causes thermal discomfort, especially in the peak of the summer around April – July. However, the design of buildings in this region in response to the harsh climate is characterized with isolated dwellings with compound open surroundings, series of courtyards and verandah and external shading devices with surrounded somewhat dry vegetation during this peak of the hot climatic condition (Srivastav, *et al.*, 2008). This allows for differential heating in the courtyards and verandahs so as to maximize night ventilation. Studies on the best orientation in this region are North or East orientation (Srivastav, *et al.*, 2008). The buildings are characterized with a high thermal mass wall with small high windows and low moderate roof due to low rainfall in this region. These small windows limit the dusty winds flow and direct solar radiation. The walls are often dressed mud and stones. This serves as good thermal mass which reduces the lagging time of heat during to prevent over heating building, and then release the need night ventilation.

In summary, globally, passive design and bioclimatic approaches are important for thermal comfort in buildings.



Chapter Four

4. Case study: Climate Responsive Architecture in Sokoto State

Sokoto is a state located in the extreme North-West region of Nigeria which is a West African country. Sokoto State currently has 23 Local Government Areas (LGAs) (figure 12). Figure 14 shows the map of Nigeria and Sokoto State with its 23 LGAs.

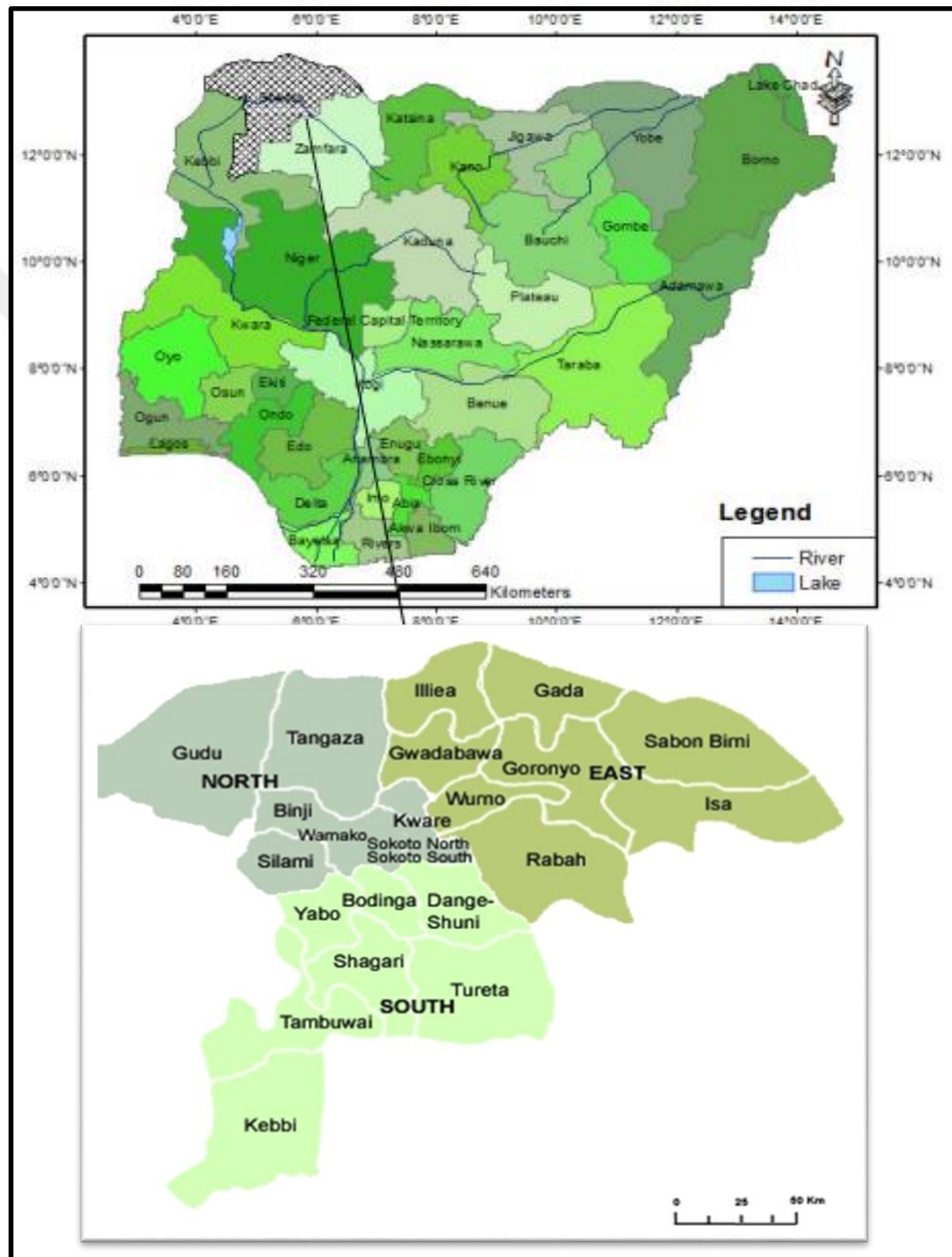


Figure 14: Map of Nigeria and Sokoto state showing its 27 LGA
(Metro Area Population, 2022)

To the North and West, the state shares a national boarder with Republic of Niger and to the East and South; it shares borders with Zamfara and Kebbi state respectively. The state which lays between the Sokoto River and Rima River rests on coordinates 13⁰⁰3'44N and 5⁰⁰14'02'E. The topography of the state is made up of alluvial plains and the vast land of the Sokoto-Rima River often dissects the plain and provides rich alluvial soil (Abubakar, Choy and Jafaar, 2018).

The metro-area population report (2022), recorded that the current population of Sokoto in 2022 is 685,000; this shows a 3.47 increase from 2021. According to Abubakar *et al.*, (2018) Sokoto State boats an average population density of 300 persons per kilometer with majority being the Hausa people of Northern Nigeria.

The most developed Local Government Area of the state is the city of Sokoto which is arguably the largest city. Figure 15 shows the major cities in Sokoto LGA.



*Figure 15: Map major cities in Sokoto State LGA,
(MAP, 2022)*

This thesis is centered on the Climate Responsive Architecture of Sokoto State, Nigeria.

4.1 Climate of Sokoto State

In the dry Sahel surrounded by sandy savanna and isolated hills, Sokoto State has a hot semi-arid climate (Köppen climate classification). According to World

Data Info on climate (2022), Sokoto State is one of the warmest region in Nigeria with an average daily temperature of 37⁰C making it yearlong warm or hot. Figure 16 shows the average daytime and nighttime temperatures in Sokoto State.

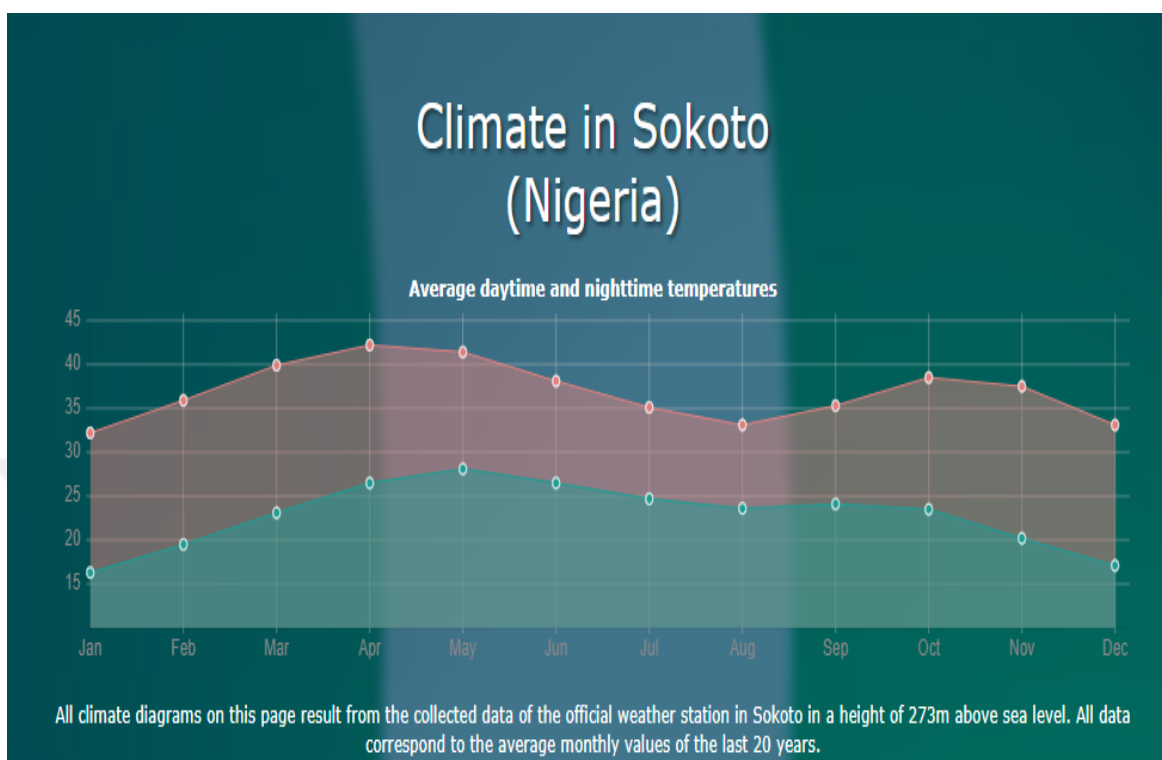


Figure 16: Climate in Sokoto; Average daytime and nighttime temperature (World data info on climate, 2022)

As a result of the maximum average daytime temperature recorded in this chart, Sokoto is a very hot city in Nigeria. Studies have shown that it is amongst the hottest cities in the country averaging a daytime temperature of almost 40⁰C all year round (Ismail *et al.*, 2012 Ekoh, 2020). The hot climate in Sokoto State also comes with dryness which makes the heat unfavourable to its inhabitants (Adegboyega, 2016).

According to a report by the Nigeria Information and Guide (2022), the months with the warmest temperature in Sokoto ranges from February to April. In this period, temperature at daytime often exceeds 40⁰C. In a research, by the Nigeria metrological council in 2019, the highest recorded temperature in Sokoto was 45⁰C. In Sokoto State, the rainy season are often recorded from June to October. In this period, rain showers often occurs on a daily base though the showers do not last long and they are often regular torrential showers synonymous to dry regions. The cold season is usually from late October to February, during this period the climate is dominated by the harmattan wind blowing Sahara dust over the land. This dusty

hamattan wind often dims sunlight. Thus, lower temperatures are experienced during this period (Nigeria Information and Guide, 2022).

4.2 Vernacular Architecture in Sokoto State

The Hausas constitute the population in the Northern part of Nigeria. The Hausas are the originator of the vernacular architecture of northern Nigeria and due to the fact that Sokoto is a state in the Northern region of the Nigeria, this architecture is practiced there. According to Auwalu (2019), Hausa vernacular architecture defines the shaping of the dwelling spaces in Northern Nigeria. It also contributed greatly to the shaping of the environment of the Hausa people in Northern Nigeria in relation to the climatic conditions of the region. Plate 1 shows a typical Northern Nigeria settlement in Sokoto State.



*Plate 1: A typical Northern Nigeria settlement in Sokoto State, Nigeria
(Ibrahim, 2023)*

Hausa vernacular architecture portrays the beliefs and culture of the Hausa's. The architecture is often referred to as “Tubali” (Auwalu, 2019). The vernacular architecture of Sokoto State is synonymous to the Hausa architecture of northern Nigeria which in most cases have a family compounds that is of a homestead situated within a wall compound with a number of huts therein (Arome *et al.*, 2021).

In a typical Sokoto vernacular architecture floor plan, the compounds are usually surrounded with a fence of matting made from grasses referred to as Zana or with mud. The design of the floor plan provides provision for living and sleeping area for both members of the nuclear family and in some cases the extended family (Auwalu, 2019; Arome *et al.*, 2021). The floor plan is often divided into two major

sections for security and privacy reason. In the floor plan, the “zaure” as it is locally referred to, is a passage for reception which serves as the central entry hall that connects to other sections of the building. The courtyard after the zaure which is open to visitors and the street is referred to as “kofar gida” while the courtyard that connects to the innermost section of the building is known as the “shigifa”. The “shigafa” is often restricted to visitors especially males because it is it is mainly for the wives and children. The courtyards are usually enclosed; they often serve as playing grounds for young adults and children. The rooms are referred to as “daki”. One important features of a Sokoto vernacular architecture plan is the “dakali” which is like a verandah where family members often sit to have meals and other interactions. In most cases the “dakali” is located at the main entrance and in the courtyards of the building. Due to the hot-climate in Sokoto, the courtyards and “dakali” often aid members relax outside the house for longer periods. The kitchen is often far from the entrance and it is often isolated to protect the building in terms of fire outbreak. The toilet is also at a distance from the entrance and it is locally referred to as “Bayan Gida”. Figure 17 shows a schematic sketch of a typical northern Nigeria vernacular architecture floor plan that applies also in Sokoto state.

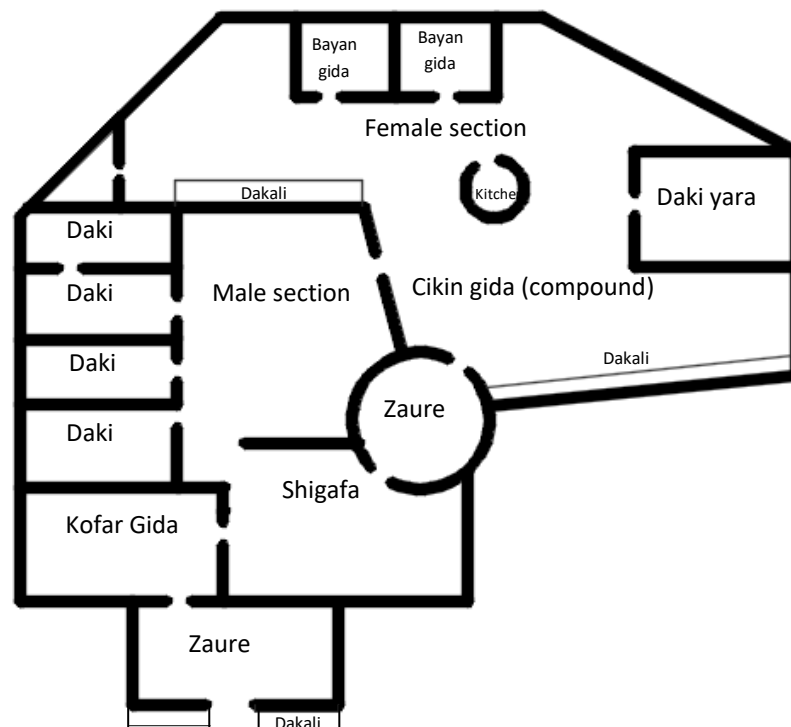


Figure 17: A schematic sketch of a typical Sokoto Vernacular Architecture floor plan (Ibrahim, 2023).

In most cases, the vernacular architecture plans of Sokoto State, there are spaces created specifically for rearing domestic animals and spaces where the house heads practices his craft work such as tie and dye, leather work, blacksmithing, etc.

The construction of a typical Sokoto vernacular architecture building is similar to that of Northern Nigeria which is often done with locally sourced materials by locally skilled artisans. According to research by numerous authors the designs are often distinctive in their characteristics (Agboola *et al.*, 2014; Arome *et al.*, 2021). One of the most common distinctive characteristics is wall engravings usually made on the walls by builders who are local trained craftsperson with vast knowledge on engraving. The surface designs are usually done with a sharp pointed instrument or they are drawn with hand manually with a long-lasting paint (Plate 2). Plate 2 shows a photograph of a typical Sokoto building showing engravings on walls



*Plate 2: Photography of a typical Sokoto building showing engravings on walls
(Ibrahim, 2023)*

It is often believed that the level and amount of decoration portrays the social status of the individual owners. Another important characteristic of this Hausa vernacular architecture is that all the building materials are often sourced locally and often adapts to the climate of the state at different time of the season. The most important building materials in Sokoto vernacular architecture include:

i. *Earth*: The major building material in Sokoto State vernacular architecture is the earth. The construction method employed in using the earth as a building material is the wattle and daub technology which is locally known as Tubali. The building technique require first making of post frames from hardwood to serve as support and the filling them up with earth balls so as to form the walls. In preparation for this construction technique, the earth is first scattered and watered on a flat ground and allowed to soak for some days. Little dried grasses (datsi as it is locally called) are added to add strength to the earth after pounding the earth with the feet. This makes the earth have a uniform thick paste which will be suitable for the construction. The earth molds are sundried to make them ready for construction”.

The major advantage of using earth material for construction is that it has a very high thermal capacity that enables it to keep the inside of the building cool when the outside is hot and vice versa. Other important advantage is that they are often resistant to fire, cheap and readily available and also absorbent to noise (Awalu, 2019). Plate 3 shows a photograph of a typical wall made with earth in a typical sokoto vernacular architecture settlement.



Plate 3: Photography of Earth walling in a typical sokoto vernacular architecture settlement

(Ibrahim, 2023)

ii. *Stones*: Stones are also used as materials for building construction in a typical Sokoto vernacular architecture building. As recorded by Arome *et al.*, (2021), in some Northern states in Nigeria where Vernacular Architecture is prominent, stones are one of the commonly used building materials. They are mostly used for foundations in regions where the soil is loose and highly moisturized due to their strength and ability to retain the capillary action of soil moisture. In Northern regions where erosion is common due to higher rainfall, stones are also used to control erosions.

However, this is rarely used in Sokoto State due to low rain fall experienced in the region experienced in the region though there are quite a few traditional buildings where stones were used for construction in Sokoto especially in water logged areas where soil erosion is likely to be experienced. Plate 4 shows photography of a stones used for foundation and walls in a building construction in Sokoto, Nigeria.



*Plate 4: Photography of Stones used for foundations and wall construction in a traditional building in Sokoto State, Nigeria
(Ibrahim, 2023)*

iii. *Grasses and Thatch*: Grasses and thatch are important building materials for construction in a typical northern Nigeria vernacular. Grasses are used to make the thatch which often serves as roofing materials. The thatch being one of the oldest known building materials in the Vernacular Architecture in Sokoto State is often

made from stalks dried from farms after crops are harvested from farmlands. According to Auwalu (2019) and Arome *et al.*, (2021) the grasses for thatch are harvested easily from farms and allowed to dry up before they can be used. They are also often used as composite building materials which are added to earth walls to help improve their tensile strength. The good thermal property of thatch encourages their use as roofing material and also materials for fencing compound in a typical Sokoto vernacular architecture building construction. Also, studies have shown that thatches are good thermal insulators and as such helps to maintain optimum thermal comfort within indoor space (Auwalu, 2019). Plate 5 shows a photograph of a thatch used as a roofing material in a typical Sokoto vernacular architecture building.



*Plate 5: Photography of a thatch roof in a typical Sokoto vernacular architecture building
(Ibrahim, 2023)*

iv. *Timber.* Timber is often duct as building materials in a typical Sokoto vernacular architecture construction. The woods are often sourced from trees in farms and forest. Fibrous plants are also used for the construction when pressed into lumber and timber, such as planks and boards. According to Arome *et al.*, (2021), the finest timbers are often used for construction in vernacular architecture re usually heavy, durable and of good resistance to termites. They are often harvested from tree trunk

and branches of hard tress for instance, the palm tree which is locally known as *daleb* or *giginya* in Hausa term.

In Hausa vernacular architecture, timbers are to be used to create a shielding layer that often restrains storm water from moving down the roof, a local technology which is usually efficient is used. This technology require a water proof membrane treatment which requires the use of ashes mixed from timber pod and root infusion before carefully spreading on the flat roof. Plate 6 shows a photograph of the application of timber as a roofing material as adopted from (Auwal *et al.*, 2019).



Plate 6: Photograph of the application of timber as a roofing material
(Auwal *et al.*, 2019)

4.3 Thermal comfort on vernacular buildings in Sokoto State

Traditional building materials such as earth, adobe, bamboo, thatch, azara, rama etc. are known to enhance thermal comfort. That is why most traditional vernacular building types easily provide occupants with thermal comfort in different regions of the world. In Sokoto, the traditional vernacular building types are commonly of circular shaped and rectangular huts with engravings depending on affluence and social status of owners, although circular huts are more prominent. The circular shaped vernacular buildings were usually beautiful with domed roof, while the rectangular shaped vernacular building had flat roof to enhance thermal comfort due to the hot nature of the climate and low rainfall. Plate 7 shows a photograph of a typical Sokoto circular and rectangular shaped building with domed and flat roof as adopted from (Haruna, 2020)

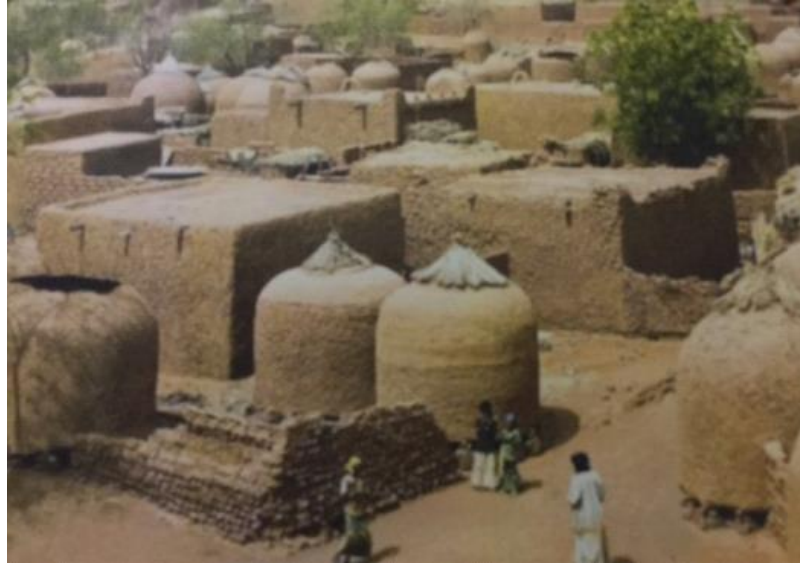


Plate 7: Photograph of a typical ancient Sokoto circular and rectangular shapped building with domed and flat roof (Haruna, 2020)

These vernacular building types in Sokoto enhanced thermal comfort due to the fact that the building materials used for their construction are locally sourced building materials and have the ability to adapt to the different climatic conditions of the region at a particular time. It is important to note that as construction techniques improved over time, some of these ancient sokoto vernacular buildings have been replaced with more recent of traditional vernacular building using the same building materials. Plate 8 shows a photograph of a more recent traditional vernacular building typology of circular and rectangular in Sokoto state.



Plate 8: Photograph of a recent traditional circular and rectangular vernacular building typology in Sokoto State (Ibrahim, 2023)

The design of these circular and rectangular vernacular buildings in Sokoto in relation to the climatic conditions of the region in order to provide thermal comfort to occupants has some unique features exhibited in the major elements that make up the architecture of a building. These features include:

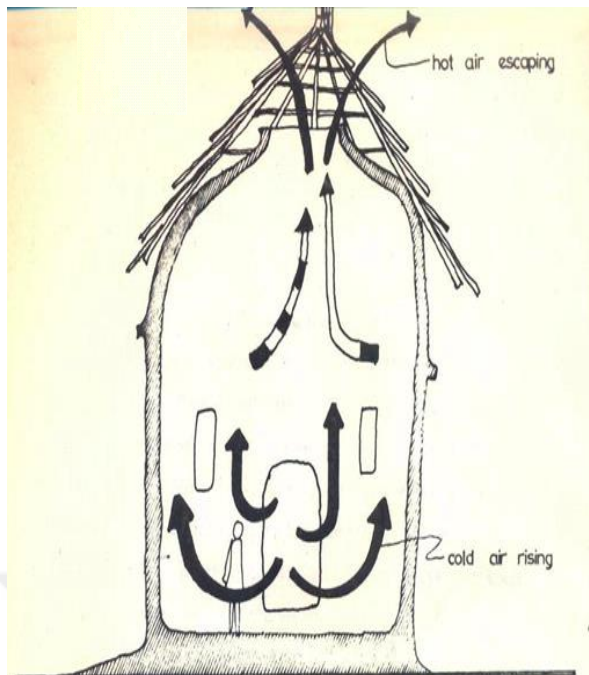
Walls: The walls are constructed to be high. The idea of constructing large and high walls round the courtyards of the building is as a result of the hot climatic condition of the region. Hence the high walls built around the courtyards to provide larger shaded areas in the building which enhances thermal comfort by reducing areas directly exposed to intense radiation from the sun, ground and surrounding of the building. Also the walls of the huts that are mostly circular are built to be very high so that hot air can move up to the roof and heavy cooled air lowered during hot weather. This also applies to the rectangular huts.

Windows: The window are designed to be a little bit higher because of the dusty nature of wind and also to allow room for the adequate amount of solar radiation needed for thermal comfort in the buildings during hamattan seasons.

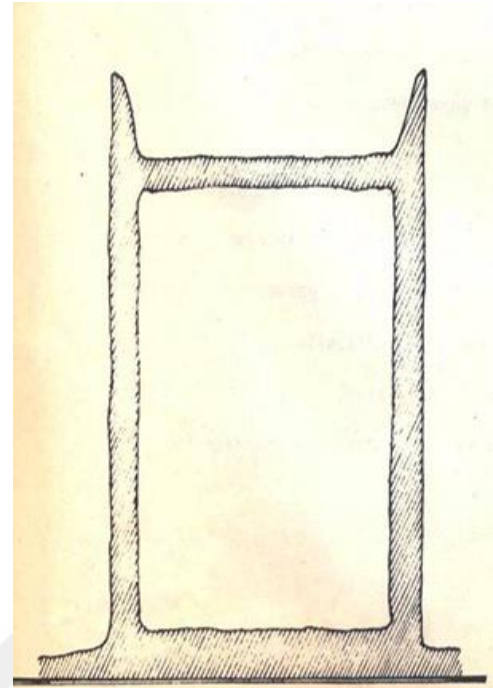
Roof: The roofs are constructed in two ways. In the circular buildings the roof is constructed with mud to form domes, where thatch is to be used, the roof is constructed with wood / bamboos locally sourced and covered with elephant grass or other thatch roofing materials. While for the rectangular buildings, their roofs are usually flat due to the low rainfall and hot weather condition experience in the region. The flat roofs are held with the help of “azara” – timber on which mud is poured.

Floor: The floor are built to be high because the higher the floor to roofing height, the more it allows room for the lighter hot air to rise and be replaced by heavier cooler air lower human lever thus maintaining thermal comfort.

Figure 18 shows a cross section of a typical Sokoto circular vernacular architecture building “kudandami” and typical flat roof “soro” as adopted from (Haruna, 2020)



a. Section cut through a typical circular hut "kudandami"



b. Section cut through a typical flat roof "soro"

Figure 18: Cross section of a typical Sokoto circular vernacular architecture building "kudandami" and typical flat roof "soro" (Haruna 2020).

However, the advent of modernization saw a deviation from the traditional vernacular architecture techniques employed in these design of these traditional vernacular architecture building types in Sokoto State. The flat roof, monolithic curved circular and rectangular wall buildings with decorative plasters and engravings depending on affluence and status of owners have been substituted with modern designs of rectangular concrete prototypes of imported roman column replicas. In most cases these modernized buildings are constructed without considering their impact on climate of the region. Also most of the materials used for this modernized building are imported and as such most of them are not compatible and adaptive to the climate of Sokoto, hence leading to the increased thermal discomfort experienced in majority of the building in the state.

4.4 Exploration of study

The purpose of the study is getting the opinion of respondents and their level of awareness on Climate Responsive Architecture as it affects thermal comfort in Sokoto State. This study was conducted in two phases. The first phase is the qualitative survey while the second phase is the quantitative survey.

4.4.1 Qualitative survey method

The targeted population that made up for the qualitative aspect of this study is registered professional architects in Sokoto State. The selection criteria that defined their selection, is based on years of working experience. Therefore, only registered architects who have at least 1 year post-graduation working experience were considered to be included in this study. This is because at this stage they are qualified to handle designs and construction works.

The sampling technique method used to select these architects is random sampling technique. This probability sampling technique method was adopted to give every qualified architect in the study area equal chance of being selected for the research. A total of 25 architects were selected using this sampling technique method. The 25 randomly selected architects made up for the sample size population for the qualitative aspect of the survey.

Data collection for this aspect of the survey was via interview. The interview was conducted virtually with each of the selected architects. Each interview session lasted for at least 30mins. The procedure involved giving each of the selected architects a consent forms to fill. The consent forms were then scanned for documentation (Appendix A).

4.4.2 Quantitative survey method

The targeted population that made up for the quantitative aspect of this study is households residing in residential building in Sokoto State. The criteria that defined their selection include age and duration of residence.

Age: Households age is one of the criteria that defined the selection of the target population. Hence, only household owners who are > 18 years will be considered for selection in the quantitative aspect of the survey.

Duration of residence: The duration of household residence is also one of the vital criteria that defined the targeted population selection. This is because household during of stay of residence gives them a well-tailored experience on thermal comfort

in the State. Therefore only permanent residents who have been residing in Sokoto State for >1 year are considered for selection.

Random sampling technique method was also used to select the household owners that took part in this aspect of the survey. This probability sampling technique method was adopted to give every household that meet the selection criteria equal chance of being selected for the research. Therefore 100 household owners were randomly selected to serve as the sample size for this aspect of the survey.

The method of data collection for this aspect of the survey was via administering questionnaires to the house hold owners in Sokoto State. The questionnaires were self-administered to household owners in Sokoto State. The procedure for administering the questionnaire involves reading out the consent to selected participants. Each participant was made to understand the purpose of the study before engaging them for the survey. Hence only participants who agreed to partake in the questionnaire survey were presented copies of the questionnaire to fill. A sample of the consent form read to participants for the survey is presented in appendix C.

4.5 Results

The results from the qualitative and quantitative aspect of the survey are presented as follows:

4.5.1 Qualitative survey results

A total of 25 registered practicing architects in Sokoto State were interviewed in the qualitative survey. The results from the interview in line with the interview questions are summarized and presented as follows:

1. Awareness on Climate Responsive Architecture: Architects were asked on ways that can be used to create awareness on Climate Responsive Architecture in Sokoto State. All the architects interviewed stated to create awareness among house owners (clients) on CRA, all construction process needs to go through the right processes from seeking professional architects knowledge in designing buildings and going through the right process for development approval. By so doing professional architects will enlighten their client while designing for them on why certain decisions and standards that are adhered to. This will help create awareness for

household in Sokoto State on the need to consider climate before designing and choosing building materials for construction for optimum thermal comfort.

2. Beneficial impacts of considering of the Climate in Sokoto State before using the right techniques / method to design buildings in Sokoto State: Architects who responded to the interview question on the beneficial impacts of considering the Climate of Sokoto State before using the right techniques / method to design buildings in Sokoto State revealed that the beneficial impacts of considering climate before using the right techniques/method to design building in Sokoto State will creates thermal comfort and energy efficiency in buildings, reduce the cost on HVAC, enhance natural ventilation and lighting in buildings and to enhance durability of building materials in Sokoto State. The appropriate techniques as agreed by interviewed architects pointed out at the passive architectural techniques should be used as regards information obtained from climatic analysis from sites where the buildings is to be designed. This will also give the required information of the right building materials that will enhance durability of the design.

3. Factors that limit the practice of Climate Responsive Architecture principles: The interviewed architects stated that the factors that limit the practice of Climate Responsive Architecture principles in Sokoto State in terms of maintain optimal thermal comfort are: poverty, lack of awareness on CRA, lack of enforcement of building laws and regulations, incompetent professional colleagues (architects), climate change and negligence the continuous usage of traditional vernacular building materials.

4. Hindrances to effective delivery of thermal comfort in the design of buildings in Sokoto State: Interviewed architects response to the question on hindrances to effective delivery of thermal comfort in the design of buildings in Sokoto State revealed that most of the architects stated that poor designs, clients perception that architects charges are outrageous, neglect on incorporating traditional building materials to designs, engaging quacks and unskilled artisans for building construction and design, the rise of unqualified architects engaging in construction projects and other professionals in the building industry doing architects job are the hindrances to effective delivery of thermal comfort in the design of buildings in Sokoto State.

5. Most widely used Climate Responsive Architecture techniques and passive design approaches by architects: The most widely used Climate Responsive Architecture techniques and passive design approaches by architects for maintaining thermal

comfort in Sokoto State as stated by interviewed architects is landscaping , natural cross ventilation and the use of shading devices.

4.5.2 Quantitative survey results

A total of 100 questionnaires sample were distributed to the household owners in the study area for the survey to garner information on the data of their building and the level of thermal comfort derived in their buildings. Out of the distributed questionnaires 87 were properly filled and retrieved for the research analysis while 13 questionnaires were wrongly filled and not retrieved for the analysis. Therefore 87/100 questionnaire data is accepted as valuable data for academic reference.

The bar chat shows that the percentage of retrieved questionnaire valid for analysis was 87% while 13% of the questionnaire were not retrieved, thus invalid. Figure 19 shows the percentage of questionnaires Distribution.

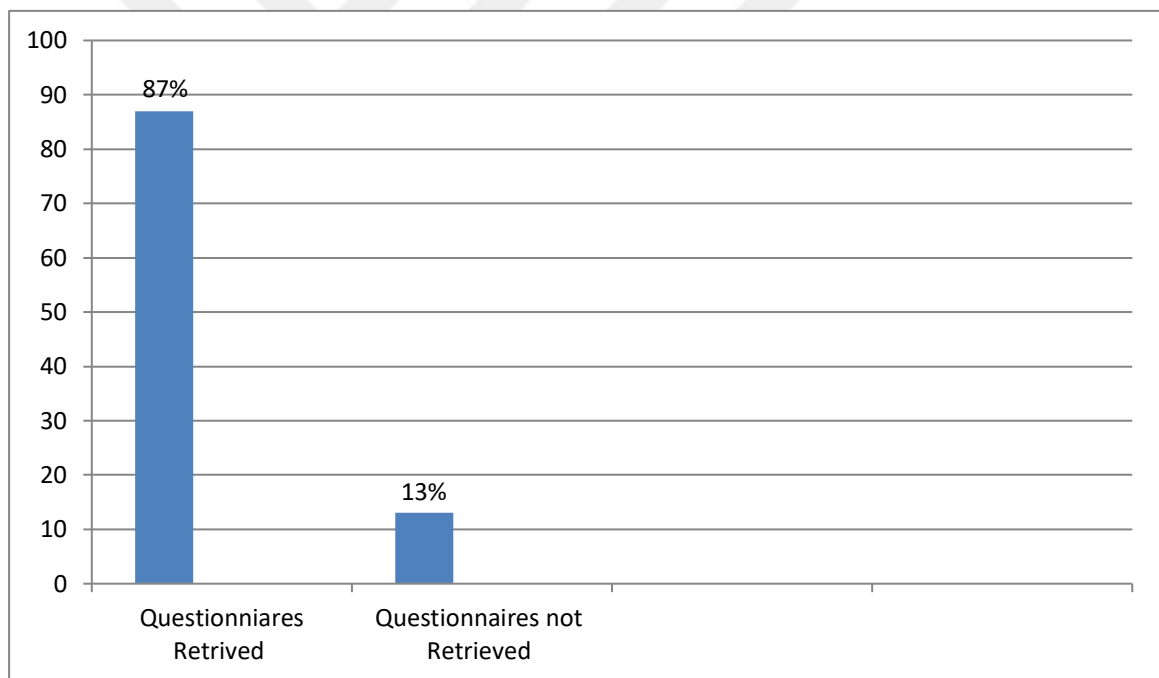


Figure 19: Bar chart showing parentage of questionnaires Distribution

(Source: Researcher's field survey, 2022)

The results from the valid questionnaires surveyed are presented in table and chart below as follows:

4.5.2.1 Results on demographic data of building types in Sokoto State

The demographic data of building types Sokoto State as it affects thermal comfort were surveyed. The results are presented in table and charts below.

Table 1: Type of Residential building

The residential building types in Sokoto State were surveyed in Table 1 below. The results from the table reveal that 73.6% of the residential building types in Sokoto State are bungalows, 12.6% are storey buildings, 9.2% are duplexes while only 4.6% of the buildings are mansions.

S/N	Type of residential building	Frequency (f)	Percentage (%)
1	Bungalow	64	73.6
2	Duplex	8	9.2
3	Storey building	11	12.6
4	Mansions	4	4.6
	Total	87	100

Source: Researcher's field survey, 2023

Table 2: Status of Occupants

Households' occupancy status was surveyed in Table 2 below. The result from the table reveals that 64.0% of the household are owners of the building they reside in while 36.0% were tenants

S/N	Occupant status	Frequency (f)	Percentage (%)
1	Tennant	31	36.0
2	Owner	56	64.0
	Total	87	100

Source: Researcher's field survey, 2023

Table 3: Building Form

The building form of the surveyed residential building types in Sokoto State were surveyed in table 3. The table reveals that 47.1% of the building forms are rectangular, 30.0% were square like, and 12.6% were circular while 10.3% had irregular building forms

S /N	Building form	Frequency (f)	Percentage (%)
1	Irregular	9	10.3
2	Circular	11	12.6
3	Rectangular	41	47.1
4	Square	26	30.0
	Total	87	100

Source: Researcher's field survey, 2023

Table 4: Number of occupants per building

Table 4 presents the result of the number of occupants per building in the surveyed households. The table reveals that 62.1% had > 8 occupants per buildings, 25.3% had 5-8 occupants per building while only 12.6% had <5 occupants per building.

S/N	Number occupant per building	Frequency (f)	Percentage (%)
1	< 5	11	12.6
2	5-8	22	25.3
3	> 8	54	62.1
	Total	87	100

Source: Researcher's field survey, 2023

4.5.2.2 Results on Thermal Comfort in Residential Building in Sokoto State

The thermal comfort in residential buildings in Sokoto State was surveyed in line with the aim of the research questionnaire for this survey. The questionnaire designed in line with the research questions and objectives of the study is aimed at determining:

1. The Rate of indoor thermal comfort achieved in residential building in Sokoto State
2. Factors that limit the Rate of Indoor Thermal comfort achieved in Residential Building in Sokoto State
3. Impacts building material choices have on achieving thermal comfort in residential building types in Sokoto State
4. Hindrances to the effective delivery of designs that enhances thermal comfort in buildings (passive and active) in Sokoto State

Table 4 present the results on thermal Comfort in Residential Building in Sokoto State. From Table 4, to determine the rate of indoor thermal comfort achieved in residential building types in Sokoto State, occupants were asked that at what time of the day they feel more uncomfortable in their homes; at what time of the day do they feel slightly comfortable in their homes; how comfortable do they feel with their clothes on while performing an activity at home; if they feel comfortable in their homes without using fans and Air conditioners regularly; and finally, how would they rate the general thermal comfort in their homes.

From Table 4, to determine factors that limit the Rate of Indoor Thermal comfort achieve in Residential Building Types in Sokoto State, occupants were asked if they have idea about building orientation; the type of orientation in their house; if all bedrooms and living room windows in their house were cross ventilated, if external shading devices are incorporated in their buildings designs; and if they think the functional areas in their buildings are properly zoned.

From Table 4, to determine the impacts building materials choices have on achieving thermal comfort in residential building types in Sokoto State; occupants were asked the type of building wall materials use in their houses; if the walls were painted with bright color, type of roofing materials and the color of the roofing sheet.

From Table 4, to determine the hindrances to the effective delivery of designs that enhances thermal comfort in buildings (passive and active) in Sokoto State, occupants were asked the type of landscape provided in their buildings; if the Sizes /

position of door and windows in their house is adequate; if there was adequate power supply to run appliance needed for thermal comfort; and the type of mechanical ventilation in their houses.

Table 4: Results on the *Thermal Comfort in Residential Building in Sokoto State*

S/N	Questions	Frequency (f)	Percentage (%)
1	At what time of the day do you feel more uncomfortable in your homes		
	6am – 12pm	25	28.8
	1pm – 6pm	50	57.5
	7pm -12am	12	13.7
	Total	87	100.0
2	At what time of the day do you feel slightly comfortable in your homes		
	6am – 12pm	6	6.9
	1pm – 6pm	12	13.8
	7pm -12am	69	79.3
	Total	87	100.0
3	How do you feel with your clothes on while performing an activity at home		
	Slight comfortable	30	34.5
	Comfortable	12	13.8
	Uncomfortable	45	51.7
	Total	87	100.0
4	Do you feel comfortable in your homes without using fans and Air conditioners regularly		
	Yes	12	13.8
	No	75	86.2
	Total	87	100.0
5	How would you rate the general thermal comfort in your homes		
	Excellent	6	7.0
	Good	13	15.0
	Fair	21	24.0
	Poor	47	54.0
	Total	87	100.0
6	Do you have idea about building orientation		
	Yes	25	29.0
	No	62	71.0
	Total	87	100.0

Table 4 cont.			
7	What is the pattern of orientation of your house	Frequency (f)	Percentage (%)
	Length of building facing North-South direction	15	17.2
	Length of building facing East-West direction	30	34.5
	No idea	42	48.3
	Total	87	100.0
8	Are all bedrooms and living room windows in your house cross ventilated	Frequency (f)	Percentage (%)
	Yes	20	23.0
	No	67	77.0
	Total	87	100.0
9	Are external shading devices incorporated in your house designs	Frequency (f)	Percentage (%)
	Yes	13	15.0
	No	74	85.0
	Total	87	100.0
10	Do you think the functional areas in your building are properly zoned	Frequency (f)	Percentage (%)
	Yes	29	33.0
	No	58	67.0
	Total	87	100.0
11	Type of building wall materials in your house	Frequency (f)	Percentage (%)
	concrete blocks	36	41.4
	burnt bricks	12	13.8
	Mud	28	32.2
	Bamboo / timber	11	12.6
	Total	87	100.0
12	Are the walls of your building finished with bright color	Frequency (f)	Percentage (%)
	Yes	14	16.1
	No	43	49.4
	Wall not painted	30	34.5
	Total	87	100.0
13	Type of Roofing materials	Frequency (f)	Percentage (%)
	Long span aluminum /corrugated zinc with ceiling	24	27.6
	Long span aluminum /corrugated zinc without ceiling	52	59.8
	Thatch roof	11	12.6
	Total	87	100.0
Table 4 cont.			

14	What colour is your roofing sheet	Frequency (f)	Percentage (%)
	Black	24	27.6
	Silver	34	39.1
	Others	29	33.3
	Total	87	100.0
15	Type of landscape provided in your building	Frequency (f)	Percentage (%)
	No landscape is provided	66	76.0
	Landscape is provided with trees, short grasses and concrete interlocks	21	24.0
	Total	87	100.0
16	The Sizes / position of door and windows in your house is adequate	Frequency (f)	Percentage (%)
	Yes	42	48.3
	No	45	51.7
	Total	87	100.0
17	There is adequate power supply to run appliance needed for thermal comfort	Frequency (f)	Percentage (%)
	Yes	12	14.0
	No	75	86.0
	Total	87	100.0
18	Type of mechanical ventilation in your house	Frequency (f)	Percentage (%)
	None	42	48.3
	Electric fans only	25	28.7
	Air conditioners only	13	15.0
	Electric fans and air conditioners	7	8.0
	Total	87	100.0

Source: Researcher's field survey, 2023

The result from Table 4; on the time of the day occupants feel more uncomfortable in their homes reveals that 57.5% of the occupants feel more uncomfortable in your homes at 1pm-6pm, 28.8% at 6am-12pm while 13.7% of the occupants feel more uncomfortable in your homes at 7pm-5am. Figure 20 presents a pie chart showing the result of the time of the day occupants feel more uncomfortable in their homes.

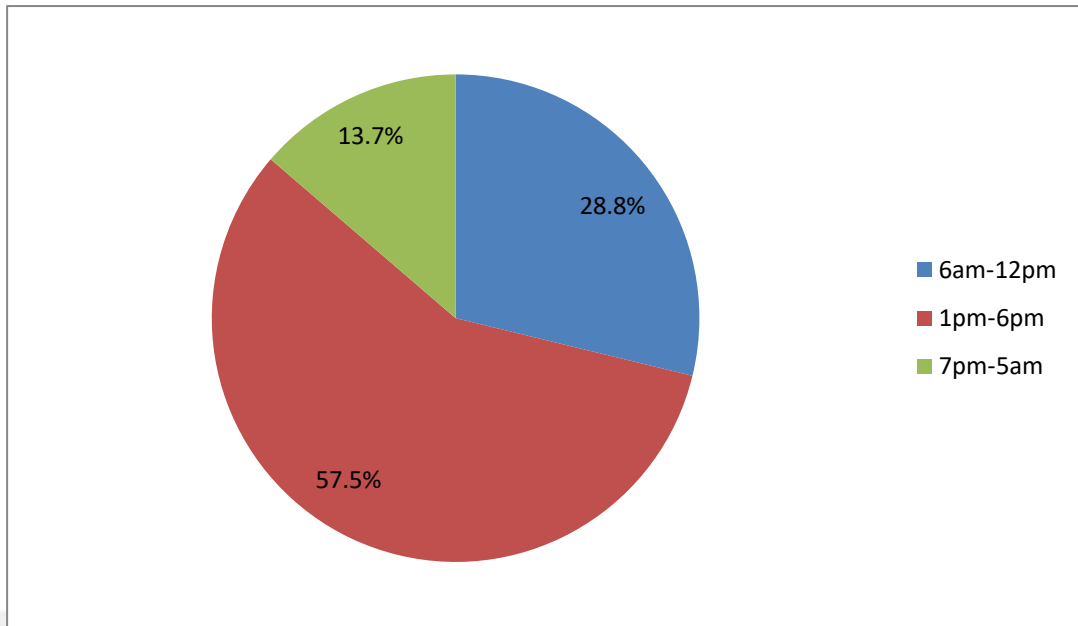


Figure 20: Pie chart showing the Time of the Day Occupants Feel More Uncomfortable in their Homes.

(Source: Researcher's Field Survey, 2023)

The result from Table 4 on the time of the day occupants feel slightly more comfortable in their homes reveals that 79.3% of the occupants feel slightly more comfortable in their homes at 7pm -5am, 13.8 % at 1pm – 6pm, while 6.9% of the occupants feel slightly more comfortable in your homes at 6am – 12pm. Figure 21 presents a pie chart showing the time of the day occupants feel slightly more comfortable in their homes.

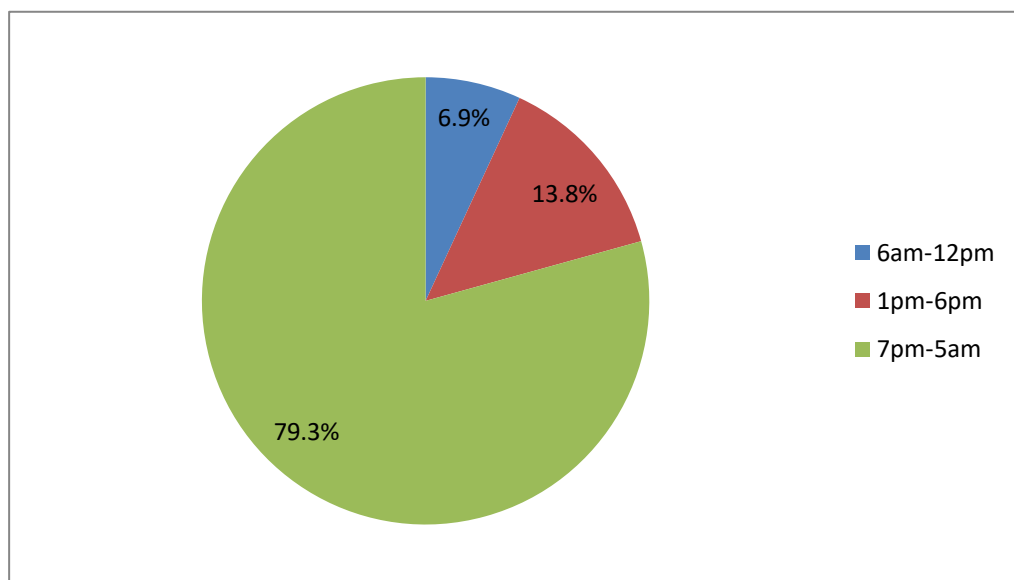


Figure 21: pie chart showing the Time of the Day Occupants Feel slightly more comfortable in their Homes

(Source: Researcher's Field Survey, 2023)

The result from Table 4 on how occupants feel with their clothes on while performing an activity at home, reveals that 51.7% of the occupants feel uncomfortable, 34.5% feel slightly comfortable while only 13.8% feel comfortable feel with their clothes on while performing an activity at home. Figure 22 presents a pie chart showing how occupants feel with their clothes on while performing an activity at home.

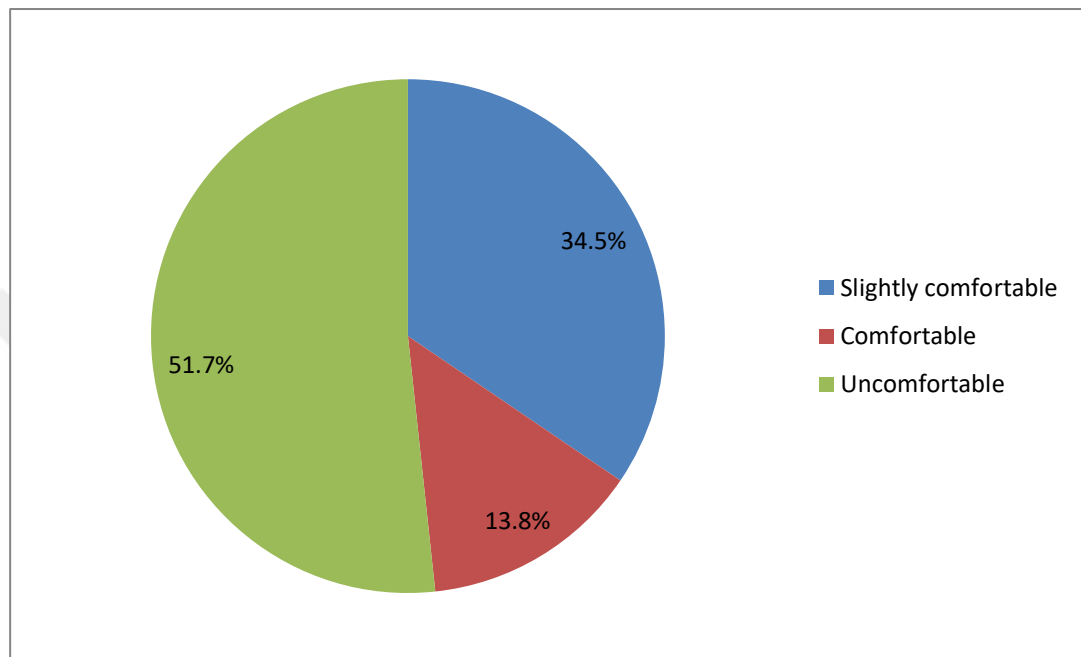


Figure 22: Pie chart showing how Occupants feel with their clothes on while performing an activity at Home
(Source: Researcher's Field Survey, 2023)

The result from Table 4 on if occupants feel comfortable in their homes without using fans and Air conditioners regularly further reveals that 86.2% of the occupants said 'No' they do not feel comfortable in their homes without using fans and Air conditioners regularly while 13.8% of the occupants said 'Yes', they feel comfortable in their homes without using fans and Air conditioners regularly. Figure 23 presents a pie chart showing if occupants feel comfortable in their homes without using fans and Air conditioners regularly.

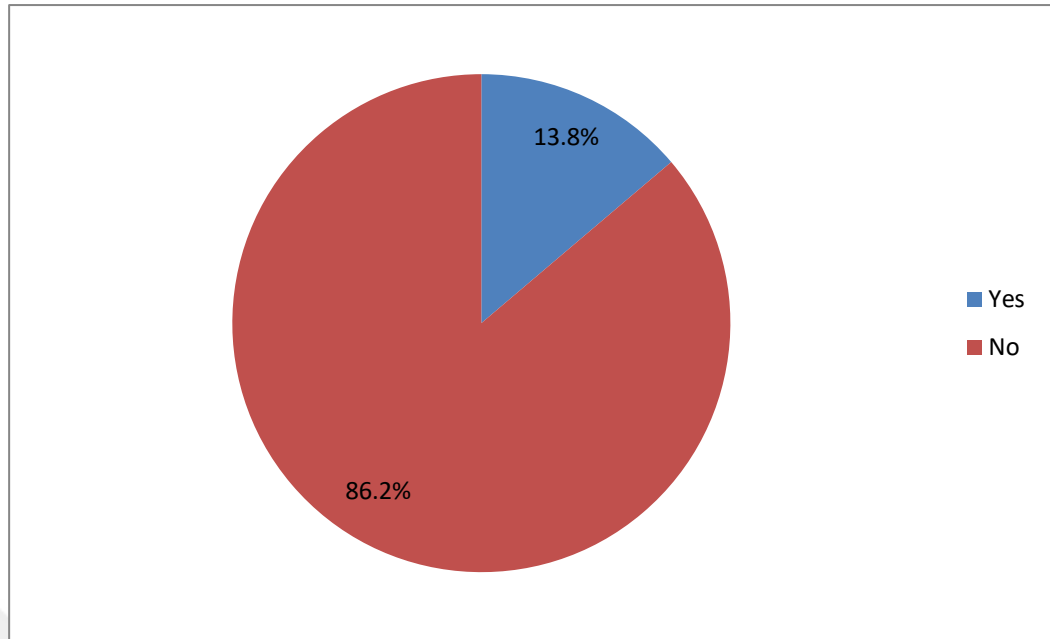


*Figure 23: Pie chart showing if occupants feel comfortable in their homes without using fans and Air conditioners regularly.
(Source: Researcher's Field Survey, 2023)*

The results from Table 4 on occupant general rating of thermal comfort in their homes reveal that 54.0% of the occupants said it was poor, 24.0% said it was fair; 15.0% said it was good while only 7.0% said it was excellent. Figure 24 presents a bar chart showing occupant general rating of thermal comfort in their homes.

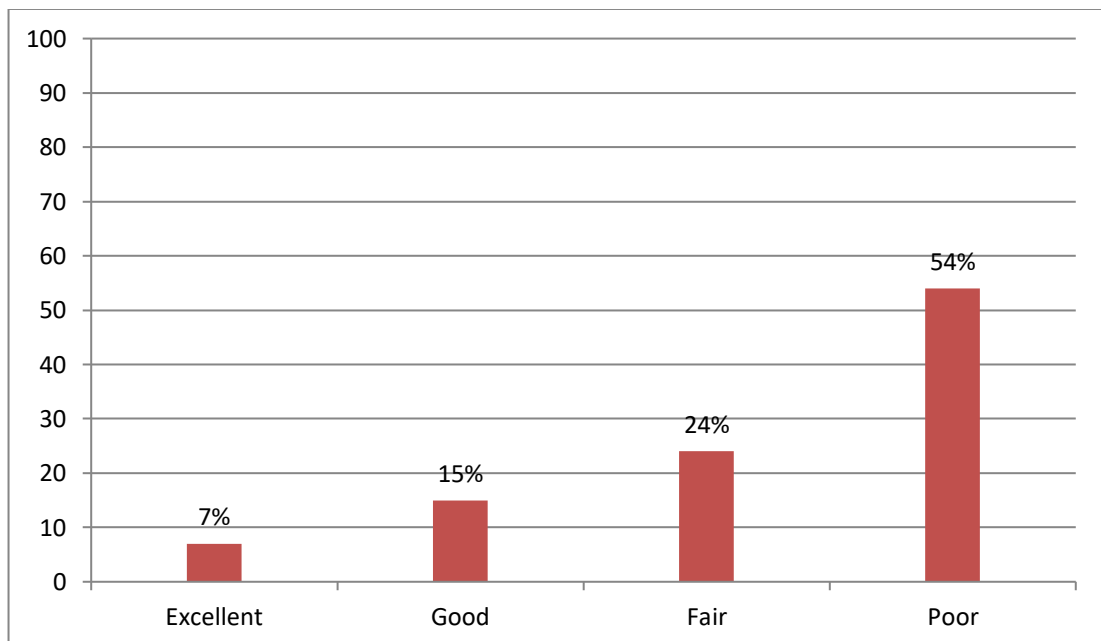


*Figure 24: Bar chart showing occupant general rating of thermal comfort in their homes
(Source: Researcher's Field Survey, 2023)*

Further result from Table 4, on if occupants have idea about building orientation reveals that 71.0% of occupants do not have idea about building orientation while 29.0% have idea about building orientation. Figure 25 presents a pie chart showing if occupants have idea about building orientation.

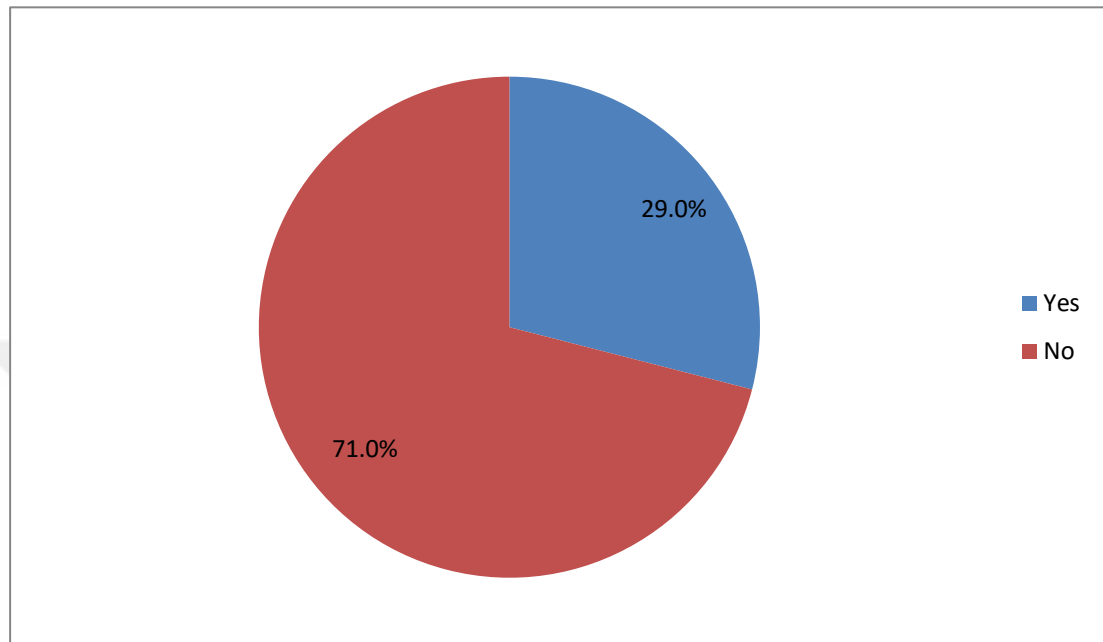


*Figure 25: Pie chart showing if occupants have idea about building orientation.
(Source: Researcher's Field Survey, 2023)*

More results from Table 4 on the pattern of orientation of occupants' house reveal that 48.3% have no idea on the pattern of orientation of their house, 34.5% said it was Length of building facing East-West direction pattern of orientation while 17.2% said the pattern of orientation was Length of building facing North-South direction pattern of orientation. Figure 26 presents a Bar chart showing the pattern of orientation of occupants' house.

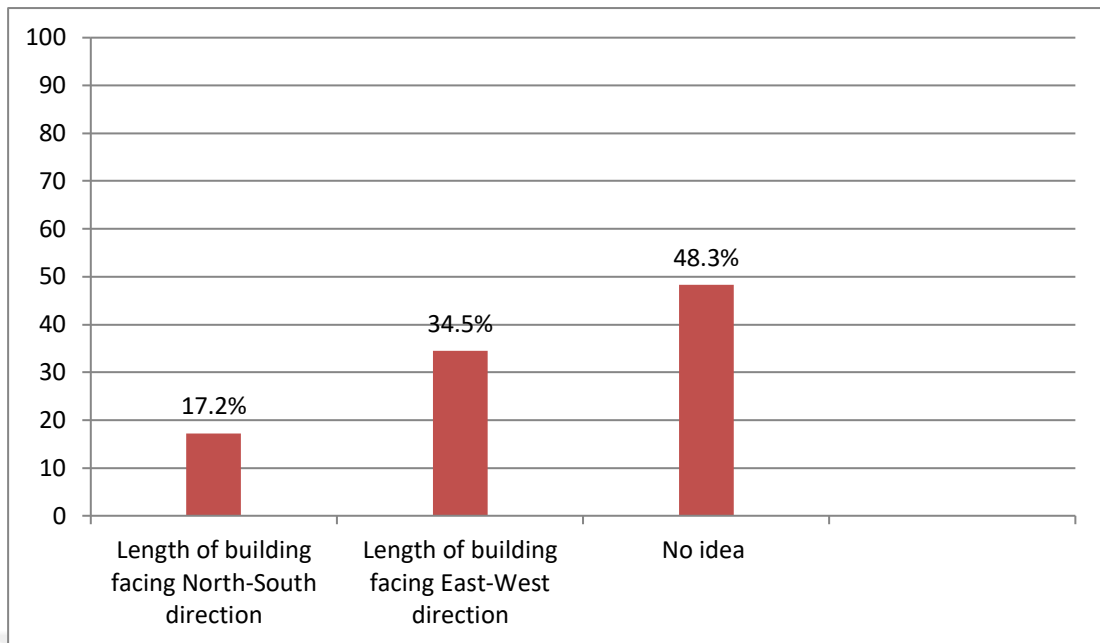


*Figure 26: Bar chart showing the pattern of orientation of occupants' house.
(Source: Researcher's Field Survey, 2023)*

The result from Table 4, on if all bedrooms and living room windows in occupants house are cross ventilated reveals that 77.0% of occupants said 'No'. This implies that not all bedrooms and living room windows in the respondent house are cross ventilated while 23.0% said 'Yes'. This implies that all bedrooms and living room windows in this respondent house are cross ventilated. Figure 27 presents a pie chart showing if the result of if all bedrooms and living room windows in occupants' house are cross ventilated.

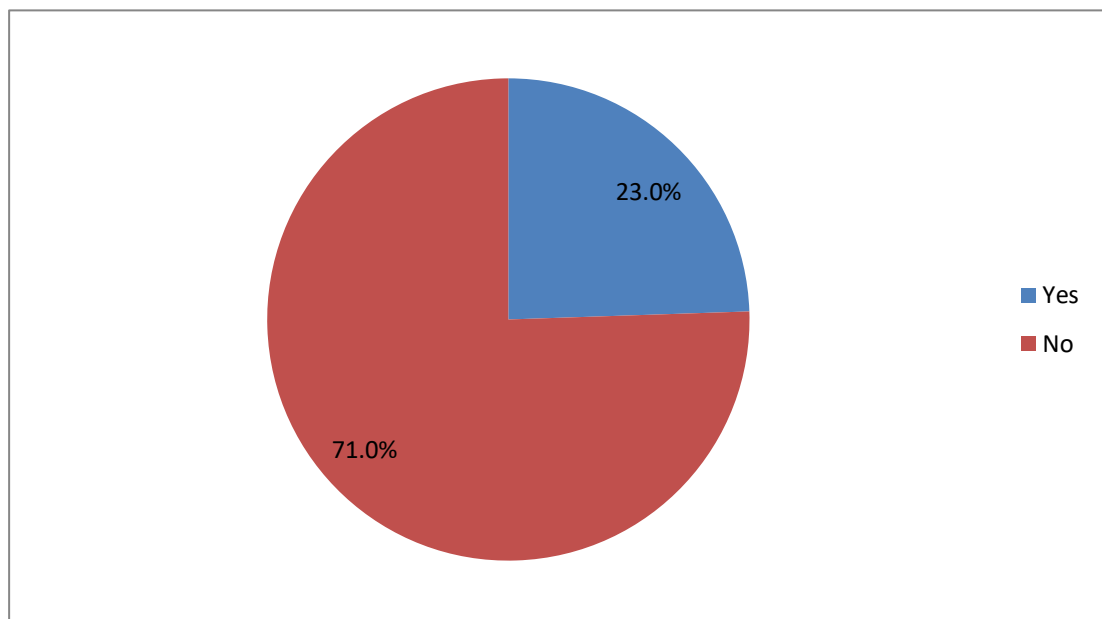


*Figure 27: Pie chart showing occupants' response to if all bedrooms and living room windows in their house are cross ventilated.
(Source: Researcher's Field Survey, 2023)*

The result from Table 4, on if external shading devices are incorporated in occupants' house designs reveals that 85.0% said 'No'. This implies that external shading devices are incorporated in most of the occupants' house designs while 15.0% said 'Yes'. Figure 28 presents a pie chart showing if the result if external shading devices are incorporated in occupants' house designs.

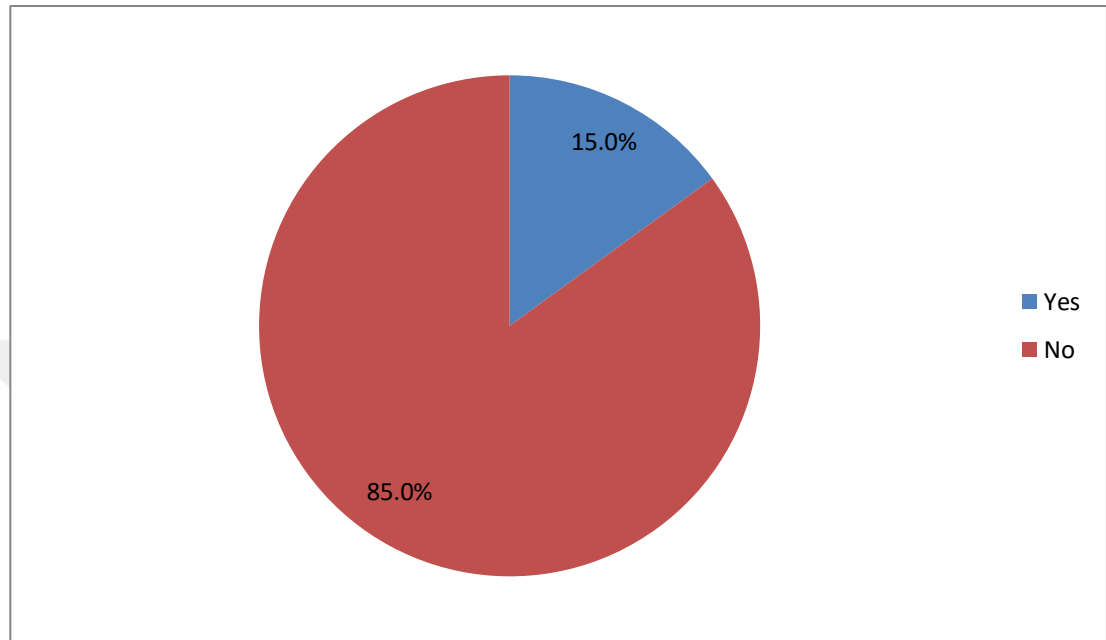


*Figure 28: Pie chart showing occupants' response to if external shading devices are incorporated in occupants' house designs
(Source: Researcher's Field Survey, 2023)*

The result from Table 4, on if occupants think the functional areas in their building are properly zoned designs reveals that 67.0% said 'No' while 33.0% said 'Yes'. This implies that majority of the occupants do not think the functional areas in their building are properly zoned. Figure 29 presents a pie chart showing the result of if occupants think the functional areas in their building are properly zoned designs.

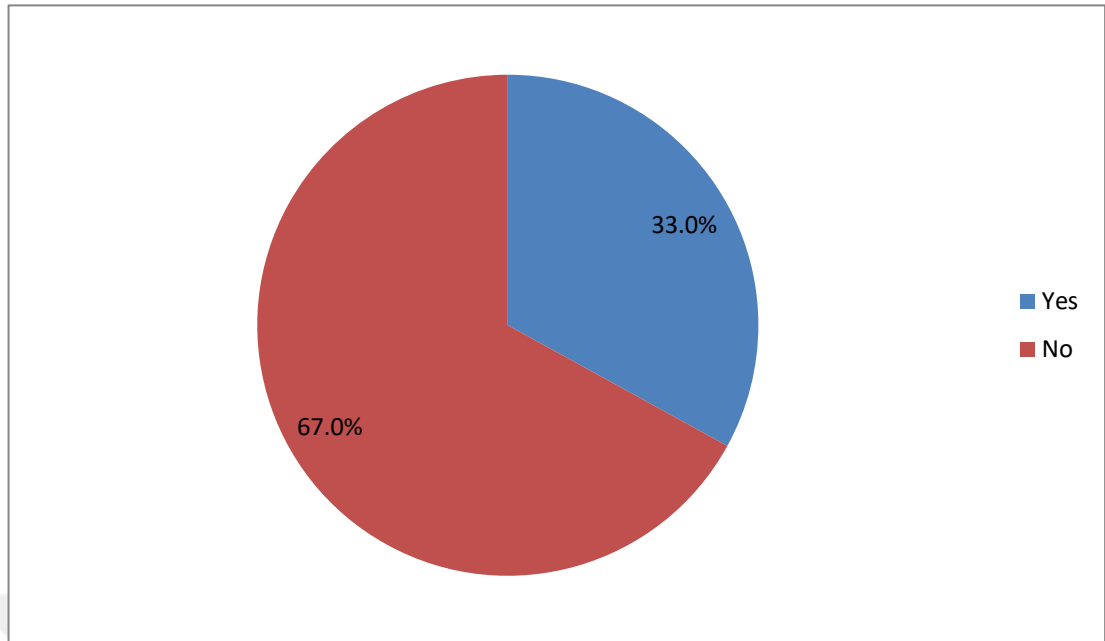


Figure 29: Pie chart showing occupants' response to if they think the functional areas in their building are properly zoned designs
(Source: Researcher's Field Survey, 2023)

Also, the result from Table 4 on the type of building wall material use in occupants' house reveals that 41.4% of the occupants use concrete blocks, 32.2% mud, 13.8% brick and 12.6% Bamboo / timber. Figure 30 presents a bar chart showing if the type of building wall material use in occupants' house designs.

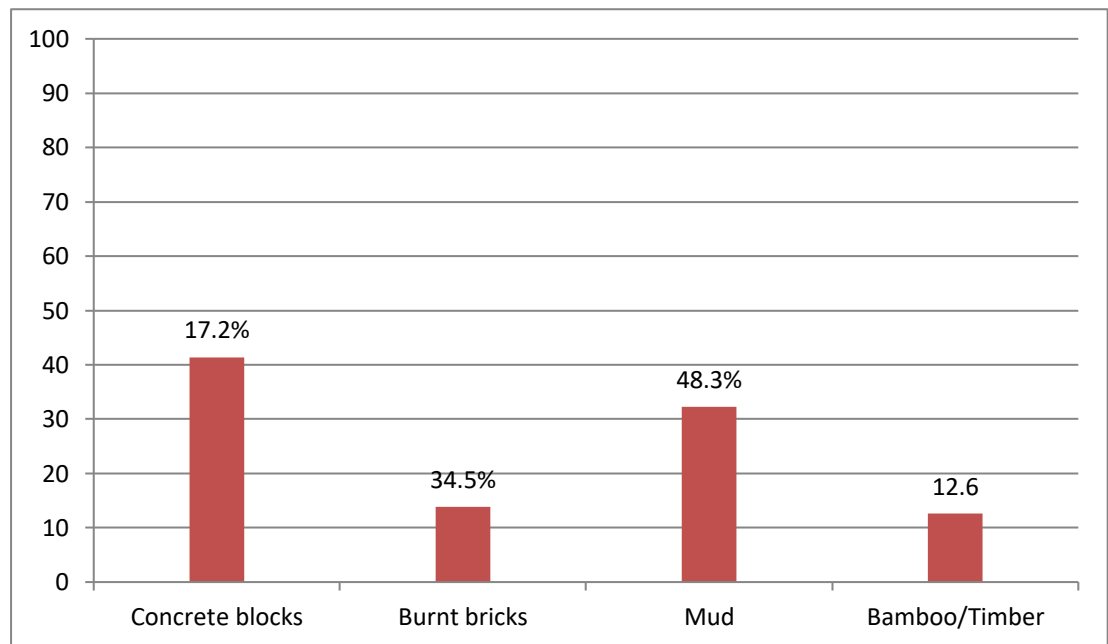


Figure 30: Bar chart showing the types of building wall material use in occupants' house designs
(Source: Researcher's Field Survey, 2023)

More result from Table 4 on if the walls of occupants houses were finished with bright colors reveals that 49.4% of occupants said ‘No’, 34.5% of occupants said the walls of their house were not painted while only 16.1% said ‘Yes’. Figure 31 presents a bar chart showing if the walls in occupants’ houses were finished with bright colors.

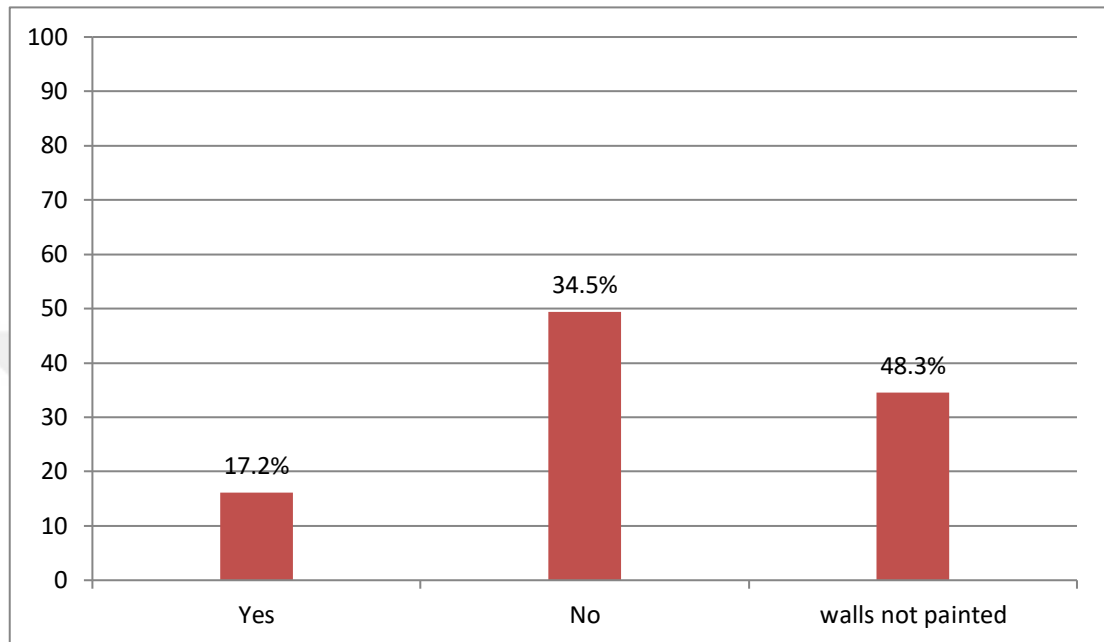


*Figure 31: Bar chart showing the result to if the walls of occupants’ houses was finished with bright colors
(Source: Researcher’s Field Survey, 2023)*

Result from Table 4 on the type of roofing materials use in respondents houses revealed that 59.8% of the occupants use long span aluminum /corrugated zinc without ceiling, 27.6% use long span aluminum /corrugated zinc with ceiling, while only 12.6% use thatch roof. Figure 32 presents a bar chart showing the type of roofing materials use in respondents’ houses.

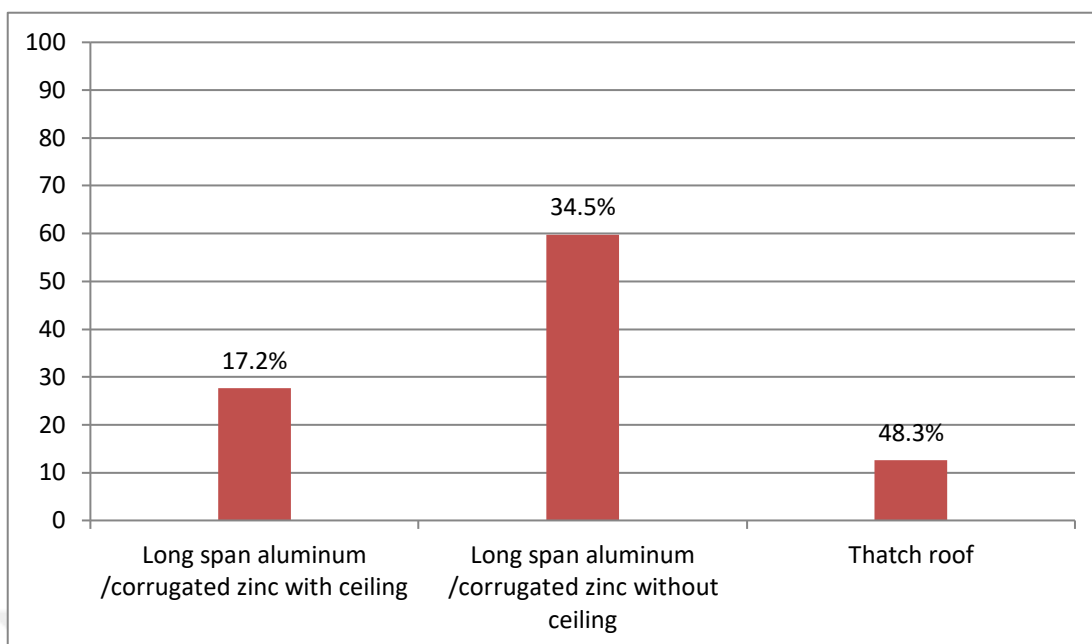


*Figure 32: Bar chart showing the type of roofing materials use in respondents' houses
(Source: Researcher's Field Survey, 2023)*

Results from Table 4 on the color of the roofing sheet in respondents' houses reveal that 39.1% used Silver colored roofing sheets, 27.6% use black colored roofing sheet while 33.3% use other colors. Figure 33 presents a bar chart showing the color of the roofing sheet in respondents' houses.

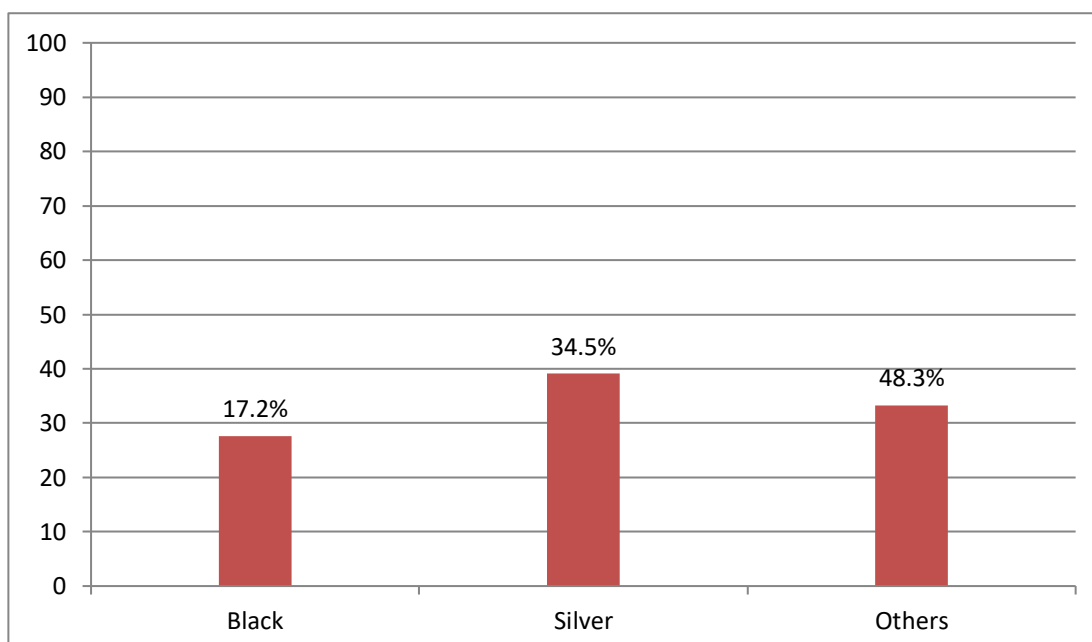


*Figure 33: Bar chart showing the colour of the roofing sheet in respondents' houses.
(Source: Researcher's Field Survey, 2023)*

The result from Table 4 on the type of landscape provided in respondents building reveals that in 76.0% of respondents' buildings no landscape is provided, while in 24.0% of respondents buildings landscape is provided with trees, short grasses and concrete interlocks. Figure 34 presents a pie chart showing the he type of landscape provided in respondents building.

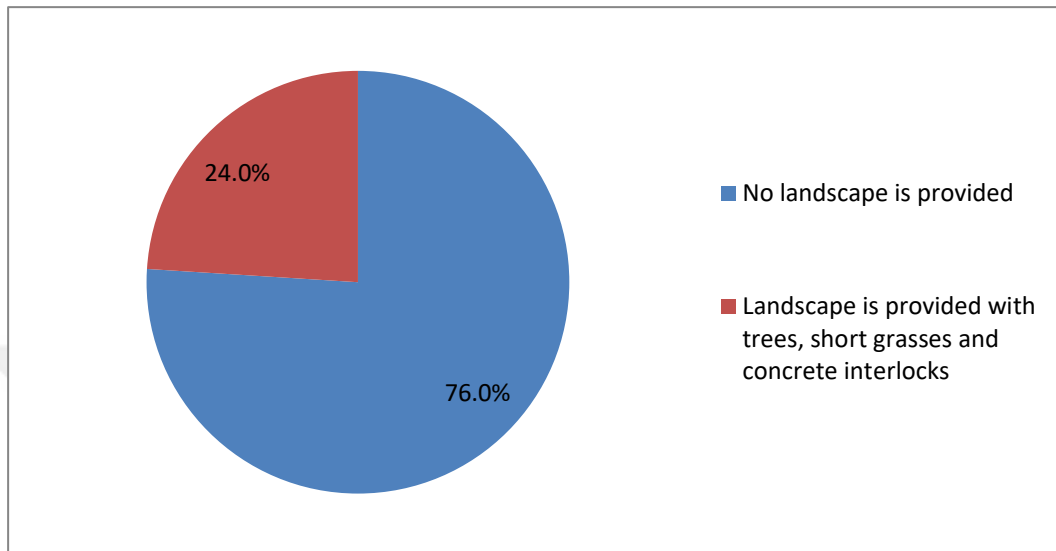


Figure 34: Pie chart showing the type of landscape provided in respondents building.

(Source: Researcher's Field Survey, 2023)

The result from Table 4 on if the sizes of doors and windows in occupants house is adequate reveals that 51.7% said 'No' while 48.3% said 'Yes'. Figure 35 presents a pie chart showing the result on if the sizes of doors and windows in occupants' house is adequate.

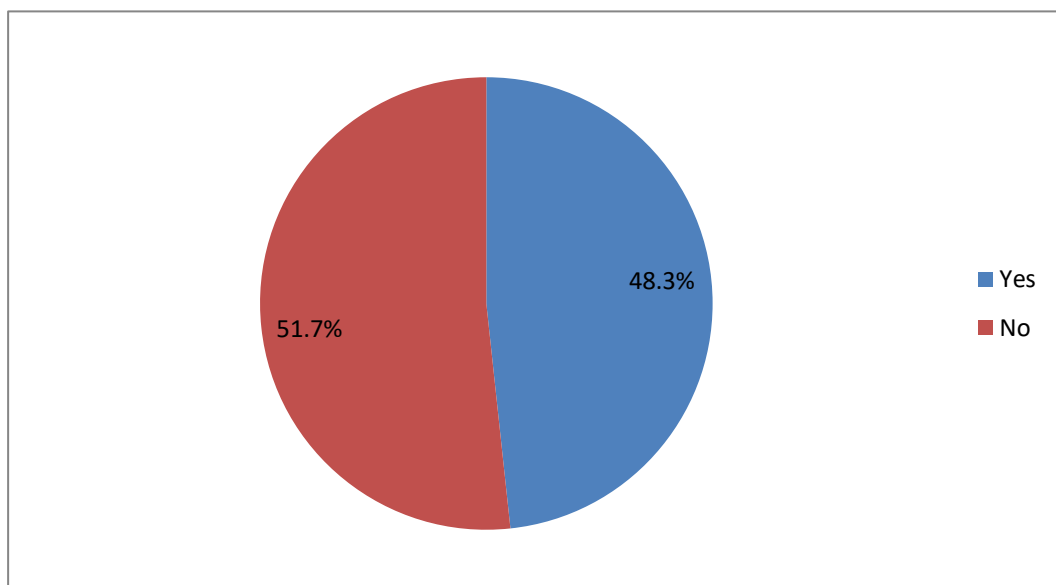


Figure 34: Pie chart showing adequacy of the sizes / position of doors and windows in occupants' house

(Source: Researcher's Field Survey, 2023)

The result from Table 4 on if there is adequate power supply to run appliance needed for thermal comfort reveal that 86.0% said ‘No’ while 14.0% said ‘Yes’. Figure 36 presents a pie chart showing the result on if there is adequate power supply to run appliance needed for thermal comfort.

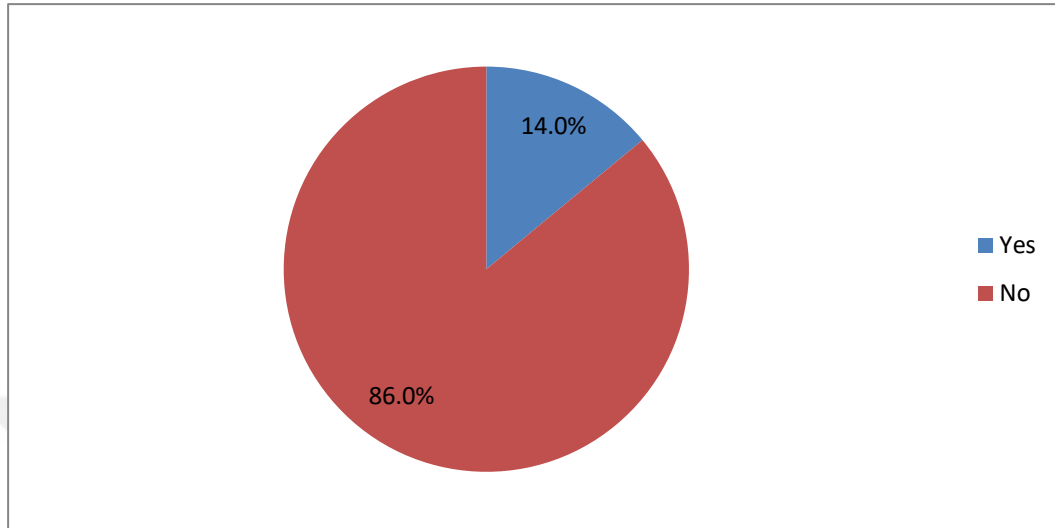


*Figure 36: Pie chart showing the result on if there is adequate power supply to run appliance needed for thermal comfort
(Source: Researcher’s Field Survey, 2023)*

The result from Table 4 on the type of mechanical ventilation in respondents’ house reveals that 48.3% had none, 28.7% had Electric fans only; 15.0% had Air conditioners only while only 8.0% had both Electric fans and air conditioners in their houses. Figure 37 presents a pie chart showing the type of mechanical ventilation in respondents’ house.

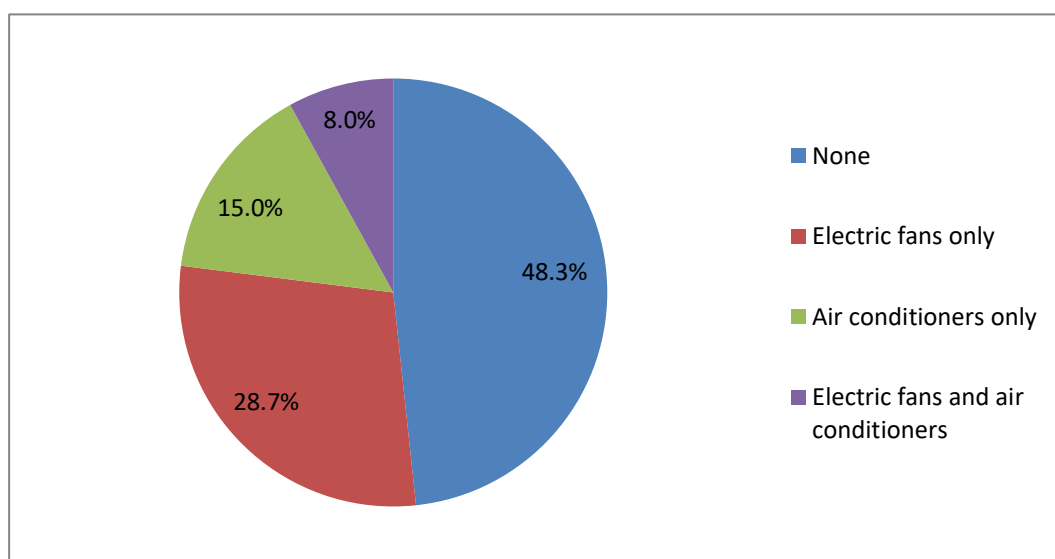


*Figure 36: Pie chart showing the type of mechanical ventilation in respondents’ house
(Source: Researcher’s Field Survey, 2023)*

4.5.3 Results Interpretation

The interpretation of the results from the 87/100 questionnaire data accepted as valuable data for academic reference is presented below.

4.5.3.1 Demography of buildings in Sokoto State

The interpretation of results on the demographic information of buildings in Sokoto State as it affects thermal comfort is as follows:

Investigated Building Types:

From the result 73.6% of the residential building are bungalows. This implies majority of the type of residential building types in Sokoto State are bungalow which ranges from semi-detached to detached bungalows.

Status of Occupants:

From, the results 64.0% of the occupants are owner occupiers. This implies that majority of the houses in Sokoto state are owned by residents. In a study by Haruna *et al.*, (2019) average room temperatures of occupant owners' building are higher than the average room temperature of tenant occupiers. This is due to short period that tenants occupy a building before moving to new residence.

Building Form:

From the result 47.1% of the residential building types in Sokoto State are rectangular building forms. Studies have shown that these building forms are good for orientation (Akande, 2010; Akaat, 2021). According to Akande (2010) building with simple rectangular and square floor plan are relatively easy to orient compared to irregular building forms.

Number of occupant per Building:

From the result 62.1% of the number of occupants per residential building types in Sokoto State is more than 8 (>8) person per building. This implies that more person per building which could impact the rate of thermal comfort in buildings if necessary measures are not put in place. This is in line with survey of Haruna *et al.*, (2019) which established that more persons per room increase indoor air temperature thus affecting thermal comfort.

4.5.3.2 Thermal Comfort in Residential Buildings in Sokoto State

The thermal comfort of residential buildings in Sokoto State is assessed under:

- i. The Rate of indoor thermal comfort,
- ii. Factors that limit the rate of indoor thermal comfort
- iii. Impact of the choice of building material
- iv. Hindrances to the effective delivery of designs that enhance thermal comfort both passively and actively.

4.5.3.3 The Rate of indoor thermal comfort,

The interpretations of the results on the rate of indoor thermal comfort in residential buildings in Sokoto State are as follows:

Time of the day occupants feel more uncomfortable:

From the result, 57.5% of building occupants feel more uncomfortable at 1pm-6pm daily especially in the peak of dry seasons around January – May. This implies that there is more overheating during these hours due to the hot climate and increased average temperature.

Time of the day occupants feel slightly comfortable:

From the results 79.3% of the occupants feel slightly comfortable at 7pm-6am. This is attributed to the fact that at these hours the sun begins to tune down and the environment becomes cool. The air temperature in indoor becomes relatively thereby making occupants feel slight comfortable. This implies that

How occupants feel with clothes while performing an activity at home:

From the results 51.7% of occupants feel uncomfortable with their clothes on while performing activity. This is linked to metabolic and clothes insulation and it differs from individuals. According, to ASRAE standard 55 (2020) the personal factor which significantly influence thermal comfort in human are metabolic rate and clothing insulation.

Occupants comfort without using fans and Air conditions

From the results 86.2% do not feel comfortable in their homes without using fans and air conditioners. This implies that providing thermal comfort actively is

effective in ensuring thermal comfort. This is in line with the study of Haruna *et al.*, (2019). The study reveals that air temperature in rooms with fans and air conditioners is low. This enhances thermal comfort.

General rating of thermal comfort in Sokoto State

From the results 54.0% of occupants in Sokoto State rate the general thermal comfort in residential building types poor. This implies that there is need to improve the thermal comfort of buildings in Sokoto State. Gram *et al.*, (2014) identified the factors required for improving thermal comfort in residential building to include proper orientation, ventilation, use of shading devices, creation of microclimate/ landscaping etc.

4.5.3.4 Factors that limit the rate of indoor thermal comfort

The interpretations of the results on the factors that limit the rate of indoor thermal comfort achieved in residential building types in Sokoto state are as follows:

Building Orientation:

From the results 71.0% of occupants in Sokoto State do not have idea about building orientation. This implies that there is need to enlighten occupants on the need and importance of building orientation in building designs.

Pattern of Orientation:

From the results 34.5% of the pattern of orientation in Sokoto State is the Length of the building facing East-West Direction. Studies have shown that this pattern is not favourable in Sokoto State which is a dry climate characterized by hot climate (Haruna *et al.*, 2019; Ekoh, 2020). According to Haruna *et al.*, (2019) the required pattern of orientation in dry region is North-South orientation in dry climate. This orientation pattern allows the building to be exposed to only minimum solar radiation.

Cross ventilation in Living spaces:

From the results 77.0% of occupants' bedroom and living room are not cross ventilated. This limits the rate of thermal comfort achieved in residential buildings in Sokoto State. Studies have shown that natural ventilation (cross ventilation and stack ventilation (SERPA, 2019) are essential for thermal comfort. Therefore without cross

ventilation thermal comfort is limited. Haruana *et al.*, (2019) identified the effect of insufficient ventilation in living spaces as fatigue, boredom, insomnia, headache etc.

External Shading

From the results 85.0% of the occupants' houses are not incorporated with external shading device. This implies that buildings types in Sokoto State from direct heat gain. Several studies have discussed the importance of shading on thermal comfort (Gratin and Herde, 2007; Ochedi *et al.*, 2018). In a study by Don (2016) external shading devices reduces solar radiation into buildings by 80%. External shading devices such as overhangs, blinds, roof eaves have tendencies of controlling solar radiation into the building.

Zoning of Functions

From the results, 67.0% of the occupants think their building is not properly zoned. This implies that more thermal discomfort is likely experienced by occupants in their living spaces. Zoning of functions enhances thermal comfort as it is an important passive design approach (Akande, 2010). Favourable room should be located along East-West dimension to mitigate overheating and other unfavourable weather conditions in living spaces (Haruna *et al.*, 2018).

4.5.3.5 Impacts the choice of Building materials have on thermal comfort in Sokoto State

The interpretations of results on the impact the choice of building materials have on thermal comfort in Sokoto State are as follows:

Building Walls:

From the result 41.4% of occupants buildings walls are made of concrete blocks. A study by Ochedi *et al.*, (2019) reveals that concrete is a good conductor of heat and conducts heat from the sun through radiation. This implies that this building material is not suitable for construction in Sokoto State due to the hot climate of the region.

Wall Colours:

From the result, 49.5% of the colours used as wall finishes are not bright colours. This implies that majority of the walls in residential building types in Sokoto

State are either not painted or painted with dull colours which are known to absorb heat and poise the risk of thermal discomfort in living spaces. In a study by Haruna *et al.*, (2019) the use of bright colours on wall finishes that retard or reduces the penetration of heat into a building is a passive design technique for enhancing thermal comfort.

Type of Roofing Material

From the results 59.8% of occupants' buildings in Sokoto State use long span / corrugated zinc without ceiling. This implies that majority of the roof in most of the buildings in Sokoto State lack the adequate insulation. This exposes such roof to overheating which affects thermal comfort in living spaces. In Dekone (2022) study to enhance thermal comfort in buildings, conduction needs to be inhibited by using poor conductor such as ceiling sheets, timber boards etc.

Commonly use roof colours

From the result, 39.1% of the commonly use roof colours in Sokoto State were silver colours. This roof colours are good for thermal comfort due to their reflective and retarding properties to reduced overheating as noted in the study of Ochedi *et al.*, (2018)

4.5.3.6 The Hindrance to the effective delivery of design that enhance thermal comfort in building in Sokoto State both passively and actively

The interpretations of results on the hindrance to effective delivery of design that enhance thermal comfort in residential building types in Sokoto State both passively and actively are as follows:

Landscaping:

From the results 76.0% of occupants building in Sokoto state have no landscape. This hampers natural ventilation. Research has shown that buildings with proper landscaping in the surroundings contribute to lowering the room temperature in residential which enhance thermal comfort. Therefore landscaping is essential for thermal comfort as captured in the study of Haruna *et al.*, (2019).

Erratic power supply:

From the results 86.0% of occupants do not have adequate power supply needed to run the appliances needed for thermal comfort. This implies that the poor supply of power significantly affects thermal comfort in the Sokoto State.

Size of windows / doors:

From the results 51.7% of the occupants said the sizes of doors and window in their homes were not adequate. Although a good number of 48.3% said it was adequate. This implies that the designs of most building types in Sokoto State are poorly done.

Mechanical ventilation:

From the result 48.3% of occupants do not have access to mechanical ventilation such as electric fans and air conditioner. This implies that most occupants live in homes without electric fans and air conditioners and as such the perceived thermal discomfort experienced in living spaces. Haruna *et al.*, (2019) established in his study that mechanical ventilation or active ventilation of residential buildings is effective in lowering room temperature necessary for thermal comfort in dry hot climate.

4.6 Discussion of Findings

The findings from the qualitative and quantitative aspect of this survey which entails interviews with professional architects in Sokoto State and administering of questionnaire sample to household in Sokoto State are discussed as follows:

4.6.1 Finding from interview with architects:

The major findings from the interview conducted with professional architects in Sokoto State as regard the climate responsive architecture of Sokoto state are as follows:

1. *The need for Awareness on Climate Responsive Architecture:* Findings on awareness on climate responsive architecture in Sokoto State revealed that most of the architects in the state have good awareness on climate responsive architecture and vernacular architecture while on the part of house owners (clients) little is known about climate responsive architecture. Therefore all architects interviewed opined that architects and allied professionals in the

Sokoto State should take time in highlighting the importance of climate responsive architecture to potential house owners (clients).

2. *Importance of considering climate before designing and choosing building materials for construction:* Findings on the importance of considering climate before designing and choosing materials for construction revealed that due to the hot climatic conditions in Sokoto State, if climate responsive architecture vernacular architecture is practiced it will enhance thermal comfort in a building; add to durability of a building and reduce the cost on passive energy for HVAC.
3. *Factors that limit the practice of Climate Responsive Architecture principles:* Findings on the factors that limit the practice of CRA principles from interviews conducted revealed that poverty, lack of awareness on CRA, lack of enforcement of building laws and regulations, incompetent professional colleagues (architects) and allied professionals, climate change and continuous negligence to the use of traditional vernacular building materials, Socio-cultural factors and the high cost perception potential house owner (clients) have on hiring architects to design buildings. The poverty rate and high cost perception clients have on hiring architects explains why building designs in Sokoto State don't go through the proper procedures before construction. Therefore to avoid spending much on hiring architect clients prefers to employ the services of low cost artisans (masons) to get building construction done.
4. *Hindrances to effective delivery of thermal comfort in the design of buildings in Sokoto State:* Findings on the hindrances to effective delivery of thermal comfort in the design of buildings in Sokoto State from the interviews with professional architects and survey with house owners revealed that house owners Lack of awareness on the importance of Climate Responsive Architecture / Vernacular Architecture, negative perception about local / traditional building materials and the Non engaging professional architects for designs / construction are amongst the common causes of the hindrances to effective delivery of thermal comfort in the design of buildings in Sokoto State. Interviewed architects also attributed the common hindrances to effective delivery of building designs that enhances thermal comfort in Sokoto State to poor designs, clients perception that architects charges are outrageous, neglect on incorporating traditional building materials to designs, engaging quacks and unskilled artisans for building construction and

design, the rise of unqualified architects engaging in construction projects and other professionals in the building industry doing architects job.

5. *Climate Responsive Architecture techniques and passive design approaches by architects:* Findings revealed that the most widely used climate responsive architecture techniques and passive design approaches to achieve thermal comfort by architects in Sokoto State is landscaping, cross ventilation, courtyard designs and use of shading devices. Though modern design in the state have seen courtyards and deep verandah beginning to lose their importance regardless of their enormous importance of providing shade to maintain thermal comfort in buildings

Therefore, it is important to understand that the lack of awareness on climate responsive architecture amongst house owner (clients) in the state has encouraged them to engage in buildings without considering climate. Also the high rate of poverty in the state has prevented house owner from engaging professional to build houses. Therefore majority of their construction are carried out by local mason who have little or no knowledge about climate responsive architecture vernacular architecture practices which would have enhanced environmental sustainability and thermal comfort in buildings. To this quacks artisans and house owners, their concerned is strictly on aesthetic and prestige rather than considering climate before construction. This explains why there is a drastic shift from the use of traditional building materials.

The architects in the state have also raised concerns about the rise of unqualified architects engaging in construction projects and other professionals in the building industry doing architects job. These personnel with lack of skills tend to handle building designs and construction without considering the climate of the region. They lack the rudiment required during the schematic stage of the design before construction. Therefore proper site climatic analysis is often omitted during design stage. This affects decision making as regards the design and building materials that is to be used for construction, thus this eventually leads to the use of building materials that are not compatible and adaptable to the climate of the state and as such the thermal discomfort in the built environment of state continuous to increase.

4.6.2 Findings on thermal comfort in Sokoto State from questionnaire survey with occupants

The major findings from the questionnaire survey with households in Sokoto State as regard climate responsive architecture of Sokoto State as it affects thermal comfort are as follows:

1. Rate of indoor thermal comfort achieved in residential building types in Sokoto State:

Finding reveal that the general rate of indoor thermal comfort achieved in residential building types in Sokoto State is poor.

Finding also reveal that the time of the day most occupants in residential building types in Sokoto State feel more uncomfortable is during the hours of 1pm-6pm. This is due to the fact that during this hours the sun becomes more peak.

More findings also reveal that the time of the day majority of occupants in residential building types in Sokoto state feel slightly comfortable is during the hours of 7pm-5am. This is because during this period the sun begins to set and tunes down leaving the environment to be relatively cool.

Further finding reveal that most occupants feel uncomfortable with their clothes on while performing a task or activity at home. This is likened to metabolism and clothing insulation and it is subjective in nature because humans are built different and attain thermal comfort at different level. However the temperature of the surrounding has a significant impact on this. This agrees with Lechner (2015) claims that the heat produced during metabolism is partly a function of outside temperature mostly a function of an activity.

More findings reveal that occupants feel uncomfortable in their home without using fans and air conditioner regularly. This is attributed to the hot climate of the region, choice of building materials, poor nature of passive designs.

2. Factors that limit the rate of indoor thermal comfort achieved in residential building types in Sokoto State

Findings reveal that the major factors that limit the rate of indoor thermal comfort in residential building types in Sokoto State is lack of building orientation and majority of the occupants in the state have no idea about building orientation.

Findings also show that the orientation pattern of most building in Sokoto State had the length of the building facing East-West direction. Studies have shown that this orientation is not suitable for thermal comfort in dry climate like Sokoto State because it exposes the lengthy walls to more direct sunlight (Haruna *et al.*, 2019).

Further finding reveal that most of the living spaces windows in residential buildings in Sokoto State are not cross ventilated. This reduces the opportunity of natural ventilation needed to lower indoor air temperature for thermal comfort. This is in line with the finding of Haruna *et al.*, (2019) and Ochedi *et al.*, (2018).

Findings further show that external shading devices are not incorporated in majority of the design of residential building in Sokoto State.

More findings on the factors that limit the rate of indoor thermal comfort achieved in residential building types in Sokoto State reveal that most occupants in Sokoto State think the functional areas in their building are not properly zoned. This is largely attributed to the thermal discomfort occupants experience from 1pm-7pm.

3. Impact of building material choices on thermal comfort in residential building types in Sokoto State

Finding reveals that concrete blocks are the most widely used building materials for walls in residential building types in Sokoto State. This building material is not suitable for construction in dry hot climate because it limit the rate of indoor thermal comfort compared to other building materials like burnt brick, mud, bamboo/timber because of its high rate of conducting heat through radiation. This agrees with the findings of Haruna *et al.*, (2019)

Findings also reveal that the wall of most building in Sokoto State are not painted and most of the painted buildings are not painted with bright colours which have reflective and retarding properties to heat thereby reducing indoor heat. This is also confirmed in the finding of Ochedi *et al.*, (2019).

More finding reveal that the type of roofing material commonly used in residential building types in Sokoto state are long span aluminum/ corrugated zinc without ceiling. This is roofing types are not suitable for thermal comfort because more heat is allowed into the building space due to lack of ceiling that serve as insulation. This agrees with the findings of Haruna *et al.*, (2019) that provision of insulation such as ceiling to roof in building help improve the thermal comfort derived in such building. Finally, finding reveal that majority of roofing sheets in Sokoto State are silver coloured roofing materials which have tendencies of

reflecting and retarding solar radiation due to dark coloured roof that have more absorbing properties. This is good for the region considering the hot climate in the region.

4. Hindrance to the effective delivery of designs (passive and active) that enhance thermal comfort in building types in Sokoto State

Finding on the hindrance to the effective delivery of designs (passive and active) that enhances thermal comfort reveals that there is no landscaping in most houses designed in Sokoto State. This significantly hinders the effective delivery of thermal comfort. In a study by Haruna *et al.*, (2019), designs with landscape such as concrete interlocks, short grasses and trees have lower average temperature necessary for thermal comfort compared to designs without landscape.

More findings reveal that erratic power supply is another hindrance to effective delivery of designs that enhance thermal comfort actively in building types in Sokoto. Research have shown that Sokoto State is one of the many States in Nigeria with poor electricity supply (Ajala, 2022; Energy Progress Report, 2022)

Further findings, on the hindrance to the effective delivery of designs that enhances thermal comfort passively reveals that the sizes / positioning of doors and window in most building in Sokoto state are not adequate. Adequate sizes of window have a significant impact on thermal comfort. This agree with the finding of Haruna *et al.*, (2019) which reveal that buildings with more windows or doors opening area have lower average temperature needed for thermal comfort than those with less opening area.

Finally, findings on the on the hindrance to the effective delivery of designs (passive and active) that enhances thermal comfort reveals that most households in Sokoto State do not have access to mechanical ventilation to actively provide thermal comfort. Studies have shown that rooms with electric fan and air conditioners have lower air temperature necessary for thermal comfort compared to rooms without fans and air conditioners. However findings show that most household in Sokoto State are without electric fans and air conditioners in their homes. This could be attributed to the high rate of poverty in Sokoto State. The National Bureau of Statistics reported that the rate of poverty in Sokoto State is 87.7% (NBS, 2022).

Chapter Five

5. Conclusions and Recommendations

It is an evident fact from this research's findings and reviewed literature that the climate in Sokoto State is hot and most buildings in the state were designed and built without considering climate and consulting professional architects for the designs and construction. This has significantly had negative effects on delivering optimal thermal comfort and energy efficiency in buildings in Sokoto State. As a result many household owners in Sokoto State have practically been subjected to thermal discomfort and high rate of energy consumption in their living spaces in the quest to actively attain optimal thermal comfort via other mechanical means. This in the long run, has caused households owners to spend more on electrical energy. Therefore, it is pertinent to note that this situation is largely attributed to the lack of awareness on climate Responsive Architecture on the part of households' owners, lack of perception about local / traditional building materials and the non-engagement of professional architects for designs / construction. However, if household owners had awareness on climate responsive architecture, they would definitely have sought to engage professional who they know and have the required expertise on climate Responsive Architecture. This will help house owners in Sokoto State get more passively designed buildings properly thought out to attain optimal thermal comfort in living spaces. The architects harnesses some identified Climate Responsive Architecture techniques and passive design approaches to ensure households owners achieve the desired thermal comfort in their living spaces. Some of these identified Climate Responsive Architecture techniques and passive design approaches include landscaping, cross ventilation, floor plan zoning, building orientation, courtyard designs, use of shading devices, and cooling pools etc.

This shows that considering climate before designing, constructing or even choosing building materials for any structure is very important and professional architects and other aligned professionals are tasked with the role of designing buildings to suite a regions particular climate and also creating awareness on Climate Responsive Architecture to household. Therefore, a number ways through which this awareness can be created includes raising awareness on sustainability, stating the need to engaging professionals for design of buildings, learning lessons from vernacular architecture / use of traditional building materials etc. This awareness will enable households owners become more exposed to Climate Responsive Architecture

and some of its numerous benefits which includes; attaining optimum thermal comfort in living spaces, energy efficiency / reduction of GHG emission, Reduction in the amount of money spent on electric energy etc.

However, lots of factors such as socio-cultural factors, clients' preference / choices, poverty / high cost perception of choosing climate responsive architecture principles and neglect of vernacular architecture / traditional building materials have been identified to limit the practice of Climate Responsive Architecture principles in Sokoto State. Therefore, in the quest improve the practices of Climate Responsive Architecture principles to maintain optimal thermal comfort the following recommendations can be made:

1. The government of the state and other relevant stakeholders in the building sector need to ensure that all design constructions are carried out strictly by professional in the field.
2. Building codes and regulations that can improve Climate Responsive Architecture practices need to be encouraged and enforced by the government.
3. Professional architects and aligned professional need to revive the culture of Vernacular Architecture in a more modernized way. They will aid in preserving the traditional inheritance of the state.
4. Architects and designers need to take advantage of the hot climate of the region and incorporate the use of renewable energy source like solar panels and inverters into building designs so as to provide affordable mechanical energy ventilation.

As an insightful recommendation to improve the quality of building in Sokoto State in regards to provision of thermal comfort, it is important for professional and aspiring architects in Sokoto State to reinstate some elements of the traditional vernacular architecture into their modern designs. Passive design principles that are centered on achieving thermal comfort from solar radiation need to be prioritized due to the hot climatic condition in the state. Therefore climatic site analysis should be properly harnessed to schematic design phase. This will enabling decision to be made by professionals on the right building shape and orientation in regards to the result from the site climatic analysis to be adopted.

5.1 Recommendations for Thermal Comfort Oriented Designs in Sokoto State

Climate responsive vernacular architecture studied in Chapter 3 shows that passive and bioclimatic design approaches are the two main approaches for thermal comfort in buildings. The lesson from the passive design approaches will be embedded in the design proposal for improving thermal comfort in new buildings in Sokoto State. From the lessons on passive design approaches the following recommendations are proffered as measures for improving thermal comfort in Sokoto State.

1. Orientation: Since studies have shown that the best optimum orientation for buildings in dry hot climate is facing the shorter side of the building to the East and West. This orientation is recommended for all new constructions in Sokoto state
2. Floor Zoning: In cases where orientation is not attainable due to site topography and other factors floor plan zoning is recommended. Here functional spaces with less use need to be zoned to be zoned to positions that receive more sunlight.
3. Natural Ventilation / lighting: In the observational survey of the cases study it was mentioned that building suffer from natural ventilation and light. Therefore, to ensure for natural ventilation / lighting fenestrations (doors and windows) should be properly designed to take advantage of the climate. it is recommended that all building should be cross ventilated with sufficient windows.
4. Landscaping: To improve thermal comfort in building in Sokoto, landscaping need to be efficiently utilized. Since the region is a very hot and dry region, it is recommended the all building need to be landscaped with the right mix of green areas comprising of trees and flower. This provides cooling and reduces over heating
5. Shading: Due to the hot climate in Sokoto, extensive use of overhangs need to be incorporated in designs to provide shads
6. Building materials: Vernacular building materials need to be incorporated to modern design due to their adaptability and compatibility tendencies to climate and climate change. Trombe wall as mentioned in chapter 3 can be effective in order to provide thermal comfort in houses since the wall is

designed to trap excessive heat energy in the day and release it at night (Lechner, 2015).

Finally, in line with the key findings from the research study, the following as recommendation as regard material decision are made:

1. Fire bricks and muds are recommended as preferred building materials for walls than concrete block walls who are more common due to their high reflective abilities
2. Bright and light colored wall finishes and roofing sheets are recommend for wall and roof.
3. Window and Doors need to be designed with the required standards that ensured more opening area. This is likely to passively enhance thermal comfort in buildings in Sokoto State
4. Flat root design and pitched roof with vents and insulation need to be incorporated in designs since they allow for heat loss during the summer and heat gain during the winter.
5. Due to the hot climate, terrace designs that incorporate the use of timber and bamboos is recommended to enable occupants to be comfortable during hot hours and at night.

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