PROTECTING HERITAGE BY QUANTIFYING THE THERMAL COMFORT BENEFITS OF TRADITIONAL ADOBE BUILDINGS IN ILORIN, NIGERIA

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ABSTRACT

Traditional adobe buildings are often recognized for their lower environmental impact and responsiveness to climate. However, they can be susceptible to erosion and damage caused by exposure to weather conditions, and their maintenance can be laborious and reliant on craft skills passed on through generations. Therefore, they can fall into disrepair and/or replace parts with less laborious materials that may impact their performance. In this work, interventions focused on improving performance and optimizing building fabric to ensure occupant comfort were explored to help safeguard these culturally significant buildings from extinction.

In Nigeria, the usage of adobe material is widely spread in areas where there is a shortage of construction materials and/or limited access to modern building techniques. The country has a wealth of heritage adobe buildings, with their characteristics responding to ethnical diversity. The assessment of these buildings has gained increasing interest among researchers in Nigeria, driven by concerns about their rapid deterioration and erosion despite their cultural value. In this study, the author has quantified the ability of traditional adobe buildings to provide thermal comfort through four main case studies based on the tropical savanna climate of Ilorin City (latitude 8.5°N, longitude 4.45°E), which is warm and humid all year. A multi-method approach combining qualitative and quantitative methodologies was taken, and it included a series of occupant surveys, interviews, in-situ measurements, and computer simulation analysis. Four existing traditional Adobe residential building designs, with various layouts, courtyard systems, plan configurations, forms, and shapes, were characterized to assess their distinct cultural aspects and investigate their suitability for performance improvement alongside conservation.

Survey findings indicated that 91% of the occupants were satisfied with the indoor thermal living conditions, and this also gave insights into the cultural value, attachment, and sense of belonging of Ilorin people. The in-situ monitoring has revealed that the standard effective temperature (SET) point was 28.7 ˚C while the lower and upper indoor temperatures were 25.2 and 32.1 ˚C, respectively, which surpassed the temperature range (22 – 27 ˚C) for naturally ventilated residential buildings by a standard for the tropical warm-humid climate. These findings were used to produce dynamic simulation models that enabled the exploration of the impact of the materials on comfort. The simulation analysis revealed that the original (as-built) building was within comfort for 65 % of the time compared to 59 % for the current as-occupied buildings. However, when heritage-sensitive strategies were applied to create an improved/optimized building, the spaces were within comfort for 81 % of the time. Based on the findings, a maintenance, performance, and improvement framework were developed with practical recommendations for preserving and enhancing traditional Adobe buildings. The results were used to shape a framework to inform Nigerian policymakers, architects, builders, and occupants to improve the adoption of best practices for adobe construction in warm-humid climates and help protect their heritage.

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DEDICATION

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LIST OF ACRONYMS

ACH	Air Change per Hour
ADF	Average Daylight Factor
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BEE	Building Energy Efficiency
BIM	Building Information Management
BOQ	Bill of Quantities
BREEAM	Building Research Establishment Environmental Assessment Methodology
CHLM	Cultural Heritage Legislation and Management
CIBSE	Chartered Institution of Building Services Engineers
CO_2	Carbon dioxide
DBT	Dry Bulb Temperature
DF	Daylight Factor
DPC	Damp proof course
EPW	Energy Plus Weather files
GBP	Great British pound
GHI	Global Horizontal Irradiance
GNI	Gross National Income
IBM	International Business Machines Corporation
ICCROM	International Centre for the Study of the Preservation and Restoration of Cultural Property
ICOMOS	International Council on Monuments and Sites
IES	Integrated Environmental Solutions
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standard Organisation
NASA	National Aeronautics and Space Administration
NBC	National Building Codes
NCMM	National Commission for Museums and Monuments

NESP	Nigerian Energy support program
NNBC	Nigerian National Building Code
NUC	Nigerian University Commission
PHPP	Passive House Planning package tool
PMV	predicted mean votes
POE	Post Occupancy Evaluation
PPD	percentage of dissatisfaction
RH	Relative humidity
RQ	Research Question
SET	Standard Effective Temperature
SPSS	Statistical Package for the Social Sciences
TC	Temperature comfort
TFA	Treated floor area
TH	Temperature in Harmattan
TR	Temperature in rainy/wet
TSV	Thermal sensation votes
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
VSD	vertical shading device
WBDG	Whole Building Design Guide
WWA	Window- wall - area
WWR	wall-to-window ratio

LIST OF ABBREVIATION, NOMENCLATURE, AND SYMBOLS

ΔT = temperature difference (°C)

ASurface = surface area (m2)

Afloor = Floor area (m2)

ATF= total area (m2)

clo = clothing insulation (unit)

Earthen buildings = Eco-friendly and energy-efficient structures made primarily from natural materials such as clay, sand, and straw. They offer durability and adaptability to various climates.

Earthen architecture = A sustainable building construction method that utilizes natural materials such as clay, Adobe, sand, and straw to build energy-efficient structures.

ET = Effective temperature (°C)

HTC = heat transfer coefficient (W/m2K)

HSA = horizontal shading angle (deg)

M = metabolic rate (W/m2)

pa = vapor pressure of air (kPa)

Qc = conduction heat flow rate (W)

Qe = evaporative heat flow rate (W)

Qi = Internal gains heat flow rate (W)

Qs = solar heat flow rate (W)

Qv = ventilation heat flow rate (W)

Rcl = clothing thermal insulation

RT= Thermal Resistance (K/W)

Traditional architecture = A building style that has been handed down through generations, showcasing cultural heritage, historical influences, and the use of local materials.

Traditional buildings = Subtypes of vernacular architecture, representing historical structures that reflect the long-standing architectural heritage of a place.

Tcomf = comfort temperature (°C)

Tn = neutral temperature (°C)

T_{out} = Mean outdoor dry bulb temperature ((°C)

T_o = Monthly mean of the outdoor dry-bulb temperature(°C)

U = conductance or U-value (W/m2K)

V = air velocity (m/s)

Vernacular Architecture = A region-specific construction approach that utilizes local materials and techniques, designed according to climate and community needs.

VSA = vertical shading angle (deg)

Introduction

In this section, the context of the study is introduced, providing background information and identifying key issues and gaps in existing knowledge. The primary aim and objectives of the research are described, along with the justification for its relevance and significance. Additionally, the research methodology is outlined, highlighting the framework and strategies used for data collection and analysis. The study's novelty is emphasized, showcasing its unique contributions. Finally, the thesis structure is described, offering a clear roadmap of the chapters to guide the reader through the research. This section lays a solid foundation for understanding the study's direction and purpose.

Background of the Study

In recent years, there has been a growing awareness of the historical and current use of adobe as a building material, prompting a renewed focus on conserving and safeguarding traditional architectural heritage in rural Nigerian communities. According to Harmad (2016), there is a global push to mitigate the environmental and social impact of the construction industry, leading to a revived interest in earth construction. Furthermore, Houben & Guillaud (1994) and Kulshreshtha et al. (2020) argued that the quality of earth construction has significantly declined due to the loss of traditional expertise, and specific previously viable solutions are no longer feasible due to the evolving economic conditions and technologies. As explained by Pardo (2023), Vernacular architecture refers to a type of regional architecture created by non-experts, drawing on knowledge transmitted from generation to generation. This architectural style is deeply intertwined with local traditions and reflects a region's social, cultural, and environmental contexts. The importance of vernacular architecture is further elaborated by (Reeves & Sims, 2006 and Morel et al. 2021), who pointed out that adobe serves as a prevalent building material worldwide. The presence of adobe structures in various historical and contemporary cities across Asia, Europe, America, the Middle East, Africa, and Ilorin City in particular highlights the material's durability and adaptability.

A region's vernacular architecture reflects traditional building characteristics shaped by geography, available materials, climate, traditions, and culture (Pardo, 2023). Adekeye (2013) enhances this understanding by categorizing traditional buildings as a subset of vernacular architecture, representing historical structures that exhibit a city's long-standing architectural heritage. These buildings deserve study because they speak volumes and serve as invaluable historical records, providing insights into the lifestyles, construction techniques, and cultural evolution of past societies. Ilorin City offers a distinctive case for the study of vernacular architecture due to its cultural diversity. Ilorin has historically served as a melting pot for various Nigerian ethnic groups. This cultural amalgamation has profoundly influenced the city's architectural landscape (Omoiya, 2005; Akogun; 2013; Omoiya; 2013; Adeyemo, 2019). Examining the architectural history of Ilorin reveals a fusion of different ethnic influences, ultimately shaping a unique local culture known as ‘Ilorin’ (Omoiya, 2005). Therefore, mapping and studying Ilorin’s vernacular and traditional architecture not only preserves its historical identity but also enhances understanding its cultural evolution

In Nigeria, buildings built of earth (Adobe) are still a common practice, especially in rural and urban regions, thereby revealing adobe traditional buildings as the most common type in Nigeria. Similarly, Abdullahi (2020) ascertained that earthen architecture is a sustainable building construction method that utilizes natural materials such as clay, Adobe, sand, and straw to build energy-efficient structures. He further claimed that adobe traditional buildings are one of the oldest forms of construction in Nigeria and other parts of the world. These traditional buildings comprise structures made from unfired earthen materials, including adobe (or sun-dried mud brick), rammed earth, and a host of other earthen components and construction techniques that vary from culture to culture and region to region. The adobe material is the primary structural element in such architecture and is also very useful in rendering, decorating, and conservation. Interestingly, the city of Ilorin features diverse traditional buildings stemming from its multicultural heritage and social history. Research by Doat et al. (1991) argues that earth is undoubtedly the most ancient construction material known to humankind; Doat further explains that raw earth is a material that has been used for ages as a building material. Vernacular architecture has many benefits on economies and environmental factors. Earth is readily available and accessible on-site, requiring no transformation; it is also the simplest natural material we have at our disposal, used by humankind in construction with techniques.

For many years, protecting the built heritage and conserving communities' local traditional and cultural values for future generations has been an enormous challenge to both scholars and the Nigerian government. Nigeria has a population of over 200 million people, with rich cultures across its 250 ethnic groups and different languages spoken. There are significant cultural values and historic traditional buildings/ornaments depicting building styles and cultures specific to regions and particular tribes. Traditional buildings constructed from local materials started to disappear rapidly in the 19th century, and this can be attributed to the persistent human need to solve environmental problems caused by global warming and deforestation (Adekeye, 2013). Similarly, Alonge (1994) suggested that new architectural building styles were introduced by slave merchants and combined with influences from Western countries, led to the adoption of modern building materials to preserve traditional heritage and local cultural sites/buildings. According to Onyegiri et al. (2016), local civilizations have employed local materials for construction and upkeep in an environmentally friendly ma nner. However, African building techniques are under threat due to the increasing use of foreign materials. Consequently, there has been a shift from using local materials despite research showing that approximately 3 billion people worldwide, including about 50% of Nigeria's rural and urban population, reside or work in buildings made from earthen structures (Onyegiri et al., 2016). This research addresses the challenges these adobe buildings face, particularly in terms of providing thermal comfort and using modern materials for preservation, as observed in Ilorin, Nigeria. This shift can potentially alter the cultural identity of Ilorin's adobe traditional buildings, leading to the disappearance of these indigenous heritage structures. Therefore, the thesis focuses on Ilorin's prevalent adobe traditional house types. On the other hand, the negative consequences of global climate change, which manifest as abrupt, severe weather events and gradually altering weather patterns, significantly influence human well-being, comfort, and standard of living. With global warming continuing, there is increasing concern about the possibility of building overheating and the potential health effects for occupants (Lomas and Porritt, 2017).

According to the Carbon Brief (2024) report, Nigeria has been facing prolonged extreme heat this year, surpassing 40 °C in February. A recent analysis indicated that human-induced climate change has increased the likelihood of these extreme conditions by tenfold. The heatwave persists within the cities in northwest Nigeria, registering a record-breaking 44.8 °C on April 1. According to Nimet (Nigerian Meteorological Agency,2024), heat waves, characterized by prolonged periods of abnormally high temperatures and humidity, are becoming more frequent and intense. The report also highlighted the dangers caused by heat waves becoming more persistent in Africa due to climate change. The North-central climate zone of Nigeria experiences consistently high humidity and temperatures, leading to significant challenges in managing human thermal discomfort in residential buildings. Consequently, occupants often resort to active cooling systems (Nwalusi et al., 2019). The growing demand for space cooling energy, driven by global warming, increases greenhouse gas emissions. As a result, there is an urgent need for adaptation in the residential building sector to address the impact of climate change on buildings and construction. Global interest is in developing buildings with low or almost zero energy use to reduce environmental impact and energy expenses (IPCC, 2014b, p678). Research on the thermal comfort of traditional residential buildings in Southeast Nigeria, using Igbo traditional residential buildings as a case study, revealed that adobe traditional buildings provided thermal comfort (Nwalusi, et al., 2019). However, the impact of ventilation was found to be limited. This research highlights the importance of prioritizing and preserving improved low-energy building designs to alleviate their influence on the environment, improving living standards and saving energy expenses.

There has been limited research on preserving traditional buildings in Nigeria. However, various sources suggest that practical preservation, conservation, and maintenance are crucial for ensuring the enduring existence of traditional houses, thereby safeguarding a longstanding sense of place for the people. Todd's (2015) publication highlights the benefits of cultural preservation of buildings and advocates for their restoration and construction using environmentally friendly models by aptly asserting, "Restoration fosters community connection, provides a sense of place, links individuals to their neighbors, and encourages public participation." Neza and Koenraad (2008) also delved into "the spirit of place". They emphasized how preventive conservation and maintenance of architectural heritage can foster an environment where people are connected with their heritage and uphold the pride of their cultural space.

The concept of preserving the spirit of a place is rooted in local identity elements. Therefore, maintaining a daily connection with the environment holds great potential. This approach, referred to as "collective control" by Rapoport (1969), is well-known in more traditional societies but is not as evident in Europe, though it does exist. Karakul (2015) noted the disappearance of traditional craftsmanship, particularly the master-apprentice relationship that ensured the transmission of knowledge and preservation of traditional architecture. He suggests a methodology called "integrated conservation methodology" to reestablish the master-apprentice relationship, focusing on tangible and intangible aspects for the sustainability of traditional craftsmanship. Furthermore, given that climate change is a multifaceted problem, a few researchers, Nwalusi et al. (2019) and Hailu et al. (2021), investigated the link between vernacular adobe buildings and thermal performance. Both cases concluded that traditional vernacular building envelopes provide good thermal comfort in different climatic zones when combined with other factors. Similarly, Weber and Yannas (2014) argued that although vernacular architecture and material selection may suggest a building's resilience to a particular climate, this is not always a reliable indicator of year-round environmental performance. It is critical to consider societal norms and inhabitants' habits in addition to building thermal efficiency.

In Nigeria, the lack of researchers taping into the potential of vernacular traditional buildings to provide thermal comfort under severe weather conditions is evident in the Nigerian National Building Code (NNBC). The NNBC lacks research and literature on resilient and sustainable vernacular building designs relevant to Ilorin and Nigeria. According to Zune (2021), regardless of regional and national variations in climate, building standards and regulations have supported passive architecture in high-performance and sustainable building design. On the other hand, the NNBC has very little information regarding building thermal performance. This offers a massive opportunity for this thesis to bridge this gap by creating and implementing crucial standards for resilient and sustainable building methods specific to traditional adobe buildings in Ilorin, Nigeria. Sonaiya and Dincyurek (2009) explored the conflict between vernacular and modern architecture in Africa and proposed integrating principles from both. Their study was based on the traditional architecture of West African Yoruba communities.

To the best of the author's knowledge, there is limited literature on the documentation of traditional buildings in Nigeria. It is important to state that documentation is a key tool to conservation strategies, and there are no in-depth records or proper documentation of most traditional buildings in Nigeria, especially ancient Ilorin buildings. Proper data collection, pictures, or documentation are kept, providing researchers and stakeholders guidance on the preservation/ restoration/maintenance of good traditional historic buildings. The lack of documentation on the inventory of historic Nigerian traditional buildings can be attributed to the fact that most Nigerian-listed buildings/ monuments are not recognized by international bodies such as UNESCO. This limitation would be addressed by conducting a comprehensive literature review and documentation process, including survey visits and applying subjective methodologies to gather data on traditional buildings and occupants to improve thermal comfort and building performance.

Tradition carries the weight of a universally respected law upheld through collective consent. It is accepted and obeyed because reverence for tradition establishes collective control, serving as a form of discipline. This approach is effective due to a shared vision of life, an established model of buildings, a limited number of building types, and an accepted hierarchy, ultimately shaping an approved settlement pattern. As long as tradition endures, this shared and endorsed vision prevails. Once tradition fades, the landscape shifts. In the absence of tradition, reliance on accepted norms diminishes, and institutionalization begins (Keitumetse,2017). Conlon (2008) underscores the importance of documentation as a form of representation, aiming to bridge the gap between various stakeholders while serving as a historical record. According to Ghaffarian and Dahlan (2012) and Bekleyen et al. (1998), vernacular architecture's social, cultural, and heritage values are pivotal and require protection and preservation to uphold the diversity of each region's culture and humanity. Researchers widely assert that Vernacular architecture showcases unique architectural styles and inspires contemporary designs. Additionally, it provides solutions to various design challenges and offers strategies for modern development that promote environmental sustainability (Ghaffarian and Dahlan, 2012; Osasona, 2007; Rashid and Ara, 2015; Dayaratne, 2018; Hatamipour and Abedi, 2008; Soflaei et al., 2017; Foruzanmehr, 2015).

The neglect of maintenance has led to the deterioration of many historic earthen and traditional buildings, resulting in the loss of invaluable experiences, knowledge, and craftsmanship associated with these structures. To tackle this issue, developing a comprehensive plan for documenting heritage buildings using traditional materials and methods is crucial. Several studies have featured the importance of documentation as a catalyst for formulating preservation master plans. Notably, the emphasis on proper documentation before and after the preservation process of historic earthen structures has been predominantly observed in the Middle East, as well as in America, Europe, and Asia (Conlon and Jerome,2008; Talebian and Ebrahimi,2008; Vatandoust et al., 2008; Hadian et al., 2008). Conversely, African studies prioritize transferring skills through technical know-how and oral traditions to preserve tangible and intangible cultural heritage, which are at risk of being lost or forgotten (Ogege,2008; Shehata et al.,2015; Van Vuuren, 2008).

There is an urgent need for thorough investigation and documentation of the impact of building fabric designs on human thermal comfort. According to Nguyen and Reiter (2017), vernacular architecture embodies design principles that facilitate adaptability to local climate and nature when applied to traditional buildings worldwide. Moreover, Vernacular architecture is credited with inspiring bioclimatic designs incorporating a specific location's environmental, cultural, technological, and historical context. While extensive research has been conducted on thermal comfort in traditional buildings and vernacular architecture in various regions across the globe, there has been limited focus on African countries, including Nigeria, despite the significant issue of thermal discomfort in the tropical region. Nguyen et al. (2019) emphasized the lack of research on vernacular architecture in certain parts of the world, including large areas of Africa, North and South America, and some parts of Asia and Europe. More scientific research studies are needed from regions such as Africa to address these gaps and contribute to a global understanding of vernacular architecture. Furthermore, there is a lack of technical and scientific knowledge for evaluating buildings in Nigeria. Many building industry professionals may lack comprehensive knowledge for assessing buildings using simulations and other thermal comfort parameters. This is evident from the limited research papers on thermal comfort in the context of building performance in Nigeria and the underutilization of simulation technology by field architects. Therefore, there is a clear knowledge gap that requires attention from scholars. A solution was provided to address this limitation by evaluating the thermal performance of traditional building forms through experimentation and simulation. This was done to test the effectiveness of passive construction strategies and develop a maintenance framework for sustainability.

Nigeria has many remarkable and fascinating earthen heritage buildings that have yet to be explored and recognised nationally and internationally. Conservation policy initiatives are therefore needed to safeguard these buildings from destruction or extinction. Several international bodies have established heritage conservation guidelines, codes, and criteria for countries to adhere to Osasona (2009) indicates that traditional heritage buildings are listed by the government for conservation and restoration for various purposes, such as tourism and the preservation of cultural heritage. However, Nigeria has not fully recognised the cultural and economic implications of the lack of political will to support policies governing its heritage buildings. According to Alonge (1994), the Nigerian government and researchers have grappled with the conservation policies of historic monuments and sites for several years. As far back as 1979, the Nigerian government enacted laws to list and schedule monuments and sites for conservation and preservation.

Despite the awareness and availability of these laws, the lack of enforcement from the national to the local level has led to underutilization.

Ahmad (2006) and Ahmed (2013) defined and analysed the scope of tangible and intangible heritage. There are various conservation and preservation guidelines worldwide in the form of charters, recommendations, solutions, and guidelines established and adopted by international organizations such as the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Council on Monuments and Sites (ICOMOS) to protect cultural property globally. The most significant guideline highlighted is the Venice Charter 1964 (International Charter for the Conservation and Restoration of Monuments and Sites), which marked a milestone for architectural conservation and restoration principles.

Based on the research reviewed, countries in Asia, the Middle East, Europe, America, and a few in Africa have adhered to ICOMOS and UNESCO policy templates on the conservation and preservation of tangible and intangible cultural heritage. As a result, they have been recognized and financed by international organizations to achieve the conservation of monuments and sites. When a nation provides and enforces policies or creates guidelines on the preservation and conservation of earthen buildings and historic cultural property, all stakeholders will abide by and respect the law, leading to much conservation collaboration being achieved. However, this is not the case in Nigeria. For example, Mali is well known for its earthen buildings but lacks strict rules on the use of adobe and rigid conservation policies. Despite this, the preservation and conservation of traditional buildings are achieved due to the transferable local knowledge and skills passed down through generations, as well as the Malian masons' sense of responsibility for conserving and preserving tradition. According to Marchand (2008), Djene Masons has an association with its senior members to direct meetings and supervise collaborative events such as the annual plastering of the town’s monumental mosque. Moreover, each household in Djene has contractual ties with a specific group of masons that continue from generation to generation. Similarly, the United Kingdom's conservation law recognizes public participation in heritage conservation practices, defining public participation as information provided by the local planning authority and an opportunity to comment on that information, a significant part of the participation process but not the whole story. Participation involves doing as well as talking, and there will be full participation only where the public can actively participate throughout the plan (Healy, 1998; Dian and Abdullah, 2013). It is imperative to have policies that can encourage more researchers to collaborate and participate in Nigeria's conservation of heritage buildings. This can be achieved through various methods outlined in the literature. For instance, Hirsenberger et al. (2019) provided valuable insights for current and future practitioners in collaborative cultural heritage conservation projects. Siravo et al. (2008) offered lessons learned and achievements from their collaboration on joint conservation activities in Mopti and Timbuktu. Additionally, Elnokaly and Elseragy (2013) emphasized the importance of integrating economic, social, and cultural sustainability into conservation policies and practices.

In conclusion, any of these methods can help safeguard historic buildings in countries like Nigeria. This country lacks conservation, maintenance, and thermal comfort policy guidelines as outlined in National Building Codes (NBC) and Building Energy Efficiency (BEE) documents. Implementing these methods can effectively intervene in the preservation of cultural property. This limitation was overcome by outlining a maintenance framework and utilizing parametric simulations to optimize building materials, with the goal of establishing cost-effective models that are accessible to community members. Additionally, it includes recommendations to enhance the nation's policy document for the built environment.

Research Aim and Objectives

This research investigates the suitability of traditional Ilorin adobe buildings in enhancing thermal comfort in warm-humid climates. This focus was established to help develop and outline guidelines to fill the gaps, update and create awareness on thermal comfort potentials, and recommend policy guidelines to improve and strengthen the preservation and conservation processes of historic adobe traditional buildings in Nigeria. To accomplish this, the following objectives were established:

i. To examine and characterize Ilorin adobe traditional buildings.

ii. To evaluate the thermal performance of traditional adobe buildings in Nigeria, using selected case study buildings in Ilorin for research.

iii. To determine the minimum thermal comfort conditions for occupancy in Ilorin adobe traditional residential buildings.

iv. To investigate the causes of deterioration in traditional Adobe building elements to provide maintenance and preservation solutions.

v. To develop and outline a maintenance framework accessible to the public and professionals in the built environment and integrate it into the nation's building policy documents.

Research Questions

The need to address the identified gaps in literature prompted the following research questions (RQ).

RQ1: How do traditional adobe buildings in Ilorin reflect the region's unique cultural, historical, and environmental factors?

RQ2: How do traditional adobe buildings in Ilorin, Nigeria, regulate indoor temperatures year-round, and what are the key architectural elements influencing their thermal performance?

RQ3: What are the minimum indoor temperature and humidity levels for thermal comfort in traditional adobe residential buildings in Ilorin?

RQ4: What causes the decay of traditional adobe building elements in Ilorin, and how can they be preserved?

RQ5: How can a maintenance framework for traditional Adobe buildings be developed for public and professional use and integrated into national building policies in Nigeria?

Novelty of Research

The novelty of this research lies in several aspects. The innovative study on quantifying the ability of traditional adobe residential buildings to provide thermal comfort in the warm, humid climate of Ilorin, Nigeria, offers a comprehensive framework and wide-ranging approach for the sustainable design, operation, maintenance, and improvement of traditional adobe buildings in Nigeria's warm, humid climate and the infrastructure in similar climatic conditions. This research is motivated by the need to preserve Ilorin's cultural heritage. The historic structures in the community are a physical representation of its history, values, and adaptation to the local environment. However, these structures are increasingly threatened by modern construction practices, urban development, and harsh weather conditions. There is an urgent need to document and preserve these heritage buildings to ensure that future generations can admire and learn from the traditional knowledge of maintaining them. It is also motivated by the importance of promoting sustainable building practices in our communities due to climate change and resource scarcity challenges. Traditional adobe buildings offer natural thermal regulation, keeping interiors cool. Understanding these benefits can encourage sustainable architectural practices that reduce energy consumption and carbon footprints. There is a desire to support local economies and artisans by promoting adobe buildings and traditional construction methods; using locally available materials can reduce building costs, making housing more affordable and creating economic opportunities within the community.

Simulated by other reasons, the research is believed to further contribute to the broader scientific understanding of vernacular architecture's role in promoting thermal comfort and energy efficiency studies in our nation's educational institutes. The data generated provides valuable insights for architects, urban planners, built environment allied professionals and policymakers. By offering guides on the advantages of traditional adobe construction, the research is believed to offer meaningful recommendations for informed policies and the development of regulations that will support sustainable urban planning and heritage conservation. The research focuses on quantifying the thermal comfort benefits of traditional adobe buildings, which is strongly believed to provide a strong case for their conservation and revival, demonstrating that these structures offer valuable solutions to contemporary challenges.

Firstly, the study presents a comprehensive analysis of the architectural characteristics and thermal performance of adobe buildings in Ilorin, marking the first documentation of its kind in the region. Through thorough fieldwork, it identifies and catalogues previously undocumented elements, including construction materials, wall thicknesses, layouts, window configurations, and cooling strategies. This research constitutes a significant advancement in the field, providing a foundational record that is critical for informing preservation, restoration, and conservation initiatives. Secondly, the research performs a context-specific evaluation and provides guidelines on thermal comfort and passive design techniques, taking into account the local climatic conditions and their effect on the performance of adobe buildings tailored to address challenges of thermal comfort and vernacular building maintenance of adobe traditional buildings in Nigeria's warm-humid climate. Thirdly, the study highlights and contributes valuable insights, such as understanding the vulnerability of traditional adobe buildings to overheating and dilapidation in Ilorin, Nigeria, particularly from the impact of climatic elements on the indoor thermal environment and the effects of different building envelope fabric properties. Fourthly, this research provides a record of a thorough one-year empirical data collection and analysis for three local government areas to enhance the reliability of findings from the simulation case studies and redefine the Standard Effective Temperature (SET) and comfort temperature thresholds for Adobe traditional buildings in the warm-humid climate zone of Nigeria. The study also provides deep insights into how the thermal performance of traditional Ilorin adobe buildings can be improved by incorporating various building materials without compromising their cultural integrity. This can be achieved by combining locally sourced materials and passive technology solutions such as building fabric, natural ventilation, and shading. Finally, this research establishes tailored information into a framework for effective maintenance practices and retrofitting measures, which can improve existing structures and support the sustainable development of adobe traditional buildings in warm-humid zones. This process aims to unify Nigeria’s building code and potentially influence future policies relating to building thermal performance design in vernacular buildings in Nigerian housing policy development.

Research Design

The conceptual framework illustrated in Figure 3-1 outlines the structural approach of the research project designed to evaluate and quantify the thermal performance of selected traditional Adobe case study buildings in a warm and humid climate.

This framework considers the local climate, the scope of the research, the types of case study buildings, the use of mixed methodology, and the assessment of building elements to achieve the desired objectives of building performance, maintenance, and compliance with minimum indoor environmental quality requirements.

Thesis structure

This section introduces the study context, provides background information, and identifies key issues and gaps in existing knowledge. The primary aim and objectives of the research are described, along with the justification for its relevance and significance. The research methodology is also outlined, highlighting the framework and strategies for data collection and analysis. The study's novelty is emphasized, showcasing its unique contributions. Finally, the thesis structure is described, offering a clear roadmap of the chapters to guide the reader through the research. This section lays a solid foundation for understanding the study's direction and purpose.

Chapter 1: This chapter emphasizes the diverse architectural styles of traditional buildings in Nigeria alongside an exploration of cultural and spiritual influences. Additionally, it delves into preservation techniques for local vernacular architectural typologies and preservation policies for heritage buildings. As part of this review, a journal paper entitled "Leveraging on building characteristics for optimizing preservation and thermal comfort strategies of Adobe traditional heritage buildings in Africa: a comparative analysis of Ilorin adobe Heritage (Adekeye et al., 2025 - expected) was prepared.

Chapter 2 This section offers a comprehensive review of Ilorin's climate conditions and historical background. The study thoroughly examines traditional building layouts, earth construction techniques, and heritage structures while considering thermal comfort. It proposes passive design strategies specifically adapted to Ilorin's warm and humid climate. Additionally, it provides targeted recommendations for naturally ventilated traditional buildings in the area. Furthermore, the research explores various thermal comfort models to determine the most applicable one for this study.

Chapter 3 outlines the research methods used to evaluate the thermal comfort of traditional adobe buildings in warm-humid climates, specifically in Ilorin, Nigeria. The study employed a mixed-method approach, combining quantitative methods such as field data collection and computer simulations with qualitative case studies and interviews to gain local insights. By identifying gaps in current practices, the research aims to develop guidelines for enhancing awareness of Adobe’s thermal potential and informing preservation strategies. Adhering to building regulations and ASHRAE standards, the goal is to provide policy recommendations for the sustainable conservation of traditional adobe architecture in Nigeria.

Chapter 4: This chapter presents the first stage of the core research. It focuses on the case study area of Ilorin, including traditional buildings with historical significance. It evaluates and compares the selected structures with traditional buildings. Architectural data is used to evaluate the performance of existing building envelopes in terms of heat transfer and solar gains. The thermal properties of the building envelope are used to identify the main parameters that influence the building fabric performance by exploring them in the parametric study and approach to gain a greater understanding of the common architectural characteristics defining typical Ilorin traditional adobe building/ domestic compound and also to inform the design. In addition, the base case study will be formed to understand the significant challenges, opportunities, and novel approaches being developed and deployed. Two papers entitled "Investigating Thermal Comfort in Traditional Adobe Buildings in Warm-Humid Climates: A Case Study of Ilorin Heritage Buildings in Nigeria"(Adekeye et al., 2023 – published at the SET 2023 conference proceedings) and “Leveraging on building characteristics for optimizing preservation and thermal comfort strategies of adobe traditional heritage buildings in Africa: a comparative analysis of Ilorin adobe heritage” (Adekeye et al., 2024 – anticipated) was written as a result of this analysis.

Chapter 5: This chapter outlines the second stage of core research, which investigates the occupants' perceptions and thoroughly examines their thermal comfort within selected adobe traditional buildings in Ilorin. It adopts a subjective approach to assessing thermal comfort in these residential buildings in a warm, humid climate. A mixed-methods approach was utilized to gather data on environmental and human parameters. This included a field survey to understand users' perceptions of thermal comfort, indoor environmental measurements, and a post-occupancy evaluation conducted by administering and analysing questionnaires.

Chapter 6: This chapter explores the third stage of core research, focusing on the instrumentation and environmental monitoring processes utilized to establish new Standard Effective Temperature (SET) and comfort temperature benchmarks for the reference building in this study. It presents validations and simulation results grounded in the discussions from Chapters 4 and 5, incorporating detailed computer-based dynamic simulations. Selected traditional adobe structures were examined to assess the impact of ventilation and daylighting design strategies on thermal performance, as well as the thermal and visual comfort of occupants. Additionally, a paper titled “The Impact of Courtyards and Window Designs on Thermal and Visual Comfort Conditions in Adobe Traditional Buildings” was presented at the SET 2023 conference as part of this review.

Chapter 7: This section gives insight into the parametric study stage, drawing upon the field study results discussed in chapters 4, 5, and 6.

This phase involves conducting a series of specific thermal simulations to understand the simulation assessment process and the results of a parametric evaluation to enhance naturally ventilated single-detached traditional Adobe buildings. The selected model is based on the building envelope characteristics of typical Ilorin Adobe traditional buildings constructed around 1800, which serve as domestic residential buildings for prominent district heads. Utilizing a computer-based dynamic simulation tool known as the Integrated Environmental Solution (IES-ve) aligns with the methodology used by ASHRAE and CIBSE guidelines. The section evaluated the impact of passive design strategies, envelope fabric, sun cast, thermal mass, solar heat gain, ventilation, and shading on the occupant's thermal performance, comfort tests, and analysis. The solar heat gain and optimized adobe traditional building were derived from the simulation results.

Chapter 8: This chapter evaluates the feasibility and cost-effectiveness of enhancing traditional adobe buildings to achieve thermal comfort, performance, and durability in warm-humid climates. It emphasizes the importance of preserving the building fabric to maintain the comfort, cultural significance, affordability, and practicality of traditional heritage buildings for their occupants. This section presents a framework for maintenance, comfort, affordability, and relevance in conserving essential heritage buildings.

Chapter 9: This chapter outlines the research conclusions and recommendations on the evaluation of an optimized traditional adobe building, emphasizing the use of passive strategies and suitable building materials. These suggestions aim to be integrated into the national policy document, specifically the NNBC and BEE, to establish minimum standards for indoor thermal comfort and energy efficiency in building regulations. Furthermore, the report recognizes the limitations of the current study and identifies potential areas for future research.

Research Methodology:

The research methodology employed in this study is characterized as mixed-methods research. This approach integrates qualitative and quantitative data to address the research questions and effectively meet the objectives. By synthesizing these distinct data types, the study aims to understand the phenomena under investigation comprehensively.

Qualitative Methodology:

Qualitative research involves a naturalistic approach to thoroughly understanding social phenomena within their natural setting. This methodology focuses on uncovering the underlying reasons behind social phenomena, emphasizing individuals' experiences as they make sense of their daily lives. Rather than relying solely on logic and statistics, qualitative researchers utilise various approaches, including biography, case study, historical analysis, discourse analysis, ethnography, grounded theory, and phenomenology. Martinez et al. (2022) indicate that qualitative research includes subjective assessment and analysis of occupants' thermal satisfaction through questionnaires and interviews. The study involved distributing thermal comfort questionnaires to occupants and analysing the survey data to assess thermal sensation votes (TSV) and predicted mean votes (PMV), as well as the potential of traditional buildings to provide comfort. Following an adaptive methodology, the study also analysed thermal comfort variables related to occupants' expectations and clothing levels when the building was occupied.

Quantitative Methodology:

Quantitative methodology is the predominant research framework in the sciences. It requires measurement and instrumentation and uses natural science methods to produce numerical data and concrete facts. Its primary objective is to establish cause-and-effect relationships between variables using mathematical, computational, and statistical methods (Ahmad et al., 2019).

Social sciences encompass strategies, techniques, and assumptions used to analyse psychological, social, and economic processes by exploring numeric patterns. Quantitative research involves gathering a wide range of numeric data. For example, a study evaluating users' comfort in a building collected data on indoor and outdoor environmental conditions using measurement, simulation, and instrumentation. Simultaneously, qualitative data collection processes were also conducted. Actual measurements and thermal occupant satisfaction surveys were employed during the cooling season (February to April). The tools used for quantitative data collection included Building Information Management (BIM) software such as Revit, AutoCAD, and ArchiCAD, as well as online analysis software like Andrew Mash and Optivent 2.1 version. Parametric/Simulation software IES-VE was also utilised for thermal comfort and energy analysis. The Tiny Tag data logger collected indoor and outdoor variables such as temperature, humidity, and wind velocity. Table 0-1 shows the methodology, Objectives and data

Chapter 1: Political Context and Vernacular Architecture in Nigeria

An overview of the history of Nigeria, ethnic groups, and vernacular architecture demonstrates that Nigeria is a multi-ethnic and culturally diverse federation comprising 36 autonomous states and the federal capital territory. As a country, Nigeria has a multi-cultural and multi-faith population. It is a nation with over 500 languages and hundreds of ethnic groups, such as the Hausa, Yoruba, and Igbo (Ikime, 1982). Although social diversity is a considerable strength of Nigeria, it has led to some regional conflicts (Collins,2024). The analysis of the historical development of the Nigerian state started in 1914. This year is significant in Nigeria because it is the official birthday of Nigeria when Lord Lugard effected the amalgamation of the Protectorate of Northern Nigeria Colony and Protectorate of Southern Nigeria, previously administered as separate though related territories (Ojo, 2014). Despite Nigeria’s complex ethnolinguistic and religious diversity, Nigeria is globally significant for many reasons, including its political resilience. Paden (2008) argues that despite the diversity in religion, which is primarily Muslim and Christian, Nigeria could serve as a unique model for interreligious and political accommodation and as a bridging actor in the world of politics between the West and the Muslim world. Umaru (2013) has it that the mismanagement of this diversity undoubtedly has limited Nigeria's ability to foster harmony in development, as the political scene has been replete with ethnic rivalry since independence.

Nigeria's economic impact is hinged on oil, which accounts for over 80% of exports. It is interesting to note that oil prices are a determining factor in non-oil industries and services. Nigeria is faced with the problem of unemployment and underemployment, which greatly affects poor households and increases the share of the population at risk of falling into poverty. Agriculture has immensely contributed to her growth (World Bank,2021). Sen (1999) thinks that material output measures like Gross National

Income (GNI) per capita should not be a measure of the growth of a country; rather, growth should be measured based on available opportunities for the people to enjoy. On the other hand, North (2005) opined that institutional factors that support political, economic, social, and other human/social capital in a way that creates national wealth are the best way to measure economic development, as a country is said to be economically developed when the is corresponding in the quality of life of her citizens.

1.1 Ethnicity in Nigeria

Modern Nigeria dates far back from 1914 when the British Protectorate of Northern and Southern Nigeria were joined. Nigeria became independent on the 1st of October 1960 and became a republic in 1963 (Ajayi, 1998). The name Nigeria was suggested by British Journalist Flora Shaw in the 1890s, after the Niger River. The word Niger is a Latin word meaning Black. Nigeria is the most populous country in Africa, which is bordered to the North by the Niger Republic, to the East by Chad and Cameroon, to the South by the Gulf of Guinea of the Atlantic Ocean, and to the West by the Benin Republic. Nigeria covers an area of 356,669 square miles (923,768 square kilometres). The Niger and Benue Rivers come together in the centre of the country, creating a "Y" that divides Nigeria into three separate sections. This "Y" marks the boundaries of the three major ethnic groups: the Hausa in the North, the Yoruba in the Southwest, and the Igbo in the Southeast. See Figure 1-1. Nigeria is a multinational state with diverse ethnicities, the majority of which are the Hausa/Fulani, Igbo, and Yoruba, as illustrated in Appendix I. These ethnic groups share different cultures and are blessed with over 500 languages. The coming together of the ethnic groups in Nigeria under the commonly felt sense of national identity was a result of the spread of overt colonial control. This was when the people began to see themselves not as Hausas, Igbos, or Yorubas but as Nigerians in a common struggle against their colonial rulers. The coming together of the different ethnic groups to form a single entity known as Nigeria today resulted from British colonization (Ikime, 1982). Before the British consolidated their colonial power over Nigeria in 1914, which gave birth to the creation of the borders of Nigeria, there was archaeological evidence that different societies lived in Nigeria for more than twenty-five hundred years (Countries and their culture). Nigerian architecture is a reflection of the diversity of the Nigerian people (Owhonda, 1988). Most of the houses in rural areas are designed in such a way as to accommodate the environment in which the people live (Maier,2000; Forman,1972). For instance, in the North, most of the architecture is influenced by Islamic culture. The Muslims are found in all parts of Nigeria, though mainly among the Hausa and Yoruba. Christianity is most prevalent in the South of Nigeria. Most Igbo are Christians, as are many Yorubas. Detailed descriptions of distinct architectural typologies are discussed in Section 1.2.

Figure 1-1: Map of Nigeria showing her borders. (Source: Encyclopedia Britannica,Inc.)

1.2 Vernacular Architecture in Nigeria.

Traditional adobe buildings are found worldwide and can be seen in parts of Africa, Asia, the Middle East, North and South America, and Europe. Earth is a universal building material (Akinkunmi, 2016). According to Agboola and Zango (2014), traditional architecture developed from cultural practices; the buildings depict cultural identity and are characterized by local materials and knowledge. As discussed in the previous section, Nigeria has three major ethnic groups: Hausa, Ibo, and Yoruba. Each has a distinct material culture and architectural style that reflects its unique needs. Reviewing traditional Nigerian buildings highlights these cultural differences in design concepts and construction practices. These findings are illustrated in Table 1-1, which also identifies various preservation techniques used in Nigeria to maintain and protect these traditional structures. Figure 1-1 further provides a visual representation of the ethnic borders, offering geographical context for understanding the distribution of these groups and their architectural influences. Adekeye (2013) highlights the influences on Nigerian traditional architecture, including ethnicity, religion, cultural practices, the Sahara trade link, the slave trade, and colonisation, which brought about Western civilisation.

1.2.1 Hausa Ethnic Group

The Hausas represent one of the three major ethnic groups in Nigeria and are also the largest in the country (Arenibafo, 2017). They are not only the predominant ethnic group in West Africa but also exert significant influence. The Hausa language, spoken by as many as fifty million people, is the dominant lingua franca in West Africa (Coles & Mack, 1991). They are found predominantly in the Northern region of Nigeria, this region experiences a hot, dry climate with extreme diurnal temperatures. The Hausa community is bound together by a common language and the Islamic faith, which heavily influences many aspects of their daily life and culture, including clothing, social interactions, and architectural styles (Agboola and Zango, 2014). According to Danja et al. (2017), the architecture of the Hausa community is considered one of the most captivating yet least explored. Their early mosques and palaces are distinguished by vibrant colours, intricate engravings, and elaborate symbols adorning the facades. These traditional structures, which vary in shape and size, feature unique elements that set them apart from other architectural styles. Notably, these include the decorative engravings on the building walls and using indigenous materials such as mud, reeds, stones, and timber for construction. This distinctive architectural style, referred to as "*Tubali"* in the Hausa language and recognized globally as vernacular architecture, is unique to Northern Nigeria. Numerous researchers have emphasized the unique features of Hausa building technology, which involves using "*tubali"* (pear-shaped mud bricks) laid in mud mortar for walls, the mud is also mixed with water and chopped straw (Adekeye et al., 2020; Agboola & Zango, 2014; Dmochowski, 1990; and Moughtin, 1985). Denyer (1978) describes the building form types as rectangular, square, and round. Rectangular houses feature mud vaults, while round and square buildings are dome-shaped. Flat mud roofs, like the Djenne roof, cover the buildings. The walls have a few small openings believed to keep out dust, minimize sun heat and glare, and act as thermal insulators. Men are responsible for the construction of the entire building and decorative work on the walls, while women handle the floor finishing. (Denyer, 1978; Moughtin, 1985; Dmochowski, 1990; Odiaua, 2008; and Lodson, 2018).

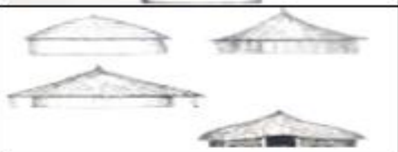
1.2.2 Yoruba Ethnic Group

The Yoruba people are predominantly situated in the Southwest region of Nigeria. Historically, they established large urban communities prior to the onset of colonization (Eades, 1980). The Yoruba are highly regarded for their artistic contributions, particularly in bronze casting, terracotta, and wood sculpting. Additionally, most of the Yoruba population has embraced Christianity as a significant aspect of their cultural identity. According to Fadipe (1991), The Yorubas constitute the second largest ethnic group in Nigeria, following the Hausas. Their rich cultural heritage and diverse traditions significantly influence the nation's identity and social structure. The traditional architecture of the Yoruba in West Africa remains consistent across the geographical spread (Adedokun, 2014). The Yoruba populace predominates the hot-humid forest region in Western Nigeria. According to Denyer (1978), the Yoruba states fall under the forest zone of West Africa. Notably, the key features of Yoruba towns are the Oba's palace and the central market, situated side by side at the centre of the town. Yoruba towns showcase their culture through various types of house forms. The Yoruba people are well-regarded for their highly organized traditional and social groupings (Osasona,2005). Sonaiya (2008) classifies traditional Yoruba house types into two categories: Urban houses (courtyard houses with interior and exterior verandas) and Rural Houses (unit houses, single or multiple units, and row houses; simple rows or rows with sides); examples are seen in Ilorin adobe buildings. See Appendix II. Gugler and Flanagan (1978) observed that compounds were the most crucial elements in traditional Yoruba towns. The thick mud walls were composed of swish-puddled mud, and the pillars were reinforced with carved wooden posts, as shown in Table 1-1. Building construction usually occurs predominantly in the dry season to expedite dryness and curing (Auwalu, 2019). Moreover, small windows were integrated into the thick adobe walls, and sloping roofs with eave overhangs were constructed to collect water in large pots placed in the courtyard. The roofs were made of palm leaf mats, bamboo rafters, or other termite-resistant timber with thatched roof construction. Also, room sizes were standardized based on a module of 10 feet (Denyer, 1978 and Osasona, 2007). Courtyards serve as a defining architectural element of the traditional houses within Yoruba cities, embodying a distinctive house form that reflects cultural and functional significance. The courtyard house is characterized by its inward orientation, featuring small rooms encircling a central open space, known as the impluvium, or a series of interconnected courtyards (Denyer, 1978). This architectural typology is prevalent in urban Yoruba environments, where such designs are recognized as 'court or compound houses.' These structures typically consist of one or more courtyards that facilitate various rectilinear spatial arrangements, promoting interaction and communal living while also providing an intimate setting that highlights the cultural practices of the Yoruba people. (Sonaiya and Dincyurek, 2009; Vlach, 1984; Osasona, 2005; Akinsemoyin et al., 2009; Marafatto, 1983; Dmochowski, 1990).

1.2.3 Igbo Ethnic group

The Igbo people are a prominent ethnic group in Nigeria, residing primarily in the southeastern part of the country and speaking the Igbo language. They are recognized for their industrious nature and involvement in diverse commercial activities (Chukwu, 2015). In rural areas, the Igbo primarily engage in craftsmanship, farming, and trade. Their traditional buildings are situated in the warm, humid tropics of the South-eastern region. According to Chukwu (2015), Igbo architecture integrates spiritual, cultural, and lifestyle values. Their architectural designs express and represent society, religious and communal life traits. A typical Igbo family compound comprises several huts or buildings, each designated for a specific purpose. The number of structures is determined by the head of the family's wives and children. Prior to the advent of Christianity, polygamy was a common practice, and having many wives and children served as a symbol of wealth and power (Lodson, 2018). The main feature of Igbo traditional buildings is the central placement of the principal building within a large square compound. The entrance is through a covered porch, and the compounds are surrounded by an adobe wall with a single entrance gateway (Denyer, 1978). According to Okoye (2001), the entrance gateway reflects the status and power of the family and the significance of the compound head, often communicated through elaborate carvings or designs. The Igbos primarily used clay for adobe walls to regulate indoor and outdoor temperatures in warm-humid conditions areas of South-eastern Nigeria. The construction techniques employed incorporated natural materials such as grass and bamboo, effectively tailored to the prevailing local climatic conditions. The walls were constructed using a mixture of puddled mud, which was sometimes supplemented with lashed palm ribs for structural reinforcement. The finishing of the floors involved a polished layer of mud, with some instances featuring decorative elements created by inset palm nuts (Denyer). 1978:74). Nsude (1987) suggests that the steeply pitched roofs were a response to the tropical rainfall in the region. The roofs were thatched with palm leaf fronds and grasses, which were readily available. There were two basic types of building forms, as described by Lodson (2018) and Nwalusi et al. (2019). The first was the circular house, usually roofed with a conical thatched roof. In contrast, the second type featured either rectangular buildings with hipped roofs, as noted by Lodson (2018), or square walls and a pyramidal roof with low eaves, as described by Nwalusi et al. (2019) as illustrated in Table 1-1.

Table 1-1:Schematics of typical traditional house forms in Nigeria (Denyer,1978)

Location	House form	Description	Elevation	Materials
Northern Nigeria (Hausa)	Round plan	The detached unit, with a height greater than its width.		mud, stone, conical thatch roof
Western Nigeria (Yoruba)	Round plan	Detached unit with a width equal to or greater than the height of the building.		mud, bamboo, palm fronds with verandah arranged in multiple units,
Southern Nigeria (Ibo)	Square plan	Detached unit with mud walls and conical roof.		Mud, Palm fronds, thatch roof and reeds, palm leaf mats, bark, and stilts
Southern Nigeria (Ibo)	Rectangular plan	Detached unit with cane walls and thatch roof		Wood planks, bamboo, cane, palm fronds, and reeds for thatch roof
Western Nigeria (Yoruba)	Rectangular plan	Thatched roofed mud units built around courtyards		Mud walls, thatch
Northern and Southern /Eastern Nigeria (Hausa and Ibo)	Rectangular plan	A detached row of decorated mud-walled buildings across a small courtyard.		Mud, wattle framework.
Northern Nigeria (Hausa)	Rectangular plan	Mudbrick walls with flat mud roofs or vaults reinforced with wood. Bungalow or two-storey		Mud, wood, and palm fronds.

1.3 Preservation Techniques Used in Nigeria

i. The Northern part of Nigeria

Denyer (1978) and Dmochowski (1990) made notes of observations on preservation techniques used in Hausa traditional buildings, as the mixture of straw and mud with potash from dye pits or an infusion of locust-bean pods and for the wealthy, mimosa imported from Egypt. Denyar (1978) also noted that the preservation technique carried out on the Hausa minaret, Gobirau in Katsina, which prevented the adobe wall from deteriorating or decaying for about 120 years, is attributed to the strength of the walls made from a mixture of mud with vegetable butter (katse) and cow blood.

ii. The Western part of Nigeria

Denyer (1978) similarly discusses various preservation techniques for Yoruba traditional buildings found in the forest region of the country. She notes that mud walls were regularly "washed" to create a hard, glossy finish. New walls were initially smoothed with half a coconut shell and subsequently washed with a liquid mixture of rich red earth, applied using a load of rotten bananas. Additionally, alternative methods for smoothing the walls included using a mixture of mashed leaves from the oilseed tree and stain derived from locust beans. Yoruba traditional houses are ingeniously designed to capture rainwater, guiding it from the leaf and thatched roof corners into large pots situated in the courtyards. This method effectively protects the walls from water damage. Denyer (1978) provided further insight into how the walls of Yoruba palaces were preserved using a mixture of peddled mud and palm oil, in addition to water. Furthermore, Adekeye (2013) noted the practice of using cow dung to plaster internal walls and floors, as it is believed to be an effective insect repellant in Yoruba traditional architecture.

iii. The Southern part of Nigeria

Nsude (1987) argues that cow dung is a plastering material on Igbo traditional buildings. This gives the walls a dull greenish colour that is more pleasing to the eye than the natural earthen colour. Cow dung also has better waterproofing qualities than ordinary mud. Igbos also practised the art of surface decoration in their buildings, which was also a preservation strategy.

1.4 Multicultural and Spiritual Influences on Nigerian Traditional Architecture

Traditional buildings in Nigeria are intricately linked to the availability of natural materials, the craftsmanship of local builders, and various religious beliefs. The onset of colonialism had a profound effect on traditional life and culture in the country (Oluwagbemiga & Modi, 2014). Each region of Nigeria features unique traditional building designs that are tailored to its specific climate and cultural context. For example, the traditional building style in Ilorin exhibits a distinct character and identity. To maintain the integrity of traditional buildings, it is vital to consider individuals' health, well-being, and spiritual needs (Massoudi et al., 1978). Security is another essential factor that influences whether buildings are arranged, dispersed, or clustered (Oluwagbemiga and Modi, 2014). According to Rikko and Qwatau (2011), traditional buildings serve as carriers of cultural heritage, passed down through generations, and must reflect the cultural lifestyles of the local communities. Therefore, the importance of traditional building designs in meeting material, spiritual, and cultural needs cannot be overstated (Ibrahim et al., 2024; Olotuah, 2001). Similarly, Imaah (2008) argues that walls indicate thermal and environmental conditions, a concept supported by building science. This concept highlights the use of local builders and materials such as timber and tempered clay. While modern designs that utilize contemporary materials can be expensive, traditional building materials offer a more cost-effective solution, benefiting from the availability of local resources and the skills of local builders (Agyekum et al., 2020; Opoko, 2001).

It is undisputable that traditional architectural expressions in Nigeria have evolved over time. Tradition and culture are not static but constantly evolve through interaction with external influences. Roenisch (2000) supported the idea that traditional buildings continuously evolve. According to Mamudu (2021) and Hardy (2003), traditional buildings in Nigeria have undergone significant changes due to factors such as trade, colonialism, industrialization, globalization, and the return of slaves. Religion, especially Christianity and Islam, also played a significant role as many traditional buildings were considered mystical and fetish, leading converts to disassociate from them. Modernization has significantly impacted traditional architecture, as highlighted by Oluwagbemiga and Modi (2014Fatiregun (1999) highlighted that modernization has brought about significant changes in recent years, with varied manifestations. He noted that modern policies and facilities have led to the following outcomes:

i. The abandonment of old traditional buildings and villages in favor of new state settlements and towns.

ii. The disruption and fragmentation of long-standing extended family bonds, which has resulted in increased personal freedom and smaller family sizes.

iii. The disappearance of large family compounds, replaced by new smaller nuclear family units.

Additionally, the introduction of modern materials and technology has resulted in changes to the physical appearance of traditional buildings. There has been a shift away from traditionally moulded decorations on clay walls in favour of modern paints. The traditional thatch roofs have been replaced with corrugated iron sheets, leading to the adoption of rectilinear designs instead of curved forms. Adeyemi (2008) and Zemanek (2016) supported that these traditional buildings now serve only aesthetic purposes because they have lost their spiritual and cultural flavor. From this standpoint, it is evident that change is permanent, even in architecture and how it is expressed. Though it is impossible to turn back the hand of time, examining and pondering how these changes occur critically is necessary. Traditional buildings should reflect the people's tradition, culture, and lifestyle. This fact is shared by many scholars (Adeyemi, 2008; Zemanek 2016); “It will be a great tragedy and a colossal loss if our traditional building styles and construction process disappear from the continent. “The benefits derived from our indigenous methods and materials were enormous and needed to be propagated, while any inadequacy associated with the traditional approach could be modified” (Oluwagbemiga and Modi, 2014).

1.4.1 Preserving Traditional Buildings: Heritage and Sustainability

The importance of preserving traditional buildings cannot be overstated, as it plays a vital role in passing cultural identity on to future generations (Misirlisoy, 2016). Franco (2017) states traditional structures are significant to every nation because they provide insights into the past and serve as valuable resources for future generations. Karakul (2015) asserts that the primary goal of preserving these buildings is to ensure the sustainability of both their physical and intangible aspects, allowing their legacy to be passed down. To achieve this, effective strategies are essential for maintaining and transmitting the rich diversity of traditional architecture to subsequent generations. Zavadskas and Antucheviciene (2007) argue that preserving and renovating traditional buildings is a more sustainable option than demolishing them to make way for new constructions, as local materials are often readily available, thereby minimizing both costs and environmental impact.

Figure 1-2: Building External preservation of rethatch roof and external decoration on the wall

Preservation techniques can be carried out in different ways. For instance, buildings in Figure 1-2 demonstrate little preservation initiative on the roof and paintings/ decoration on doorways of the Ilorin traditional buildings. Preservation focuses on stabilization, repairing traditional materials, and retaining the property's form over time (WBDG Historic Preservation Subcommittee). Preserving traditional buildings is essential for understanding our nation's heritage. These structures are often energy efficient due to their durable local materials and effective ventilation. Additionally, traditional buildings have the benefit of already existing, which means there is no need to expend energy on demolition or the production of new building materials. Sekularac et al. (2020) opined that when these traditional buildings are continuously observed, they are likely to see possible changes and defects and, by so doing, prevent irreparable damages. In the same vein Vador (2012), Roy and Chowdhury (2013), and Akinkunmi (2015) all contribute to the discussion. highlighting the significant challenges faced by traditional housing. These challenges include water penetration, erosion of walls due to water splashes from the underground surface, attacks by termites and pests, and the need for preservation. Additionally, traditional buildings inevitably experience depreciation over time, primarily due to the materials used in their construction, which are negatively affected by sunlight, rain, and wind (Donnelly, 2007).

1.4.2 Causes of Traditional Building Extinctions

Traditional buildings in Nigeria come in various forms, with the construction materials used often determined by the geographical location of each area. Commonly employed materials include adobe, straw bales, clay, bamboo, thatch, stone, timber, sheep wool, and coconut. These traditional materials have significant economic advantages compared to imported or retrofitted options. In northern Nigeria, for example, timber and bamboo, along with local construction techniques, are predominantly used for residential apartments (Muazu et al., 2017). Recently, there has been a notable increase in the adoption of modern construction techniques and a growing interest in both natural and conventional building materials. It is clear that traditional materials offer a cost-effective solution for construction due to their availability. The construction process utilizing these materials is generally simpler, incurs lower transportation costs, and places fewer economic demands on builders. Therefore, it is essential to explore the reasons behind the decline of traditional buildings, which are vital reflections of the culture and lifestyle of the communities that built them. Armilia Riza et al. (2019) argued that a primary factor contributing to the extinction of traditional buildings is the shifting perspectives of people. They suggest that following colonization, which brought about modernization, Nigerians began to adopt Western lifestyles and attitudes, leading to a perception that African culture was inferior to these new, modern ways of thinking. Adesina (2005) asserts that "with the condemnation of everything African and the introduction of everything European," culture and traditional buildings which reflect the historical activities and achievements of a community face the risk of extinction, despite their inherent value.

On the other hand, many traditional buildings have become commercialized due to the growing demand for cultural tourism. Commercializing sacred sites challenges their spiritual significance and diminishes their cultural value. Wall and Mathieson (2016) warned that the traditional importance that initially made these buildings famous is being eroded as many tourists visit them. Similarly, the rise of foreign religions has significantly de-emphasized the value of traditional beliefs. Jolaoso (2015) noted that many converts to these foreign religions had been persuaded to view traditional beliefs often derogatorily labelled as paganism, idolatry, heathenism, and fetishism as inferior. Historically, houses of worship represented the pinnacle of human architecture, designed according to the criteria and principles of the created world. Furthermore, recent technological advancements in transportation, production, and construction have impacted traditional cities, creating challenges for adaptation. The globalization process does not help matters in its quest for producing a change in values and attitudes that is affecting traditional ways of doing things and putting heritage resources under pressure. Furthermore, the impact of Climate change has been the fundamental problem of traditional building designs of our time. Not style, cost, education, community, health or justice. All other concerns, as profoundly important as they may be, are nonetheless secondary. Cramer (2017) reiterated that Climate change is the fundamental design problem of our time. The threat climate change poses is existential, and buildings are hugely complicit.

War has almost always been accompanied by the destruction of traditional resources, including buildings. Typical conflicts result in the loss of life and the devastation of homes. Unfortunately, Nigeria has experienced significant cultural and traditional loss in recent years. Much of the country's traditional heritage has been lost due to communal and ethnic conflicts. Additionally, religious extremism has had a detrimental impact, leading to the deliberate burning and destruction of monuments, shrines, and sacred sites deemed offensive by the adherents of emerging belief systems. Notable conflicts include the Nigeria Civil War (1967–1970), the Niger Delta Crisis, the Jos religious crisis, and the ongoing Boko Haram insurgency. The consequences of these crises have resulted in tragic stories related to both the tangible and intangible aspects of Nigeria's cultural heritage (Abara, 2017). Refer to Figures 1-3,1-4 and 1-5 for images of destroyed traditional buildings.

Figure 1-3:(A) Burnt and destroyed Sukur hilltop compound. Source: World magazine

Figure 1-4: (B) Burnt adobe walled church in Adamawa state. Source Christiantoday.com

Figure 1-5: (C) Destroyed mud wall School in Hawul local government area.

1.3.3 Barriers to Preservation/Restoration/ Maintenance.

As a colonized territory and developing nation, Nigeria is enriched with tangible and intangible heritage, encompassing historic buildings in rural and urban settings from pre-colonial and post-colonial eras. These heritage resources possess significant beauty and cultural value and serve as vital assets in tourism. Visitors seeking to immerse themselves in tradition, history, and cultural landmarks are often captivated by their distinctiveness. This exercise greatly benefits the nation's political, economic, and social systems. Consequently, it is no contradiction that heritage resources play an important role in any nation and, as such, should be preserved, maintained, and restored in cases of extinction (Ezenagu, 2020). Nations have experienced significant growth in art and tourism through their cultural heritage resources. This growth has attracted tourists and foreign investors to regions and countries rich in these resources. Heritage resources and tourism enhance each other: while heritage sites promote tourism development, tourism also plays a vital role in showcasing and preserving the cultural heritage of a community (Ezenagu & Iwuagwu, 2016). Comer (2012) emphasized that tourism at heritage sites helps tourists understand past and present cultures and brings economic and social benefits to the local population. However, several barriers hinder these traditional heritage resources' preservation, restoration, and maintenance, summarised in Table 1-2 below.

Table 1-2:Summary of Traditional Heritage Buildings Interventions.

Barriers	Description
Environmental	Economic pressure
	Building location
	Building condition
	Business opportunity
	Third party influence
Organizational	Opposition conservation philosophies
	Confusing laws and guidelines
	Lack of standard method of conservation
Human	Poor communication
	Stringent bylaws requirement Poor knowledge
Technical	Poor financial support
	Shortage of materials and labour
Financing	Lack of funding opportunities

1.5 Heritage Building Classifications and Scope: To address the Physical, Social, Environmental, Economic, and Historical Value

The classification of heritage buildings varies widely across different literature and organizations, leading to inconsistencies. Various factors such as age, environment, and architectural features are considered, highlighting the need for a standardized approach to define heritage buildings. Heritage encompasses buildings, structures, artefacts, and areas of historical, aesthetic, and architectural significance. Key considerations for determining heritage status include historical importance, integrity, and context. The concept of heritage has broadened to include individual buildings and sites, clusters of buildings, historic areas, towns, environmental aspects, social influences, and recent intangible heritage. UNESCO and ICOMOS recommend using the term "cultural heritage" to encompass cultural and natural heritage. Heritage buildings are categorized based on their significance and type, and different organizations use various criteria for this classification (Figure 1-6).

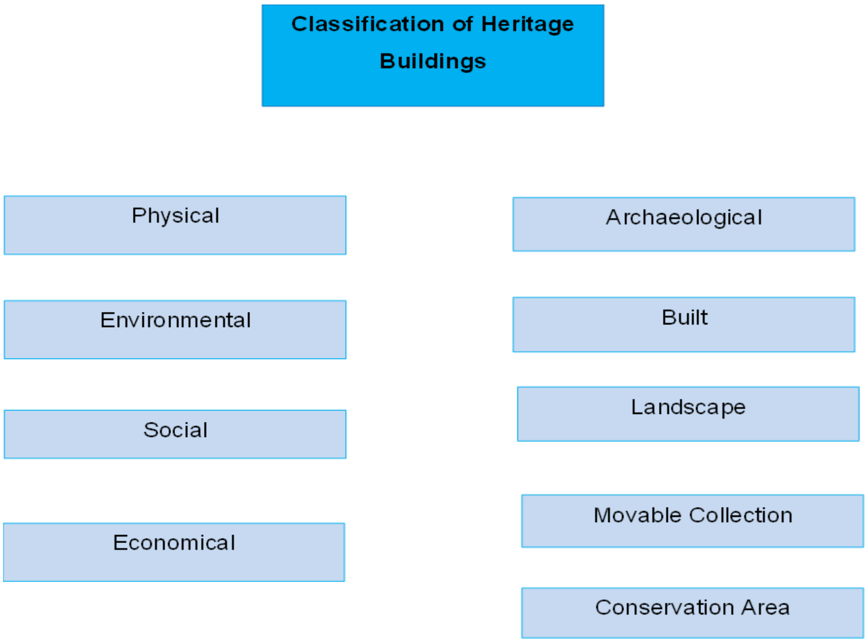


Figure 1-6: Classification of heritage buildings modified from Al-Sakkaf (2020).

Al-Sakkaf (2020) identifies five main types of heritage buildings, and there is no universally recognized best classification method, especially regarding sustainability. Similarly, Chmutina and Jigyasu (2023), as well as UNESCO (2017), further explain that heritage provides a community with identity and makes a direct and significant contribution to sustainable development in its economic, social, and environmental dimensions.

1.6 Policies and Regulations for Building Preservation: An Overview of Heritage building Policies for Preservation in Nigeria and other Parts of the World.

Nigeria as a country is blessed with unique and diverse heritage resources, which are reflections of the creativity of humans and are virtually found in every ethnic group in the country. These heritage resources include sites and build environments, historic places, collections through past and present traditions, indigenous knowledge, and technology to the contemporary life of the communities (Ezenagu, 2020). According to Ogundele (1988), heritage buildings are distinguished assets that encapsulate a nation's soul and spirit. It is also a regrettable fact that archaeologists in Nigeria do not appreciate these heritage resources. The special care and preservation of these archaeological discoveries for visitors and future generations is part of heritage management and cannot be neglected. The willingness of key players to appreciate and value heritage resources is paramount. Ezenagu (2020) defines heritage as the indispensable living traditions of a community. ICOMOS (1999) described it as our legacy "inherent" from the past, what we live with today, and what we pass on to future generations. It includes the natural and cultural environment. It encompasses historic places, built environments, past and continuing cultural practices, as well as knowledge and living experiences (Günlü, Yağcı, and Pırnar, 2013). It is the present manifestation of the human past (UNESCO, 2003). According to Ekwelem et al. (2011), cultural heritage reflects the past, which will be preserved and passed on to the next generation and the world. As such, it is an economic, cultural, and historical process. Globally, substantial efforts have been made to preserve cultural heritage and have gained considerable momentum. This is not so with Nigeria as a developing country, as preserving heritage resources is yet to be rooted in the consciousness of Nigerians (Zaid et al., 2012). Surveys carried out by Alegbeleye (1999); Bankole and Abioye (2005); and Alegbeleye (2007), show that in the early '50s, libraries, archives, and museums were the earliest institutions to recognise the need to preserve heritage resources. Due to a lack of skills and manpower, these institutions could not do much. Heritage resources are living traditions and products of human processes and activities (Aplin, 2002). They are unique and a source of identity that distinguishes one nation from another.

The Convention for the Safeguarding of Intangible Cultural Heritage, which seeks to protect and conserve the diversity of cultural traditions worldwide, took effect in 2006 (UNESCO, 2006). This led to the endorsement of individual nations' Heritage Resources as World Heritage Sites. The World Heritage Policy aims to provide states, parties, and stakeholders with a consolidated source of policy decisions made under the Convention. In addition, it could guide policymakers and heritage professionals in establishing adequate mechanisms within their legislation and heritage protection and conservation mechanisms.

1.6.1 Preservation of Cultural Heritage: Principles, Methods of Conservation, and the Sustainability of Heritage Buildings

The principles of preservation provided by Petzet, (2004) in line with the international charter for Conservation and restoration of Heritage Buildings (Venice Charter, 1964) explain that the preservation of historic monuments is a thorough process that honours both their original form, and the changes made over time, recognizing these alterations as vital contributions to their historical narrative (Article 11). According to the Venice Charter, preservation encompasses not only individual structures but also entire urban ensembles and rural landscapes, where collections of buildings and natural settings hold historical, artistic, or scientific significance. Furthermore, a fundamental principle of preservation is conservation, which focuses on safeguarding monuments by maintaining their structural integrity and authenticity. Conservation efforts typically emphasize the use of traditional techniques; however, modern methods supported by scientific evidence may also be utilized when necessary. Restoration, distinct from conservation, seeks to unveil a monument’s aesthetic and historical value while adhering to original materials and authentic documentation.

This process may involve harmonizing the structure or reversing prior interventions that have compromised its authenticity. Thorough documentation is crucial throughout the preservation, restoration, or excavation processes, ensuring that each step, from cleaning and consolidation to integration, is recorded through analytical reports, drawings, and photographs. This comprehensive approach safeguards grand architectural works and modest structures that have accrued significance over time, thus preserving cultural heritage for future generations.

This study evaluates the thermal comfort benefits of traditional adobe buildings in Ilorin, emphasizing their alignment with heritage preservation principles. This research highlights the importance of scientifically validating these structures and formulating informed restoration strategies to ensure their continued conservation by highlighting their sustainability, authenticity, and climatic adaptability.

1.6.2 General Policies Regarding the World Heritage Convention

The World Heritage Convention, adopted in 1972, is a legally binding instrument providing an intergovernmental framework for international cooperation for the identification and conservation of the world's most outstanding natural and cultural properties. The Convention sets out the duties of States Parties in identifying potential sites and their role in protecting and preserving them. By ratifying the *Convention,* each country enters a system of international cooperation to protect the world's cultural and natural heritage and pledges to conserve the World Heritage sites situated on its territory. The States Parties are encouraged to integrate the protection of cultural and natural heritage into regional planning programs, set up staff and services at their sites, undertake scientific and technical conservation research, and adopt measures that give this heritage a function in the community's day-to-day life. The Advisory Bodies to the World Heritage Committee are ICCROM (the International

Centre for the Study of the Preservation and Restoration of Cultural Property), ICOMOS (the International Council on Monuments and Sites), and IUCN – the International Union for Conservation of Nature.

Various researchers have attempted to define the concept of heritage. Since the adoption of the Venice Charter in 1964, international guidelines for heritage conservation have significantly expanded this definition to encompass more than just individual monuments. Heritage now includes groups of buildings, urban and rural environments, historic gardens, and even intangible values. Initially, the term "historic monument" was confined to physical structures; however, it has evolved to incorporate both movable and immovable cultural property. While there is a broad international consensus on this expanded definition of heritage, terminology differences still exist among countries, each adopting its unique interpretation. Nevertheless, the roles of UNESCO and ICOMOS in defining heritage and establishing common guidelines are vital for fostering a more standardized approach to heritage conservation on a global scale. Ahmad (2006) provided a summary of the scope and definitions of heritage, addressing both tangible and intangible aspects at various national and regional levels. Moreover, according to the World Heritage Policy Compendium (2021) and Acheson (2017), the General Policies of the Convention theme include policies related to the overarching framework of the Convention, the links with other standard-setting instruments, cooperation among States, and implementation of the Convention at the national level.

Heritage Policies at the National level

Article 4

"Each State Party to this *Convention* recognises that the duty of ensuring the identification, protection, conservation, presentation, and transmission to future generations of the cultural and natural heritage referred to in Articles 1 and 2 and situated on its territory belongs primarily to that State. It will do all it can to this end, to the utmost of its resources and, where appropriate, with any international assistance and cooperation financial, artistic, scientific, and technical, which it may be able to obtain".

Article 5

"To ensure that effective and active measures are taken for the protection, conservation, and presentation of the cultural and natural heritage situated on its territory, each State Party to this *Convention* shall endeavour, in so far as possible, and as appropriate for each country:

(a) to adopt a general policy that aims to give cultural and natural heritage a function in the community's life and to integrate the protection of that heritage into comprehensive planning programs.

(b) to set up within its territories, where such services do not exist, one or more services for the protection, conservation, and presentation of the cultural and natural heritage with appropriate staff and possessing the means to discharge their functions.

(c) to develop scientific and technical studies and research and to work out such operating methods as will make the State capable of counteracting the dangers that threaten its cultural or natural heritage.

(d) to take the appropriate legal, scientific, technical, administrative, and financial measures necessary for the identification, protection, conservation, presentation, and rehabilitation of this heritage; and

(e) to foster the establishment or development of national or regional centres for training in the protection, conservation, and presentation of the cultural and natural heritage and to encourage scientific research in this field".

Article 17

"The States Parties to this *Convention* shall consider or encourage the establishment of national public and private foundations or associations whose purpose is to invite donations for the protection of the cultural and natural heritage.

Policies Regarding Conservation of World Heritage Properties

Conservation of cultural and natural heritage is at the core of the Convention. Conservation includes effective and active measures that can be taken by States Parties to ensure the identification, protection, presentation, and transmission of heritage. There is no single definition of conservation in relation to both cultural and natural heritage. However, with regard to cultural heritage 'all operations designed to understand a property, know its history and meaning, ensure its material safeguard, and, if required, its restoration and enhancement' could be part of its conservation (Nara Document on Authenticity). Conservation of natural heritage refers to the protection, care, management, and maintenance of ecosystems, habitats, wildlife species, and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term permanence (IUCN). The Conservation theme includes policies related to protection, management, monitoring, impact assessments, factors affecting the properties, tourism, and sustainable development.

In Nigeria, Cultural Heritage Legislation and Management (CHLM) which was consolidated in 1979 controls and protects historic buildings. The National Commission for Museums and Monuments (NCMM) as a subordinate body is responsible for cultural heritage management conservation, preservation, and restoration. They enlist identified heritage resources and enlist in the United Nations Educational, Scientific and Cultural Organization (UNESCO) list for endorsement as a World Heritage Site.

1.6.3 Overview of Preservation Strategies for Adobe Traditional Buildings Globally

The earthen material has also proven its validity through the ages, its efficiency in architectural solutions, and its ability to appropriate design against the influence of climatic and environmental factors; these efforts are summarized in Table 1-3, indicating key policy tractions of interventions across different global regions (Akinwumi, 2016; Michael, 2008; Oliver 1983).

Table 1-3: Global preservation intervention initiatives

S/N	Location	Notes	References
1.	**Africa**	**Policy**—This shows that most African countries do not have strict rules or policies regarding the use of Adobe. **Technical know-how** - Lacks a written form of documentation - Training and practicing apprenticeship of transferable skills from generation to generation is dominant. **Common building materials** - Mud, stones, golletes, timber, palm fronts, palm leaves, and Palm stems, rammed earth, gypsum, lime, straw, water, coral.	(Marchand,2008), (Siravo and Sanogo, 2008), (Abdulgader et.al, 2008), (Ogega, 2008), (Odiaua,2008) , (Geatano et. al, 2008), (Jaeschke and Friedman,2008), (Van Vuuren, 2008), (Denyer,1978), (Hamard 2016)

		Additives - Cow dung, cow blood, horse dung, earthen pigments, graphite on shower walls and paintings, potash, dye pit, mimosa from Egypt and infusion of the locust bean pod. **Finance** - Financed by both individuals/ communities in countries located in Africa, and a few local /international organizations.	
2.	**Middle east**	**Policy**- Preservation guidelines followed. Acknowledges the importance of documentation (before and after) and documents historic buildings for the process of preservation, rehabilitation and conservation. Preservation processes using questionnaires and interviews. **Common building materials**- Post-tensioning is used as reinforcement for local building materials to construct and preserve adobe traditional buildings. Desert soil, dead soil, water, straws, gypsum, kolash, ash, stones, and lime for foundation, adobe, geotextile, jute textile, barbwire, glass, and grout. **Additives** - Sheep dung, animal hair, burnt oil on the wood. **Finance**- Preservation works are usually monitored closely, supported by the government and financed greatly by international organizations.	(Conlon and Jerome,2008) , (Talebian and Ebrahimi, 2008), (Vatandoust et. al, 2008), (Dehkordi et al., 2008).
3.	**North America &**	**Policy** - Studies reveal that countries in America are fully involved and integrated with guided management plans (documentation	(Arzaga,2008), (Gamarra,2008), (Pereira,2008), (Rodas, 2008),

	South America	and policy) for preserving traditional heritage buildings. **Technical know-how:** More scientific research, the Preservation process is inclined towards seismic resistance and insulated walls, hence, the introduction of modern materials as reinforcement to local building materials to construct and preserve adobe traditional buildings. Awareness and knowledge of preservation strategies are usually carried out through pieces of training, workshops and seminars to transfer conservation knowledge and skills. **Common building materials** - Adobe, baharque, white earth, Kaolin, asphalt, concrete, wattle and daub, smooth mud, straws, ethyl alcohol, ethyl silicate, lime and earth plasters, mud plasters, lime plasters, earthen roofs, barb wire. **Additives** – the use of termite moulds and synthetic enzymes with the same chemical and physical properties of termite saliva to strengthen the adobe with high fine particles, Horse dung, lime-based solution of coloured earth and termite mould/ saliva, alum waterproofing of the lime-plastered roofs, Lime-based paints. **Finance -** is mostly supported by social organisations, international organisations, private organisations, and Government.	(Tolles et al., 2008).
4.	**Asia**	**Policy** - Preservation training programs are put in place to guide the implementation of conservation strategies on projects (documentation and policy). **Technical know-how**- Promotes lots of awareness through training, workshops, and seminars to transfer	(Palumbo et al., 2008)

		conservation knowledge skills and to bring together the community. **Common building materials** - Mud bricks and rammed earth . **Additives**- Cow dung and straw. **Finance**- Mostly supported by social organisations, international organisations, and Government	
5.	**Europe**	**Policy**- Studies from European countries indicate that guidelines and policies for the preservation of heritage / traditional buildings are strictly followed. **Technical know-how** - Preservation and conservation training programs are put in place across Europe to guide the implementation of preservation strategies on projects with a common goal to protect and safeguard the culture and nature to ensure environmental protection and promote forms of sustainable development. **Common building materials**- Stone, adobe walls, mortars, plasters, adobe floors, mud bricks and rammed earth, cob, mud-block, wattle and daub, Mud mortar, lignosulphonate, and sodium silicate mortar. **Additives -** lime wash coloured with natural saffron, blood, or mineral pigments serve as paints used on plasters, lime-based mix Finance- private organisations, public administrations, and Government.	(Achenza, 2008) (Morton,2008) (Walker et al., 2008).

1.6.4 The Importance and Values of Historic Preservation

The significance of historic preservation cannot be overstated, as it has the capacity to uphold the lifestyle of past generations, which subsequently proves valuable to contemporary society. The present generation relies on the past for information, serving as a pivotal platform for the future (Onyima, 2016). Historic preservation is exceedingly vital due to the benefits it offers. Value has consistently been the impetus behind historic preservation. A nation, society, or people only preserve what they value (Onyima, 2016). It is crucial to conserve historic sites as they embody a significant aspect of the past. Moreover, individuals can derive benefits from heritage sites by acknowledging their existence and making efforts to preserve them for future generations. Ilorin traditional adobe buildings are valued with a deep sense of cultural identity and thus need to be preserved. For this study, the historical value of preservation will be discussed within two categories: economic and cultural value, as shown in Figure 1-7.

1.6.4.1 Economic value

According to Klamer and Throsby (2000), economic valuation involves determining the price people are willing to pay for cultural experiences at historic sites. Throsby (2008) contends that the higher the value people place on historic sites, the more they will be willing to pay to visit them. It's also important to consider that the authenticity, appearance, and significance of historic sites can greatly affect their value. Mourato and Mazzanto (2000) argue that economic valuation is a crucial tool and neglecting it may result in undervaluing historic sites. This suggests that if the preservation of unique adobe traditional buildings in Nigeria, particularly in Ilorin, is achieved, these historical sites could be more highly valued and serve as tourist attractions.

1.6.4.2 Cultural Value

People derive satisfaction from the value they ascribe to historic sites. Therefore, it is crucial for communities to identify with their cultural assets, thus increasing their cultural value (Timothy & Boyd, 2003). When individuals or communities place value on historic sites, they develop a sense of ownership and attachment. As a result, historic sites hold social importance. Additionally, historic sites carry political significance, leading to collaboration between governments and individuals (Timothy & Boyd, 2003). Preserving heritage sites can bring significant benefits to a nation. Well-preserved and promoted heritage sites attract tourists from around the world, subsequently boosting the economy and providing more resources for development (Onyima, 2016). Given the above, it can be concluded that cultural value is quite complex." Therefore, this study investigated the cultural value and sense of belonging of the Ilorin people to their culture associated with their traditional buildings. Preserving historic buildings and structures acknowledges a city's history and contributes to its character and sense of community. Historic buildings reflect a society's culture and lifestyle, providing a connection to the past. There are several key benefits to historic preservation, including: - Efficient use of resources: Conserving historic buildings reduces waste and saves money by reusing existing structures rather than demolishing and rebuilding.

Preservation of workmanship: Older buildings were constructed to last indefinitely, unlike many modern structures. Preservation of historic buildings also helps craftsmen learn traditional techniques.

Attracting investment: Preserved historic buildings can become tourist attractions, providing employment opportunities for the community.

Good investment: Rehabilitating historic buildings can be more affordable and attract businesses, tourists, and visitors due to their unique and quality designs.

Adding character and uniqueness to a community: Well-preserved historic buildings and sites contribute to the pride and beauty of a community.

Preserving community history: Historic buildings and sites help communities maintain their identity and provide insight into the past for future generations (Adapted and modified from Community Toolbox).

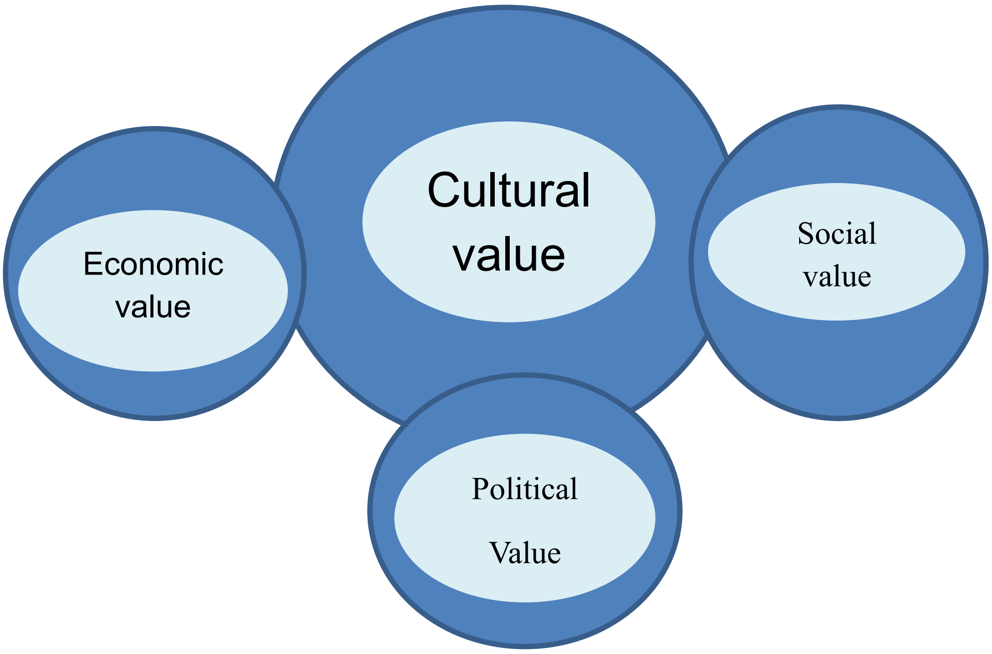


Figure 1-7: Concept of Cultural Value Adapted and Modified from Throsby (2000), Throsby (2008), Timothy & Boyd (2003)

1.7 Conclusion

The foundation for further investigation and analysis of Nigeria's vernacular architecture was established through a comprehensive understanding of the political, cultural, and environmental influences that have shaped the design and construction of traditional buildings. The challenges associated with preserving adobe structures were critically examined, highlighting the urgent need to sustain these buildings. This emphasises the necessity for ongoing research into the existing traditional building stock. This groundwork paves the way for subsequent chapters to explore specific aspects of vernacular architecture in the warm and humid regions of Nigeria.

Chapter 2: Vernacular Approach to Tradition, Cultural identity and Comfort

2.1 Introduction

This chapter explores and presents a background study of traditional buildings, earth construction techniques, and thermal comfort. It highlights the history of Ilorin and recommends passive design strategies in warm humid climates, and specific commonly recommended design strategies for naturally ventilated Ilorin traditional buildings. It also discusses various thermal comfort models to determine the thermal comfort model adopted for this research.

2.2 Faces of Earth as a building material

Earth Architecture includes contemporary, historical, and vernacular buildings, with examples drawn from many cultures and periods. According to Keefe (2005), Earthen buildings are estimated to house about 1.5 billion people globally, constituting about 30% of the world's population. Similarly, Morel et al. (2021), Al Suliman and Suliman (2016), and Vega et al. (2011) noted that one-third of the world's population currently lives in adobe-constructed buildings, See Illustration in Figure 2-1. However, Marsh and Kulshreshtha (2022) claim that the statistics depicting the most widely used estimate of 33% of the global population living in earthen housing is now out of date, and a more accurate range is suggested to be 8–10% and 20–25%.

Earthen materials are typically characterized as dense, porous, and hygroscopic in nature with high heat capacity (Ben-Alon and Rempel, 2023). Due to their high thermal inertia, earthen building materials are advantageous in warm climates, especially when daily changes offer hot days and cool nights; other studies have shown that summer thermal acceptability in earth buildings exceeds that of conventional buildings and thermal comfort standards (Costa-Carrapico et al., 2022). According to Abanto et al. (2017), the heat conductivity of earth material varied from 0.25 to 0.33 $Wm^{-1}K^{-1}$, when the heat capacity range is 460-620$JKg^{-1}K^{-1}$.

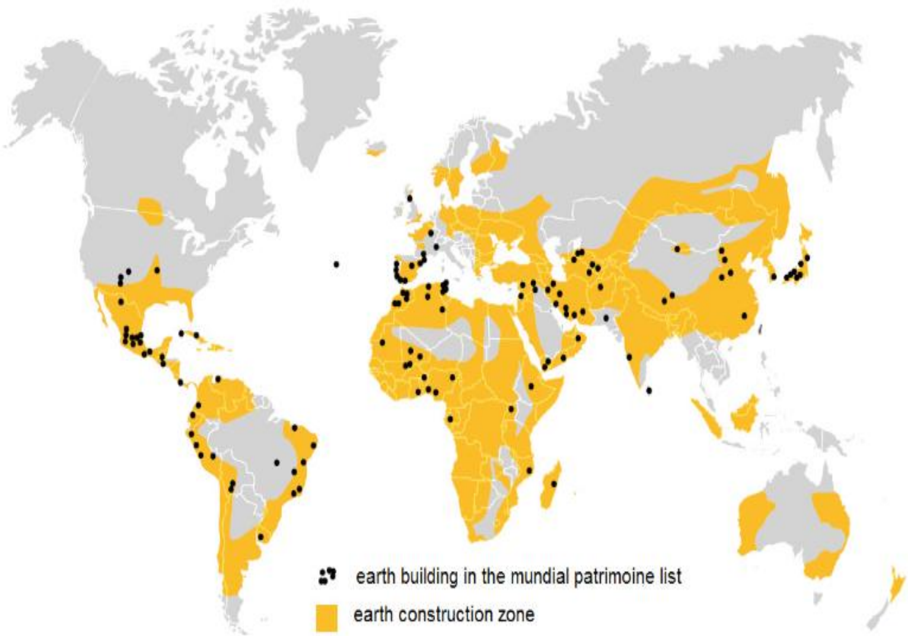


Figure 2-1:Earth construction in the world with Heritage UNESCO (Daudon et al., 2014).

2.2.1 Historical Background of Earth as a Building Material

Many researchers contend that the use of earth is among the oldest building practices known to humanity. Heathcote (1995) substantiated this assertion by presenting evidence of earth bricks that date back to as early as 10,000 BC in Mesopotamia. Doat (1991) described adobe as a building material that has been utilized for thousands of years and may well be the first construction material used by humans. He emphasized that earth is one of the earliest construction materials recognized by mankind and has been employed since ancient times. According to him, civilizations such as the Persians, Babylonians, Egyptians, Assyrians, and others have utilized earth in various forms, including rammed earth, adobe, cob, and sun-dried bricks across different regions.

Doat noted that several Egyptian bas-reliefs depict both peasants and pharaohs using sun-dried bricks. For instance, one notable relief illustrates Queen Hatshepsut (1490 – 1469 B.C.) demonstrating the use of molds to create adobe, which closely resembles modern practices. Another depiction can be found at Rekmara's tomb in Gouna, where prisoners are shown preparing and utilizing sun-dried bricks to construct the temple of Ammon at Thebes. In addition to highlighting the Egyptians' use of adobe, Doat referenced passages from the Old Testament, which mention straw and bricks (Exodus 12:31, Judith 5:11, and Isaiah 5:9). According to Doudon et al. (2014), adobe has been utilized since the 11th millennium and remains one of the most commonly employed vernacular earth construction methods. A comprehensive summary of the literature regarding the global use of earth (Costa et al., 2018; Minke, 2006) provided the following insights: The earliest adobe structures were constructed in Turkmenistan around 8000 to 6000 BC, with significant uses in Europe dating back to 5300 BC in Greece and 1600 BC in Turkey. During the Medieval period, from the 13th to the 17th centuries, earth was utilized as infill in timber-framed buildings across Central Europe, while during the Neolithic Era, it was also employed in Cyprus and along the Tigris River around 7500 BC. Ancient civilizations used earth for various public and religious buildings, including the Citadel of Bam in Iran (approximately 2500 years ago), a fortified city in Morocco's Draa Valley (constructed around 250 years ago), and the Great Wall of China (around 4000 years ago). In Mexico, the core of the Sun Pyramid in Teotihuacan was built with earth between 300 and 900 AD, and nearly all early mosques in Africa and the Middle East were constructed from mud during the 12th century.). Oliver (1983) explained that the earth is affected by natural hazards such as floods and torrential rainfall, which can directly weaken foundations or wash away walls. In dry climates, the earth faces challenges, including erosion, attack from termites or other insects, and degradation from lime and salts. Rodents, birds, and domestic animals like goats could also damage mud walls.

Earth, soil, or mud are often inexpensive and readily available. Building with mud requires minimal expertise, techniques, or special equipment, making it accessible to the unskilled and the poor for self-help structures. However, it does require a minimal level of expertise or training, and it can be labour-intensive. Mud or earth materials are not renewable like timber, but they are readily available, vast in supply, and can be recycled. Despite these advantages, earthen materials are not very resistant to lateral loads in an earthquake and other sudden-onset disasters, making them easily damaged (Vatandoust, 2008 and UNDRR, 2023).

2.3 Construction Methods of Earthen Materials used Globally for Traditional Buildings

Ideally, buildings are meant to be ecologically sensitive and made from natural materials and simple construction techniques. Buildings constructed with mud possess good quality energy efficiency; they are usually cool in Summer and warm in winter. Researchers further explain that the use of Mud/earth for building construction should not be seen as an obsolete material nor the renewed interest of earth as a building material to be a meaningless concept, as widely perceived, but in contrast, it should be perceived as a unique and flexible material with its properties of thermal inertia, malleability, wonderful plasticity, availability, easy to work with and has stood the test of time in building construction from ancient days till date. Moreover, it still has room for improvement. (Denyer 1978; Oliver, 1983; Doat et al., 1991; Minke 2006; Hall et al., 2012; Doudon et al., 2014). According to Minke (2006), Earth is often given different names when used as building material. Referred to in scientific terms as loam, it is a mixture of clay, silt (very fine sand), sand, and occasionally larger aggregates such as gravel or stones. Based on research, Doat et al. (1991) classify earth applications according to their state at the time of use, such as liquid, solid, plastic, or dry. Similarly, Minke (2006), affirmed that earth has four states of consistency: liquid, plastic, semisolid, and solid. See Figure 2-2.

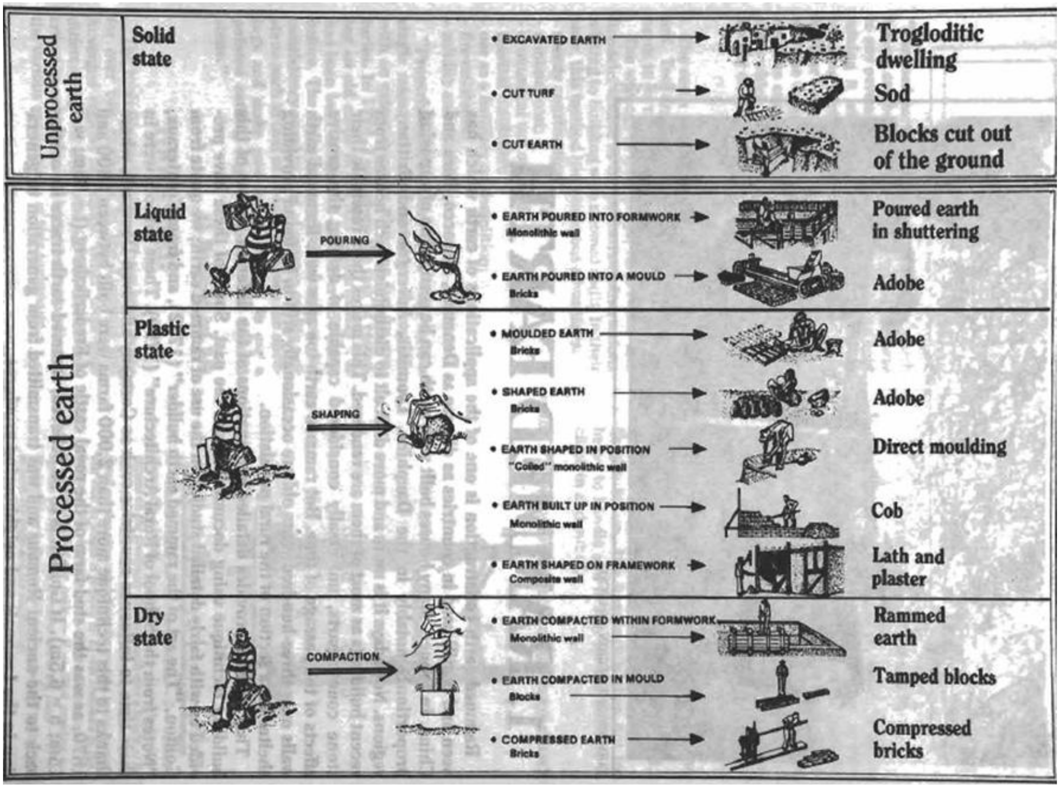


Figure 2-2: Various states of the earth are used as building materials. Source:Doat (1991:12)

2.3.1.1 Different Construction Techniques of Earth Building Materials

a) Rammed Earth

Rammed earth is a type of earth application that has been in continuous use in diverse countries such as Morocco, France, Peru, Denmark, etc. to mention a few. Its technology is simple, Doat (1991) describes rammed earth as a material that ages well, and some houses built for over 300 years can still be seen to house a section of the rural population. According to Jaquin (2012), the soil suitable for Rammed earth construction is found around mountainous areas and rivers. The technique is based on the experience of local masons (Doat et al., 1991; Minke 2006; Beckett and

Augarde 2012). Numerous researchers have provided detailed insights into the construction method of Rammed Earth as illustrated in Figure 2-3.

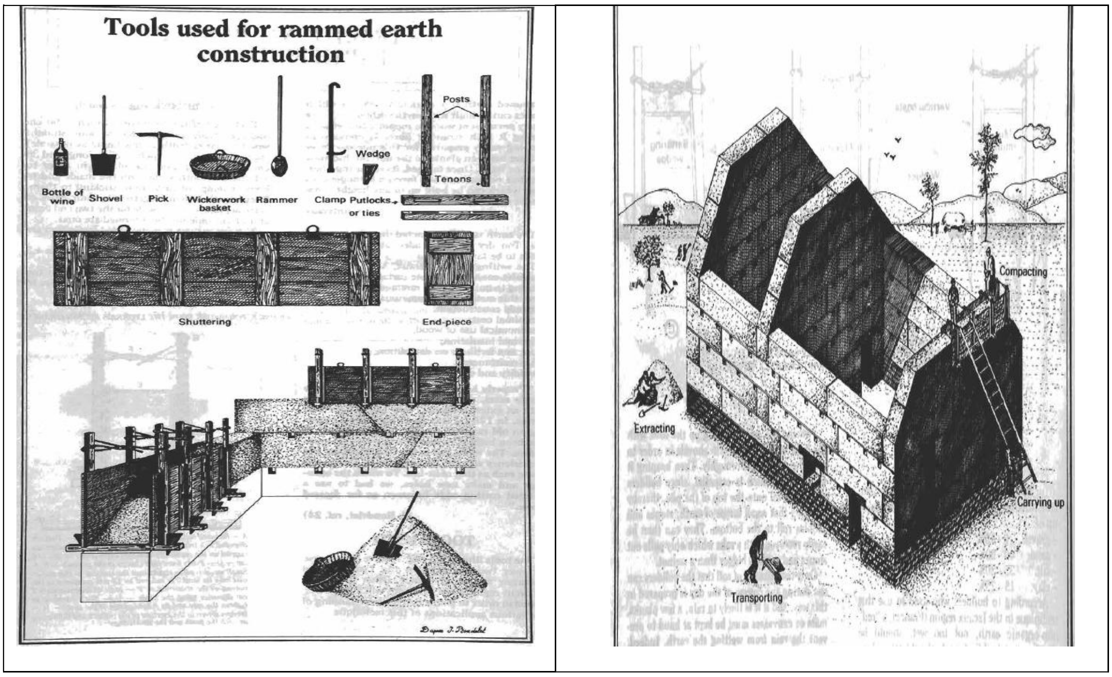


Figure 2-3: Tools used for rammed earth and rammed earth construction. source: Doat (1991)

According to Oliver (1983) and Doat (1991), this technique involves extracting earth directly from the soil and compacting it without using permanent wood or fiber mixtures. As described by Doat (1991) and Jaquin (2012), the earth is applied layer by layer in wooden formwork until it reaches the thickness of a stone wall. The compacted earth forms a cohesive mass of any desired height for the dwelling. Doat and Jaquin also emphasize the soil composition, which includes sand, gravel, clay, and silt. Additionally, lime can be added to improve the mechanical resistance of the rammed earth. Rammed earth construction has been popular worldwide, with examples in Asia (such as the rammed earth defensive walls in China during the dynasty (221–206 BC) and homes and monuments in Bhutan at the east end of the Himalayas), Africa (including the Kasbah in Asslim, Draa valley, Morocco), Europe (popular in Spain, Germany, United Kingdom, and France, with post-Second World

War East Germany using it to develop the first building standard for the material), and America (such as the David Miller house in Greely, Colorado around 1940 and the establishment of the Rammed Earth Institute by Miller). Minke (2006) also references the widespread use of rammed earth.

Figure 2-4: Wall made from rammed earth.

b) COB

The construction technique known as COB, described by Doat et al. (1991) and Niroumand et al. (2013), involves piling unprocessed earth in a plastic state, with the addition of plant extracts, to create external walls. Similarly, Morel et al. (2021) defined Cob as a building technique that originated in the early Neolithic era. It involves stacking clods of earth in a plastic state, typically with fibrous materials, layer by layer to create a monolithic wall. After a brief drying period, the vertical surfaces are smoothed by trimming off any excess material. According to Doat, this technique is carried out without the use of any formwork or moulds, while Niroumand states that few tools and formwork are indeed used in COB building construction. There are no specific types of soil required for COB construction, according to Doat et al. (1991).

Figure 2-5: COB building blocks

However, mostly clayey soils from areas with laterite and no gravel are preferred. Stabilizers are added during rendering, but not often in the composition of the block wall (Morris 1992; Akinwumi et al., 2015). The process involves digging earth and mixing it with water (15-20%) to make it plastic by peddling with the feet while simultaneously removing stones and unwanted vegetation. The mixture is then molded by hand into balls (15 – 20 cm in diameter), allowing for speedy construction through teamwork. Once the walls are completed, they are roofed with a thatch or a flat roof. Additionally, earth-stabilized extracts from plants are used to decorate the interior walls of the buildings. The COB technique is mainly found in Africa and some parts of the Middle East, where mastery of material and sizes may vary. It is commonly used in the Sahel and equatorial regions with heavy rains and high temperatures to build round houses and storage units. In Europe (France), the COB technique is known as "bauge" and is used in areas with wet climates, such as Cornwall, Devon in England, and Scotland. These houses are known to resist cold and winter. An entire village built from COB can be seen in Devon (England) and Scotland, as affirmed by Doat (1991: 101) and Morris (1992). Similarly, COB structures dated to around 1400 AD have been found in parts of the UK, and this building technique was used as a vernacular technique until the 19th century (Morris 1992; Minke 2006).

c) Wattle and daub

Wattle-and-daub is a traditional English wall-cladding system that leverages the strength and lightness of interwoven wattles and the plastic state capacity of clay daubs to fill spaces within the wattle structure (Oliver, 1983). The wattle consists of a rigid frame made from woven plant elements, providing a texture akin to wood, bamboo, twigs, branches, and tree bark found in various parts of the world. According to Niroumand et al. (2013), the mud mixture is similar to that of mud bricks but with a smaller aggregate size, often mixed with dung as a binder due to clay's poor binding with wood. In Europe, wattle and daub techniques evolved as vernacular structures, particularly the widespread use of earth with timber and half-timbered techniques in northern Europe (Minke, 2006).

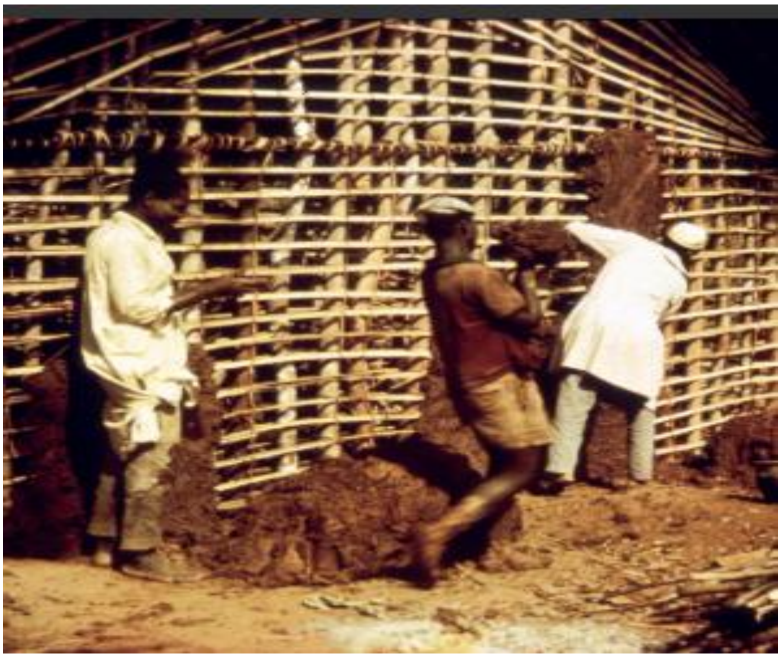


Figure 2-6: Wattle and daub building construction

d) Adobe

The term "Adobe" originates in various languages such as Egyptian, Arabic, Spanish, and French. This building material, composed of mud bricks, has been used for thousands of years and is considered one of the earliest man-made construction materials (Doat et al., 1991; Daudon et al., 2014). Adobe consists of mud bricks formed in molds without compaction and left to dry under the sun. They can be molded into different shapes: conical, square, etc., as seen in Figure 2-4.

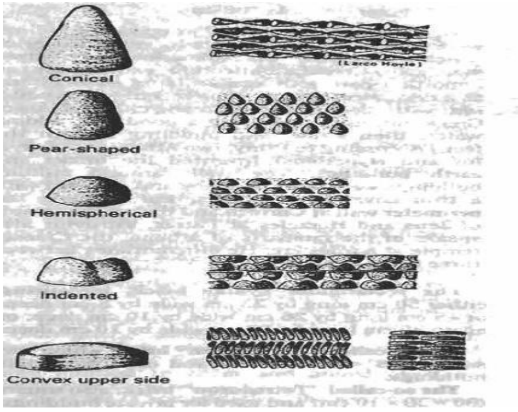


Figure 2-7: Different shapes of Adobe Moulds. Source: Doat (1991).

Figure 2-8: Adobe bricks

Adobe is often associated with regions facing construction challenges and areas experiencing unfavourable environmental conditions (Cirvini, 2011). Although adobe bricks are fragile and susceptible to damage from climatic factors, they can endure for a long time with the appropriate material mix of bricks such as Sand = 55% -70%, Silt = 10% - 28%, Clay = 15% - 18%, Organic matter = less than 3% (Oliver, 1983; Minke 2006; Burroughs 2008; Hall 2012; Daudon et al., 2014; Costa et al., 2018). The first recommended guide for Adobe constructions is provided by ASTM (2010). Adobe bricks can be shaped in two ways: "Earth adobe" and "lime adobe" (Costa et al., 2018). The use of adobe bricks from earth is the major building envelope fabric focused on in this research and its use in construction has been observed on almost all continents. In Central Asia, forts made of adobe dating back to around 300 BC can be found in Uzbekistan. Additionally, the adobe city of Panjakent in western Tajikistan, which dates back to around 500 BC, is now a popular tourist attraction (Minke, 2006). In West Africa, pear-shaped adobe buildings have been in use for over 5000 years, particularly in places like Northern Nigeria, Ilorin, Zaria, and Togo, where adobe buildings are most prominent with the bricks made from an earth and straw mix without the use of moulds.

In Egypt, Rameses II (1279–1213 BC) utilized adobe-stamped bricks with seals in many of his building projects. Although the Egyptian dynasties introduced adobe brick manufacturing techniques to the Nile valley around 2900 BC, the influence of these techniques on the rest of the continent is considered to be minimal. Across the continent, adobe structures can be found, such as the El Badi Palace in Marakesh, Morocco, and the original great mosque of Djenne in Mali, built around 1200 AD and reconstructed in 1907 (Adekeye, 2023; Adekeye, 2013; Minke, 2006; Doat, 1991; Denyer, 1978).

2.3.2 Adobe as a Global Building Material for Traditional Buildings

Traditional buildings across Nigeria's diverse geographical zones have demonstrated remarkable adaptability to the local climate, technologies, and socio-economic conditions that shaped their development. The distinct styles of these traditional structures are deeply rooted in the availability of natural materials such as adobe for local builders, along with influences from religious beliefs, cultural practices, and social taboos (Agboola and Zango,2014). Traditional building forms develop due to man’s ability to think, create, and solve problems through various steps in acquiring new sophisticated building techniques and skills. Rapoport (1968), opined that building materials are perceived to determine the character of the building and its cultural attitudes. On the other hand, building materials, technology, and construction are not building form determinants. Instead, they modify factors that can make a difference in deciding whether building construction is possible.

2.4 History of Ilorin

Ilorin, the capital of Kwara State in Western Nigeria, is positioned at Latitude 8°30' North and Longitude 4°35' East. Situated approximately 300 kilometres from Lagos, the former capital city of Nigeria, Ilorin served as the southernmost emirate in Northern Nigeria. Founded by the Yoruba people in the late 18th century, it became the capital of a kingdom that was a vassal state of the Oyo empire. Throughout the

19th century, Ilorin played a vital role as a major trade centre between the Hausa in the north and the Yoruba in the south. The modern city boasts a predominantly Muslim population and is an industrial, commercial, and educational centre. The historic central district features traditional single-story red mud houses with thatched straw roofs and numerous mosques, all protected by a mud wall (Kwara State of Nigeria, 1997). Ilorin has a mixed population. This explains why it is described as a melting pot for many Nigerian linguistic groups. Ilorin became the window route through which the north transacts businesses with the southwest of Niger. This boosted her economy significantly (Danmole, 2012). Many Ilorin people practice agriculture, producing mostly foodstuffs and cotton. The people also engage in artisans such as blacksmiths, cloth weavers, pottery makers, and producers of household utensils (Hermon-Hodge, 1929). The city is a transitional zone that connects the rainforest of the South and the open savannah to the North (Udo, 1970), which creates a channel to attract settlers from the southern and northern parts of modern-day Nigeria (Danmole, 2012).

2.4.1 Geography and Cultural Identity of Ilorin People

The city of Ilorin is believed to have derived its name from two potential sources: Iloirin (an object for sharpening tools) and Ilu Erin (Town of Elephants) (Na'Allah, 2009). Na'Allah explains the phenomenon of what is known as Ilorin town and Ilorin land as follows: Ile Ilorin and Oko Ilorin, meaning “the Ilorin house/home” and “the Ilorin suburb/village,” are two concepts that regularly feature in the spiritual, economic, and political discussions of Ilorin people. No Ilorin person often claims an origin without a root in the village or the suburbs, and vice versa (Na’Allah, 2008). Furthermore, the concepts of Ile Ilorin and Oko Ilorin highlight the diverse cultural identity of the Ilorin tradition (Na'Allah, 2008). Tradition is deeply ingrained in Ilorin culture, regulating almost all Ilorin lifestyles and behavioural activities, particularly in traditional core areas/districts. This research aligns with Rapaport’s explanation that tradition has the force of law since it is universally accepted. Therefore, respect for tradition provides collective control, serving as a form of discipline. Ilorin is a city with a fusion of cultures and multi-ethnic groups, which have had strong historical and traditional influences on traditional architecture, dress, diets, and so on. For instance, a typical traditional building in Ilorin exhibits a fusion of influences from diverse ethnic groups. It reflects Hausa traditional architecture influenced by Islam through design features such as curved conical shapes, separate courtyards for female and male quarters, and decorative symbolic patterns. Similarly, the influence of Yoruba architecture can be observed in the same buildings with slightly different features like moulded/ carved balustrades, ornamental pillars, and rectangular thatched mud houses (Adekeye,2014).

The Yoruba, Fulani, Hausa, Nupe, Baruba, Gobir, and other foreign nationals have settled there for a long time. The notable foreigners who settled in Ilorin were Malians (people from Mali) deeply rooted in Islamic culture. They, along with Hausa, Fulani, Nupe, and Gobir, brought about the influence of Islamic cultural activities, making Ilorin a predominantly Muslim city. Ilorin is made up of different cultures, which consist of Yoruba, Hausa, Fulani, Nupe, and Barba with the predominant language being Yoruba and Hausa as the second most popular language. The mode of dressing of most of the dwellers is an indication that they are influenced by Islam as a religion. While the men wear jalabia with a turban on their heads, their women put on long dresses and wear scarves or a hijab to cover their heads. This mode of dressing portrays them as religious and decent people.in addition, according to Adekeye, (2014), the lifestyle of Ilorin people encouraged communal living, leading to extended families living together and giving rise to the construction of multiple rooms around courtyards and a common sitting area.

2.4.2 Cultural Value, Attachment, and Sense of Belonging

Despite Ilorin being ruled by the Fulanis, where as of today it is believed that the population of Ilorin is almost 100 per cent Muslims, the Yoruba language can be said to be the lingua franca commonly used in day-to-day communication and business transactions in Ilorin, and this has brought about a conclusion that as far as Ilorin is concerned both Afonja and Alimi Lineage of Ilorin are considered true indigenes of Ilorin, also bearing in mind that to be a true lineage of Ilorin you are not constrained to only belong to any of the two mentioned above, you can be from any ethnic group under the Ilorin plurality (Baruba, Nupe, Tapa, Kemberi etc) all are considered true Ilorin lineage. In addition, Jamiu (2014, p. 113) Confirms and argues that there is a cultural paradox today, as Ilorin is 'predominantly Yoruba, but in both administration and politics, it takes into consideration in the northern (Islamic) tradition,' so that while some attribute it to its Islamic heritage as 'Gerin Alimi, others emphasize its Yoruba roots as 'Ilorin Afonja. The ramifications of this in society give credence to investigating the Importance of being a true Ilorin indigene (indigene's perception) and its relationship to their vernacular architectural style and traditional buildings. Therefore, this study found it essential to carry out a survey on the Importance of being a true Ilorin indigene from an Ilorin indigene’s point of view, full details discussed in section 4.5 (Chapter 4).

There are numerous stories about how the Fulani people arrived in Ilorin. It is believed that Muslims had settled in Ilorin long before a Yoruba warrior from the Oyo empire known as Aare Afonja came to settle there. However, after living together for some time, there was strife between the Aare Afonja and the Muslims, which eventually led to the death of Afonja. The Muslims chose a leader known as Shehu Alimi, a potent Fulani man who united all Ilorin clans and ethnic groups and established a Muslim empire led by Fulanis in Ilorin. It is said that in 1823, the first son of Shehu Alimi was appointed as the first kin of Ilorin, also known as an Emir. Since then, ten Fulani descendants have taken turns being appointed as the emir of Ilorin, as well as lesser titled positions across Ilorin to different Islamic status and traditional chieftaincy titles to heads of ethnic groups (Na'Allah,2008).

According to Rapoport (1969) from a practical standpoint, different cultures and subcultures coexist in our cities, necessitating the need for different housing and settlement patterns,' which the study makes a case that appears to apply even more forcefully to developing countries and this is because these societies are deeply rooted in tradition, certain forms are taken for granted and fiercely resist change. This explains the close relationship that forms have with the cultures in which they exist. This same model is eventually adjusted to meet the majority of the cultural, physical, and maintenance requirements because of this perseverance. Nigeria is a developing country, and Ilorin, is a city with many Component cultures, this is thus a potential area for research into the suitability of traditional Ilorin adobe buildings in enhancing thermal comfort in the warm-humid climate zone where Ilorin people reside. It would allow for an examination of the city's cultures and subcultures, particularly through their built form, as well as an investigation into whether their vernacular architectural strategies adequately address cultural, materiality, and climatic issues to help inform the design of more sustainable contemporary buildings. Ilorin culture is known to embrace Yoruba culture, which is embodied with oral traditions such as praise poetry, affectionately known as *Oriki,* where children go every morning to pay homage to their parents as a gesture of respect, and in turn, their parents sing these legendary praises to them as a form of acknowledgement (Na'Allah,2008). Rapoport opines that Religion is so intertwined with social life and needs that it has become inseparable; this is correct, as it is clear that Ilorin people exhibit two or more identities commonly influenced by culture and religion. Thus, they partake in traditional cultural practices during ceremonies such as weddings, performances for the Emir, burial ceremonies, and daily dressing by the Ilorin people following Islamic rites and ways. Ilorin culture promotes remotes five-time daily prayers and fasting during Ramadan under the Islamic religion.

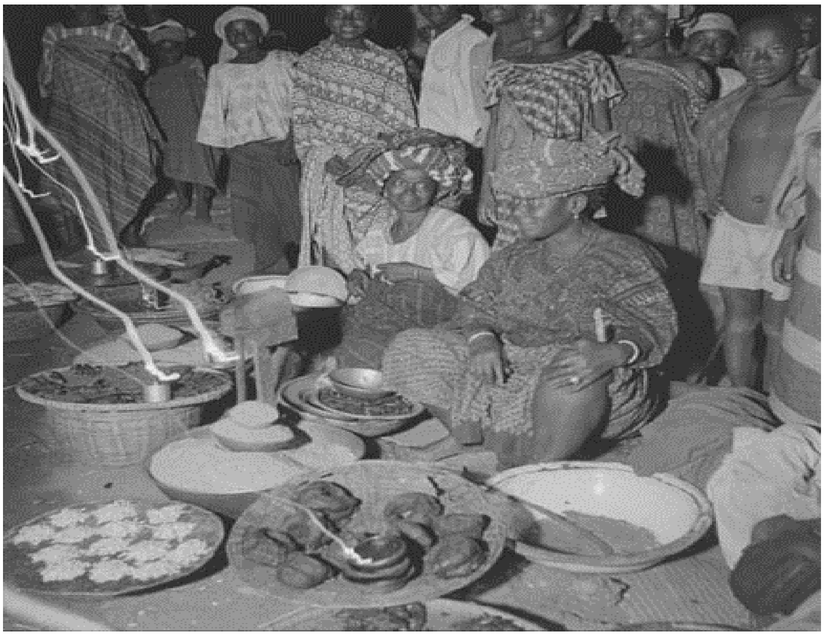


Figure 2-9: Ilorin women trading at a typical night market. Source: www.yorubas.com.ng

In the traditional district areas of Ilorin (core Ilorin), women are known to be very hardworking. They trade at night markets selling foodstuff with the use of tiny lit oil wick local lamps (Jago) from dusk till the early hours of the morning and they are well known to be talented in beautifully rendering the walls and floors of their houses with a mixture of mud and cow dung on traditional buildings built by Ilorin men who are family members (see image in Figure 2-10). The cultural Forms of Ilorin traditional houses have been discussed extensively in the previous chapter.

Figure 2-10: illustration of Cow dung plastered floor

2.4.3 Ilorin Traditional Buildings

Adekeye (2013) provides in-depth insight into the traditional buildings of Ilorin. These buildings are characterized by unique curvilinear conical designs, surrounded by trees for relaxation, and are deeply rooted in Nok terracotta art, utilizing thick mud walls. The roofs, designed for soundproofing, are constructed using thatch, reeds, and wood logs sourced primarily from Neem and coconut trees as seen in Figure 1-9. Adekeye further elaborates on the building's elements, including gothic-shaped doors that serve solely as entrance points, symbolizing a sense of cordiality and trust within the community rather than functioning as a means of security. The houses feature only a few small window openings on the sides and approach elevations, leaving the inner rooms and the rear side of the building devoid of any. The interior of the buildings showcases wall designs with decorative patterns and broken ceramics, while the floors are covered with cow dung, as shown in Figures 2-12.

Figure 2-11: A typical Ilorin Traditional Building

Figure 2-12: Typical decorated floor with cow dung

2.4.4 Memories of Pride and Sense of Cultural Identity in Ilorin Traditional Building Models

The foundation of ethnicity is rooted in culture and identity. Cultural identity shapes individuals and serves as the basis for various aspects of their lives. According to Aristova (2015), cultural identity is the sense of belonging to a specific social or cultural group, allowing for easy identification. Meanwhile, Cohen (1994) defines culture as the social process through which people create meaning to establish a sense of identity, and Orthman et al. (2013) assert that the historical resources of a place influence a person's memory and perception of the environment. Furthermore, a house is not merely a shelter but one of the most cherished assets, with a significant impact on human health, welfare, productivity, and a society's social, cultural, and economic historical value (Olatubara, 2007). A home becomes meaningful when it reflects the way of life of its inhabitants. Traditional buildings express the culture of a people. Fernandes et al. (2013) state that traditional buildings reflect an aspect of material culture and an element of cultural identity. Ilorin's traditional buildings reflect their beliefs, religion, social class, and environmental conditions. They also provide insight into the past and remind this generation of their cultural value. Ilorin's traditional buildings are specific to their locality and are constructed with local materials using local techniques, considering the local climatic conditions to enhance architectural sustainability, integrity, and environmental quality. These traditional buildings are energy efficient and use locally available materials, setting them apart from structures in other regions (Fernandes et al., 2013). They play a significant role in shaping the identity of the people, as their designs reflect their culture and historical importance, providing insight into their society.

2.5 Global Geography and Climatic Context

The Köppen-Geiger climate classification has been considered a suitable way to categorize climate types in a simple yet ecologically significant manner. It is widely acknowledged that climate is the primary factor influencing the distribution of vegetation worldwide. These geographical divisions have created climatic zones on the Earth's surface that closely correspond to global patterns of soil and vegetation (biomes). According to Beck et al. (2018), the modified Köppen-Geiger climate classification shown in Figure 2-13 is suitable for characterizing a broader global pattern of climates derived from three climatic datasets for air temperature and four climatic datasets for precipitation. Historically, the original version of this classification was developed in the late 19th century and considered vegetation as a "visible representation of climate." Even today, it continues to be widely used for various applications and research that depend on variations in climate management, such as ecological modelling or impact assessments of climate change (Beck et al., 2018; Arnfield, 2023). Köppen's map uses different colours and hues to show the five climate zones that make up the planet (Figure 2-13).

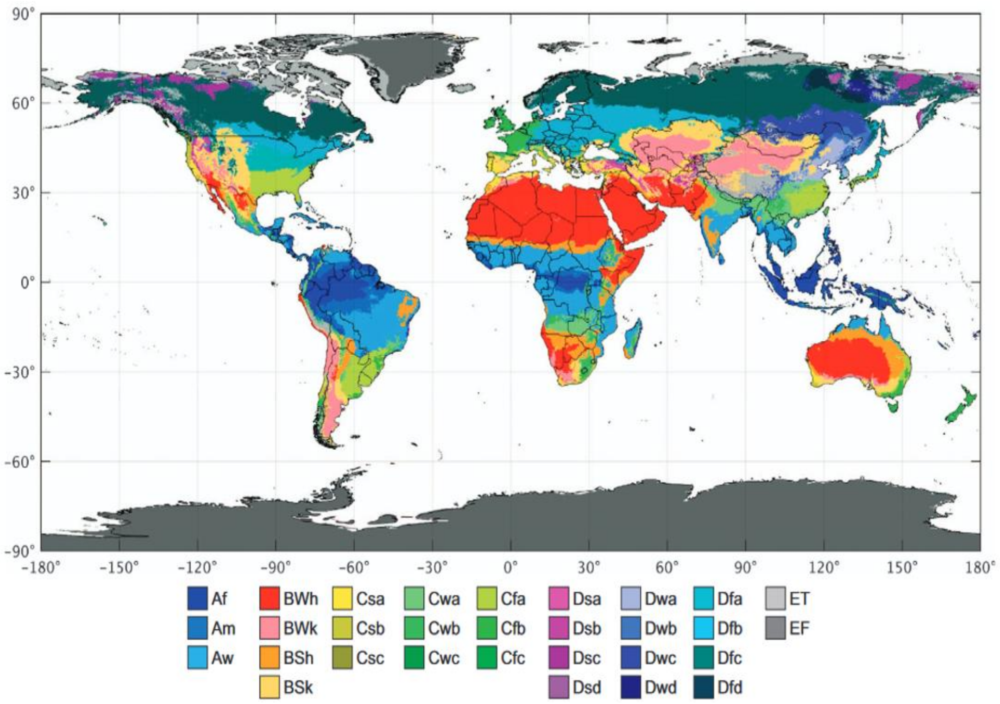


Figure 2-13: The Koppen- Geiger classification shows the present-day 1-km resolution map (1980 - 2016). Source: (Beck et al.,2018)

The zones are divided into groups according to a region's precipitation and temperature. Zone B is for dry regions, Zone C is for warm/mild temperate temperatures, Zone D is for continental climates, and Zone E is for polar climates. Zone A is for tropical or equatorial climates. The temperature or dryness of each zone is used to further separate it. Zone A, for example, is divided into three subdivisions: Zone Aw, which has a winter dry season, Zone Am, which has a brief dry season; and Zone *Af,* which has no dry season. The climate classification by Köppen-Geiger presented in Figure 2-14 which recognises five main classes and 30 different sub-climate types, is considered suitable for providing a clearer and more detailed explanation of the pattern of climates in the world as it establishes annual and monthly averages of air temperature threshold values and precipitation. Most researchers use this classification to conduct field studies concerning thermal comfort in buildings (Beck et al.,2018; Kiamba 2016; Szokokay, 2008).

Table 2-1: Classification of major climatic types according to the modified Köppen-Geiger scheme. Source; (Arnfield, 2023).

Letter symbol 1st 2nd 3rd	*Description*	*Criterion*
A	*Tropical*	*The temperature of the coolest month is 18 °C or higher.*
F	*Rainforest*	*Precipitation in the driest month is at least 60 mm.*
M	*Monsoon*	*Precipitation in the driest month is less than 60 mm but equal to or greater than 100 – (r/25).*
W	*Savannah*	*Precipitation in driest months is less than 60 mm and less than 100 – (r/25).*

Reddy (2008) explained climate as a peculiar atmospheric condition around a certain location on Earth. Some key climate elements that affect architecture are solar radiation, air humidity, air temperature, precipitation, and wind. (Szokokay 2008; Liedl et al. (2012). Liedl et al. (2012) classified climate into different zones globally, which are the cool climate zone (Moscow), Temperate climate zone (Munich), Subtropics (Shanghai), Tropics (Bangalore), Desert coastal climate (Dubai), Desert continental climate (Riyadh), each zone depicts specific characteristics that provide basic information and guidelines to professionals for building designs, these outlines show whether heating or cooling is required in particular locations. Buildings and Climates, according to Liedl et al. (2012), expressed a futuristic concern about the massive increase rate in the development of buildings and its effect on the climate. However, it is suggested that the primary solution to salvage this impending problem is for architects and designers to have full knowledge of climate and design with climate as a basic concept in each climate zone.

Climate refers to the statistical readings derived from the condition of the earth's atmosphere taken at a specific time and place over a period, and these statistics describe climatic variables such as air temperature, precipitation, air humidity, population, wind, and solar radiation that are unique to locations, regions, and the earth globe. There are three different types of climates: macroclimate, meso-climate, and microclimate, which are differentiated by the size of the locality involved (Liedl et al.,2012). Building forms and elements are dependent on thermal comfort requirements and Köppen-Geiger ‘s classification does not cover all important climate elements required for thermal comfort studies (Ogunsote and Prucnal-Ogunsote 2002; Olgyay 1963).

2.5.1 Classification of Nigerian Warm and Hot-Humid Climate

The study area, Ilorin Kwara, falls within the "Warm-humid" savanna climate zone, between 8°.45N and 4°.45E, according to the Köppen-Geiger-Pohl climate classification. Several cities, such as Mombasa, Singapore, and Australia, share a similar climate and are also situated within this climate band on the African map. The figure compares temperature and humidity, two key meteorological factors. Specifically, the average monthly maximum temperature difference between Ilorin and Mombasa ranges from 1-4°C, reaching its peak in March and dropping to its lowest point in December, with a difference of 0–7°C as seen in Figure 2-14. Additionally, the Figure 2-16 illustrates the annual monthly mean variations in humidity between the three regions, ranging from 0-5% to 52% difference in a year.

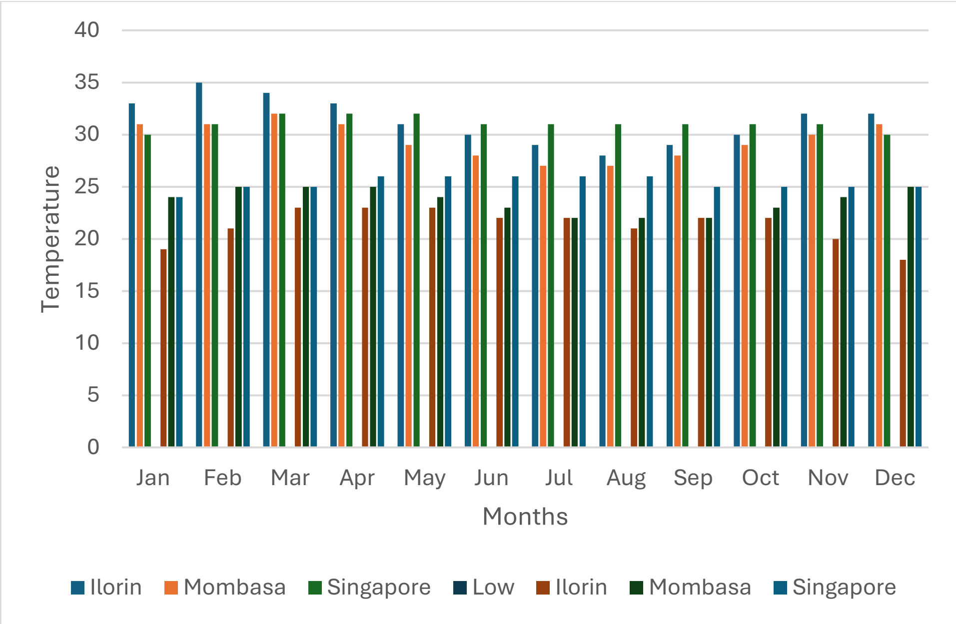


Figure 2-14: Comparison of annual Temperature of Ilorin, Mombasa and Singapore

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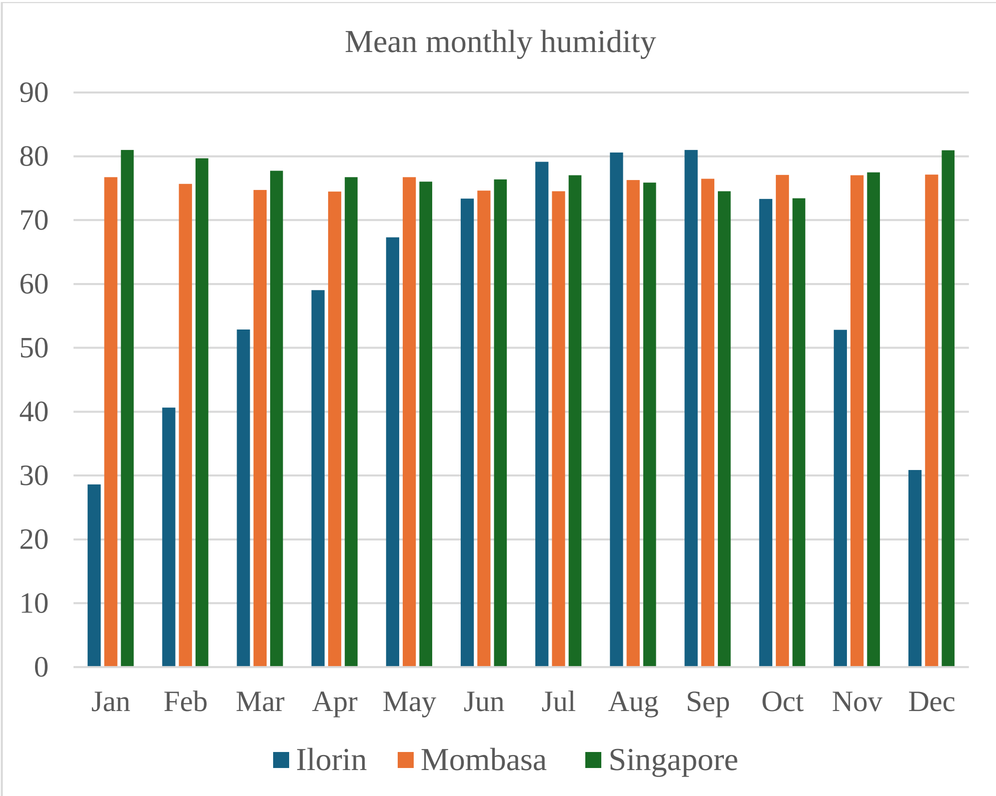


Figure 2-15: Comparison of annual average Humidity of Ilorin, Mombasa and Singapore

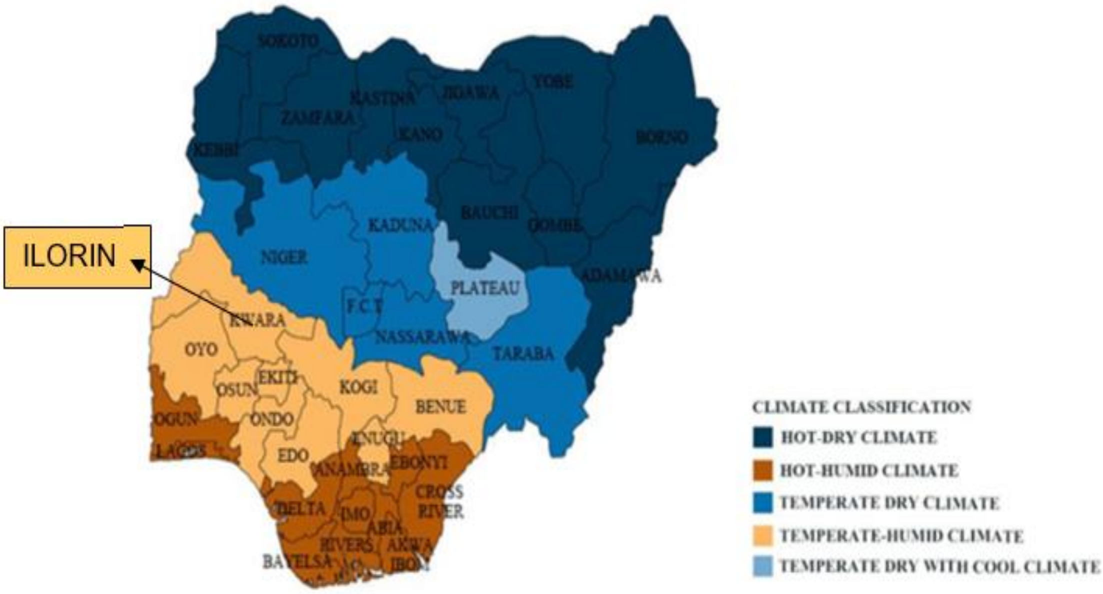


Figure 2-16: Map of Nigeria showing the classification of climatic zones. Source : (Mobolade and Pourvahidi, 2020)

2.5.2 Climate Change Risk

Climate change refers to a shift in the state of the climate that can be detected through changes in the average and/or variability of its characteristics, often identified using statistical tests. This change persists over an extended period, usually spanning decades or longer (IPCC, 2007). Nigeria is increasingly experiencing the adverse effects of climate change. These effects manifest in various ways, including rising temperatures, irregular rainfall patterns, desertification, flooding, and biodiversity loss. Of particular concern is the impact of climate change on heat levels, as extreme heat conditions have profound effects on human health, agriculture, water resources, and overall economic productivity. The evolving climate change coupled with increasing temperature has been observed to plunge some localities in Nigeria thereby disrupting agriculture, and worsening health conditions of people, with unpredictable weather patterns making communities more vulnerable (Adefolalu, 2007; Elisha et al., 2017). Crichton's (2001) risk triangle serves as a valuable framework for assessing the extent of climate change risk in Nigeria considering three key components: exposure, hazard, and vulnerability.

Exposure to Rain and Solar

According to IPCC (2019), reports indicate that West Africa has experienced a rise in mean annual and seasonal temperatures of 1- 3°C over recent decades, particularly in the Sahara and Sahel regions. Minimum and maximum temperatures are increasing at rates of 0.28°C and 0.16°C per decade, respectively. The frequency of warm days and nights has increased, while cold days and nights have diminished. Furthermore, the region is facing hotter, longer, and more intense heatwaves in the 21st century compared to the late 20th century. Nigeria faces significant exposure to climate change risks, particularly due to rising sea levels and shifting climate patterns. Over 70% of Nigeria's coastline is at risk of inundation, threatening land several kilometers inland (Awosika et al., 1992). A 1-meter sea-level rise could put up to 600 km^2 of land at risk, including parts of Lagos and smaller coastal towns, Additionally, the Sahara Desert is expanding southward at a rate of 1–10 km annually, threatening states like Yobe, Borno, Sokoto, Jigawa, and Katsina (Yaqub, 2007).

Vulnerability

The socio-economic and environmental consequences of climate change heighten Nigeria's vulnerability. Financially, the value of assets at risk along the Barrier Coast ranges from over US$1.3 billion for a 0.2-meter rise to nearly US$14 billion for a 2-meter rise. When factoring in oil fields, the risk escalates from US$81.4 million to US$2.2 billion for a 0.2-meter rise and from US$6 billion to over US$19 billion for a 2-meter rise. The Strand Coast alone could face losses exceeding US$18 billion with a 1-meter rise, primarily due to oil fields. Furthermore, Lake Chad has shrunk drastically, from 22,902 km^2 in 1963 to just 1,304 km^2 by 2000 (Odjugo, 2007), severely impacting water availability. The loss of arable land and biodiversity, combined with increasing drought and desertification, has contributed to food insecurity and heightened conflicts between farmers and herders.

Hazard

Nigeria faces multiple climate-related hazards, including rising temperatures, erratic rainfall, drought, desertification, and extreme weather events. Coastal areas are increasingly threatened by flooding, while northern regions suffer from reduced rainfall and prolonged droughts (Adefolalu, 2007). The threat of desert encroachment is particularly severe north of 12°N latitude, where migrating sand dunes have buried arable land, reduced agricultural productivity and forcing migration. Urban centers are also affected by extreme weather events; for instance, the 2010 floods displaced thousands, destroyed infrastructure (Yekken, 2011). Human displacement is a growing crisis, with estimates indicating that a 1-meter sea-level rise could displace over 3 million people, while a 2-meter rise could affect up to 10 million (Awosika et al., 1992).Nigeria's exposure to climate change is vast, its vulnerability is deeply rooted in socio-economic and environmental factors, and its hazards are intensifying with rising sea levels, shifting rainfall patterns, and increasing temperatures. Immediate adaptation measures are critical to mitigate these risks and build resilience in the face of climate change by improving / creating climate responsive buildings.

2.5.3 Traditional Buildings in Climatic Zones in Nigeria

The need to design for the climate has been one of the major considerations in architecture. This is one of the greatest environmental challenges faced in the world.

Most buildings in Nigeria are faced with the challenge of undesirable thermal comfort due to poor designs in relation to the climate. These poor architectural designs require energy to maintain a certain temperature during extreme climatic conditions (Akande, 2010). Climatic condition is an integral and significant factor to put into consideration during the process of planning building designs and the selection of materials to be used. This is being done to provide adequate shelter protection for the occupants from the outdoor climatic conditions. Akande further opined that the primary function of buildings is to provide a comfortable and conducive internal and external environment to the inhabitants that can adapt to the prevailing climate. This means that the building must meet certain requirements such as being proper, which can be achieved by people of all statuses; good, meaning socially accurate; and beautiful, which is environmentally satisfactory (Sdino et al., 2018). In other words, the kind of materials used, the design based on the prevailing climate, and the technique must be evaluated, and the final product should be sustainable throughout the whole service life. Vernacular buildings do not need to be expensive to be better.

Nigerian vernacular architecture can easily be described based on the building materials, forms, and techniques leading to the vernacular forms of architecture, especially concerning the three major ethnic groups which are namely the Hausa in the northern region of Nigeria, the Yoruba in the southwestern region of Nigeria, and the Igbos in the southeastern region of Nigeria. Therefore, the architectural forms reflect the different ethnic and cultural practices (Auwalu, 2019). Hutchison (2002) supported the idea that housing characteristics can be distinguished according to the region and culture of the people. Also, each climate has different factors, as do the region's vernacular buildings (Mobolade & Pourvahidi, 2020).

Flavin (1980) explained that there is a significant correlation between climate and building designs, as recognized by Greek and Roman architects. Roman architect Vitruvius wrote that designs for homes must conform to climate diversity. As important as other environmental factors, bioclimatic analysis should be considered to indicate thermal comfort in buildings, as demonstrated within climate zones. Mobolade and Pourvahidi (2020), explained that the warmth and high humidity experienced in the warm-humid climate (Temperate-humid) give saturated air a strong tendency to ascend and produce a large amount of rainfall, which is a result of the condensation of water vapour in the rapidly rising air. Dodo et al. (2014) went further to say that the analysis of bioclimatic conditions helps in optimizing climatic designs and reduces the use of mechanical temperature devices that would have been used in the buildings, as vernacular construction using local materials fuses the use of natural energy that bridges the gap between the accomplishment of a sustainable vernacular design and present needs.

Lodson et al. (2018) found that materials used in construction in hot and humid conditions are grass, clay, and bamboo, which are used to reduce the effects of climate change and environmental carbon footprint. Clay is used to create walls that control indoor and outdoor temperatures. Dried palm fronds or interwoven dried grass tied to wooden trusses are used as thatched roofs. To increase the resistance to rain, it uses ‘wattle and daub’ mud wall construction, often whitewashed (Meehl et al., 2007).

The warm-humid region of Nigeria, which includes some Igbo cities and Ilorin, amongst others, is characterized by high temperatures and a very small temperature range. The temperature levels throughout the year are almost constant. Some areas record a maximum of 28 °C for the hottest month, while the lowest is 26 °C in the coldest month (Nwalusi et al., 2015). Throughout the year, the inhabitants of traditional adobe buildings experience very high humidity, which causes slow evaporation and lots of rainfall. The area is characterized by a humidity percentage of 70–90%. The rainfall is heavy and short in duration, often characterized by frequent storms. The area has mangroves and freshwater swamps as vegetation. Due to the high humidity, traditional adobe buildings are constructed in an open and widespread pattern (Auwalu, 2019). The traditional buildings in this region integrate spiritual, cultural, and lifestyle values into their architecture.

2.6 Thermal Comfort in Warm-Humid Climate

Thermal comfort, as defined by the ASHRAE-55 (2017) and ISO-7730 (2005) standards, refers to being comfortable with the temperature in an indoor environment. The ANSI Standard-55 outlines the requirements for Thermal Environmental Conditions for Human Occupancy, supervised by ASHRAE. This standard, along with ISO 7730 and EN 15251, is widely recognized worldwide and is regularly updated using Fanger's PMV index. Thermal comfort is determined by assessing occupants' thermal experience and dissatisfaction. In hot and dry regions, the comfort limits can be described using anticipated mean vote (PMV) and expected percentage of dissatisfaction (PPD) indices to evaluate building comfort levels.

The term "comfortable" is subject to various external factors, including an individual's age, health, personal attributes, and activities (e.g., sleeping, working, and running) as well as their clothing (e.g., light or heavy garments). Temperature (room temperature, surface temperature, temperature changes), air quality (humidity, CO_2 levels, oxygen levels, air velocity), and radiation (from systems, materials, or solar radiation) typically affect thermal comfort. External climate conditions undoubtedly have a significant impact on internal temperatures. The body, particularly the brain, maintains a temperature of around 37˚C by regulating the amount of heat generated by metabolism and its dissipation to the surroundings.

Carlucci et al. (2015) emphasise that the primary purpose of buildings is to provide shelter and space for various activities. To achieve this, buildings should offer an efficient, comfortable environment while meeting zero energy targets. Using reliable methods to evaluate long-term thermal comfort conditions in a building is essential, as well as quantifying thermal discomfort and assessing operational performance. Predicting thermal comfort in a built environment is crucial, as it has the potential for energy savings and helps determine suitable temperatures for different environments. According to Singh et al. (2012), thermal comfort is influenced by indoor and outdoor temperatures, relative humidity, and the clothing patterns of the inhabitants. Carlucci et al. (2015) suggest that thermal comfort is affected by four environmental variables: air temperature, mean radiant temperature, relative humidity, and air speed, as well as two personal variables: metabolic activity and clothing. Auliciems and Szokolay (2007) further categorize variables affecting thermal comfort into three groups, as shown in Table 2-2 below.

Table 2-2: Variables affecting thermal comfort.

Environmental factors	**Personal factors**	**Contributory factors**
Air temperature Air movement Relative humidity Radiation	Metabolic rate (activity) Clothing	Food and drink Acclimatization Body shape Subcutaneous fat Age and sex State of health

Air temperature is a crucial environmental factor that significantly affects the thermal comfort of individuals. It is measured by dry bulb temperature (DBT) and influences the heat transfer between the human body and the air through convection. Low air temperatures result in greater heat loss from the body, while high temperatures lead to the body gaining more heat. To perceive a space as thermally comfortable, the heat received by the body from the internal surfaces of the space must offset the heat loss from the body.

Air movement is measured by its velocity (v, in m/s), and it causes moisture to evaporate from the skin, creating an evaporative cooling effect. Facilitating heat loss from the body through convection and evaporation can restore thermal comfort. Airflow through the opening of naturally ventilated buildings depends on the pressure difference at both sides of the opening and the resistance to airflow by the opening itself.

Relative humidity in buildings is influenced by various factors such as moisture sources, human presence, air change rate, and room airflow. Controlling humidity in residential buildings is crucial, as cooking, washing, and showering can rapidly increase internal relative humidity. Humidity affects the rate of evaporation and can be expressed by relative humidity (RH, %), absolute humidity or moisture content (AH, g/kg), or vapour pressure (p, in kPa).

Buildings are constantly exposed to radiation, and achieving thermal comfort within buildings relies on effectively managing interior radiation levels. Passive cooling strategies prevent overheating by regulating radiation and ensuring appropriate lighting. Personal factors such as metabolic rate (activity level), body shape, and subcutaneous fat significantly impact thermal comfort. Clothing is crucial in achieving comfort and is evaluated using the unit clo. Fishman and Pimbert (1982) revealed a strong linear correlation between clo values and outdoor weather and season, especially for women. The adaptability of clothing contributes to approximately one-half of the seasonal variations in comfort temperature. Additionally, Benton and Brager (1994) discovered that adjusting clothing was one of the most effective adaptive mechanisms for maintaining thermal comfort. These findings support the notion that outdoor climate statistically influences indoor comfort, partly due to behavioural adjustments that directly impact heat balance rather than acclimatization or habituation. Human beings are inevitably exposed to heat from different sources daily, as illustrated in Figure 2-17; these heat exchanges can be controlled by various measures taken to improve and make building occupants thermally comfortable. (Heerwagen, 2004, Szokolay,2008).

According to researchers, in tropical climates, the prevailing key issue is overheating, where the major aim for professionals is to design buildings that will cool and dehumidify to provide appropriate thermal comfort levels for occupants where the annual mean temperature is greater than 20°C. In addition, building designs should also take into consideration occupants' thermal and visual comfort without any mechanical means which can be achieved by using local climate variables (Liedl et al., 2012 Koenigsberger et al., 1973).

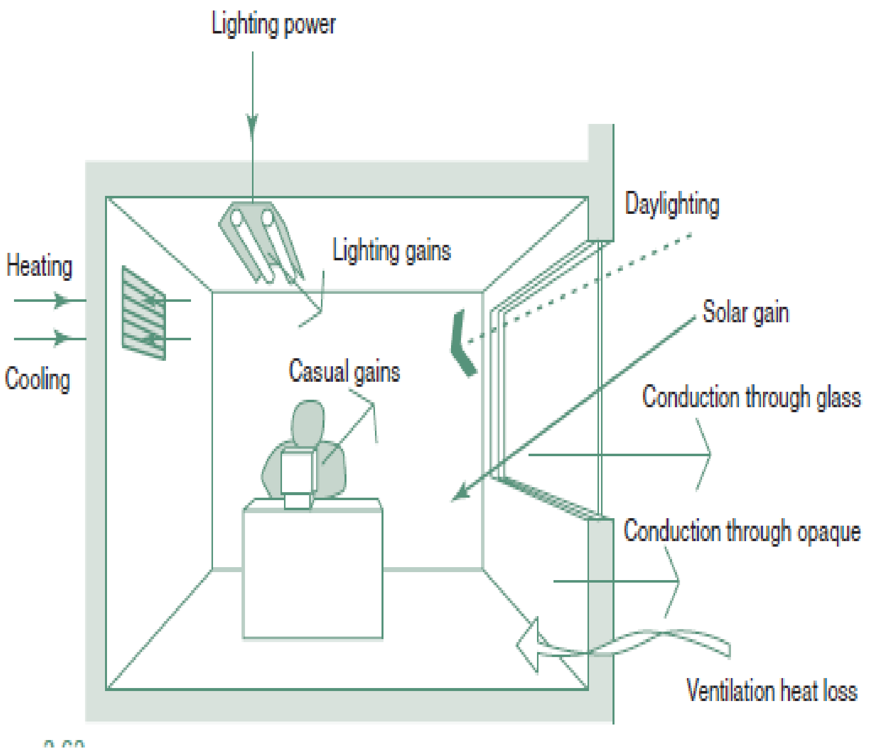


Figure 2-17: Energy flows considered in the LT model. Source: (Szokolay, 2008)

2.7 Thermal Comfort Models

According to Yang and Moon (2018), thermal comfort pertains to an individual's satisfaction with the surrounding temperature. They further elaborate that thermal comfort is a "condition of the mind" with psychological implications. Given the human ability to regulate body temperature, individuals can maintain a core temperature of approximately 36.5 °C (Loftness, 2012) across varied environments.

In line with this, Boregowda et al. (2012) propose that when an individual's thermal regulation is disrupted due to extreme conditions, their core temperature may deviate from the standard value, potentially resulting in damage if it exceeds 38.5 ˚C for an extended period.

Naturally ventilated buildings such as Ilorin traditional adobe buildings consume significantly less energy than air-conditioned structures. This can be attributed to occupants adapting to a broader range of temperatures, extending beyond the comfort zone defined by the PMV model (ASHRAE). Such adaptability can reduce the reliance on cooling and heating, thus leading to reduced energy consumption and enhanced building thermal performance (Holopainen et al., 2014). According to Djongyang et al. (2010) classification, thermal comfort models are divided into the objective and the subjective approach. The objective approach is exemplified by Fanger's renowned PMVPPD Model, which employs the classical heat-balance approach, while the subjective approach revolves around adaptive thermal comfort. This study delves into the adaptive model approach for simulations and the thermal performance assessment in traditional adobe buildings in Ilorin.

2.7.1 Predictive Model (PMV/PPD)

The Predicted Mean Vote (PMV) index utilizes a thermal scale ranging from Cold (-3) to Hot (+3) following an ISO standard. According to ASHRAE-55, the recommended PMV range for indoor thermal comfort falls between -0.5 and +0.5. The Predicted Percentage of Dissatisfied (PPD) reflects the percentage of occupants unhappy with the thermal conditions. ASHRAE-55 considers a PPD range of less than 10% acceptable for thermal comfort. Depending on the PMV, the PPD can range from 5% to 100%. Notably, these comfort levels may also vary based on the specific location within a building. The PMV index, rated on a scale of 1 to 7, predicts the comfort level that a group of people will experience (Thorpe, 2018).

2.7.2 Adaptive comfort

Adaptive comfort models acknowledge how occupants adapt their behaviours and mindsets to maintain a comfortable environment. The design of building elements, such as the number of windows and the need to comply with a range of adjustable parameters, can significantly impact comfort levels by promoting natural ventilation in areas without mechanical cooling systems. Occupants should be relatively inactive, with a metabolic rate of 1.0 to 1.3 METs (where 1 MET is equal to 58.2 W/m2) and wearing clothing that corresponds to the energy output per unit skin surface of an average person at rest (Thorpe, 2018). The adaptive temperature formula assists in determining SET points and the optimal temperature for building occupants. The adaptive model depends on thermal comfort field surveys to establish comfort limits by gathering information on occupants' thermal responses and the thermal environment where they live and carry out their day-to-day activities. This information is analysed to determine the temperature or set point of thermal factors that are commonly pleasant with most of the population. This information can then forecast comfort limits under comparable conditions in another place. (Nicol and Humpreys,2002, Kiamba, 2016). Based on the literature reviewed, Negreiros, et al. (2016) and Kiamba (2016) suggest that the key concept of the adaptive model is that the occupant interacts with and adapts to their surroundings.

2.8 Adaptive Thermal Comfort Indices in Naturally Ventilated Traditional Buildings Located in the Warm-Humid Climates of Ilorin

The concept of thermal comfort in ASHRAE Standard 55-2004, which considers the "condition of mind" and "subjective evaluation" of comfort, and it also supports the discussion in section 2.6.2 which elaborates the adaptive model to be impacted by many other comfort factors asides PMV (static heat balancing models). The thermal adaptation responsible for these variables can be divided into three processes:

1. The body's natural response to changes in the thermal environment to maintain a steady internal temperature is called physiological adaptation.
2. The occupant's perception of the thermal environment, which is impacted by prior encounters, expectations, and cultural elements, is called psychological adaptation.
3. Adaptive actions: the occupant's ability to regulate the environment's temperature by making changes to the thermostat or opening windows.

Szokolay (2004) claims that Humphreys (1978) examined numerous comfort studies and discovered a connection between thermal neutrality and typical climate conditions, leading to the development of a proposed comfort equation for naturally ventilated buildings (structures without mechanical cooling or heating). Auliciems (1981) also analysed the data and further evaluated it to develop a new equation (Equation 2-1) and a psycho-physiological model for heat perception (Szokolay, 2004).

$$\mathrm{Tn} = 17.6 + 0.31Ta \qquad (2\text{-}1)$$

Where Tn and T_a are the mean temperature neutral and average monthly temperature respectively.

Similarly, according to Nicol and Humphreys (2002), the adaptable approach can determine the indoor temperature that building occupants will likely find pleasant, particularly in naturally ventilated buildings. Nicol and Humphreys (2002) also discovered that Equation 2-2 accurately describes the relationship between comfort temperature and outdoor temperature. A change of 2°C in the comfort temperature is advised if other adaptation strategies, like air circulation or changing garments, are not accessible (Nicol and Humphreys, 2002) Variation$\pm 2{,}0°C$ = Equation 2-2

$$TC = 13.5 + 0.54Top \tag{2-2}$$

Where Tc means temperature comfort

T_{op} is the operative temperature = $Toutdoor + Tindoor \div 2$

To predict the indoor thermal comfort limits for traditional adobe residential buildings in the warm-humid city of Ilorin, the two equations mentioned above and four monitored reference buildings with distinctive qualities applicable to all other buildings were considered in subsequent chapters. The thermal comfort limits for Ilorin were calculated to determine the thermal comfort set point. For this research, the temperature set points were established from the standard guidelines for residential buildings. However, reference temperature values were obtained from:

1. In conjunction, an EPW file generated from climate.onebuilding.org produces the weather of Ilorin Kwara state.
2. Measured weather to calculate the minimum and maximum operative temperature (data loggers).
3. Climate consultant who works with the established guidelines.

2.9 Ilorin Traditional Building Designs in Response to the Local Climate

The numerous traditional building design concept in Nigeria is based on the climatic conditions and socio-economic and cultural background of that region. Hence, each design responds to the climate and reflects the people's cultural lifestyle (Olotuah, 2001). Fatiregun, (1999), iterated that environmental factors such as climate and the availability of building materials determine the nature of buildings. Ilorin, the capital of Kwara state has a tropical savanna climate, dry winter with fairly high temperature. The climate is characterised by both wet and dry seasons with mean monthly temperature varying from 25 to 28.9 $^{\circ}$C which is very high. Relative humidity in Ilorin during the wet and dry seasons is between 75 to 80 % and about 65 %, respectively (Tinuoye, 1990), and the daytime is usually sunny. The three major ethnic groups in Nigeria (Yoruba, Igbo, and Hausa), as mentioned in (Chapter 1) have specific building designs and architecture. Protection from weather and signs of cultural enrichment was their major drive (Barbour et al., 1982).

In response to the local climate in Ilorin, traditional buildings were constructed in a unique pattern. The compounds were surrounded by trees to serve as shades for sunny days and for relaxation. The buildings are characterized by curvilinear conical designs and thick mud walls that prevent extreme heat during the day, and thatch soundproof roofs. The roofs were made with reed and logs of wood. The thatched roof is designed in such a way that drains rainwater into a collection of pots and also reduces erosion caused by rainwater from the roof. Their doors are gothic shaped with few small window openings on the sides and approach elevation for natural ventilation. The smaller windows constructed at a high location from the ground level help in controlling chilly weather during the wet season and harmattan. However, with the increase in rainfall and flooding in the sub-Sahara, the mud walls became weak and stained. Hence, cement was then used to plaster the walls and support the foundation of the buildings. The interior walls were designed with floor covers made of animal dung. This mixture of animal dung and vegetable materials gives the wall a glossy finish and also repels insects. However, due to the inability of the walls to withstand the decorative and figurative terracotta wall patterns, paint was introduced to decorate the buildings. The paints lower the surface temperature. Also, strong wind accompanied by heavy rainfall contributed to reducing the use of local materials such as thatched and reeds for roofing, as these materials could not withstand the wind. Hence, aluminum roofing sheets were used on traditional mud buildings (Adekeye 2013; Folaranmi 2017; Denyer 2013).

2.10 Ventilation in buildings

Fresh air is introduced, and stale air is removed from an occupied place through ventilation. This two-way air movement is essential for removing internal pollutants, supplying oxygen for breathing and enhancing thermal comfort. Air is moved in and out of the building by natural forces as opposed to mechanical devices in a process known as natural ventilation. It results from the difference in air pressure between the inside and exterior of the building, and it is affected by the structure's height as well as changes in the temperature of the air inside and outside of the building (Bhatia, 2020). In this study, the impact of ventilation on the indoor thermal environment of Adobe traditional buildings in the warm humid climate of Nigeria will be thoroughly investigated in Chapter 6 and Chapter 7.

2.11 Daylighting in Buildings

Daylighting is incorporating sunlight into indoor areas to facilitate task performance and enhance occupant well-being. According to Sharman (2023), there are a few practical reasons for designers to embrace designing for optimal use of natural light. This includes reduced artificial energy demands, resulting in lower operational costs and increased safety in public places. Studies show that using natural light in buildings helps reduce possible threats to occupants and users. Rennei and Parand (2008) explain that when inhabitants are exposed to the difference between internal and external daylight levels, the human eyes adjust to variations in illumination after a few minutes. The lighting strategy necessitates using many tactics, including side lighting, also referred to as windows, and top lighting, also referred to as atrium, skylight, etc.

Natural sunlight originates from solar radiation during the day, according to Sharman, (2023) and Marzouk, et al. (2022); the benefits of daylighting are many, and the adverse effects that informed the needs for control. Improper installation of windows and daylighting structures can create an uncomfortable space; therefore, view window and daylighting aperture design and specification must avoid excessive glare and heat, carefully considering how best to achieve appropriate brightness levels and thermal comfort. Passive solar design recognizes the human need for natural light. For many building owners, the primary reason for considering daylighting remains the energy load reduction. The passive solar design combines daylighting and passive solar heating methods to aid in heating, cooling, and lighting a building.

2.11.1 Daylighting in Traditional Buildings

Daylight in historical buildings has a distinctive significance in reflecting and facilitating the occupant's productivity within the interior spaces and providing visual comfort for users. Adekeye (2013) describes Ilorin adobe traditional buildings as built forms that have distinctive features and are distinguished by gothic-shaped doorways, which are solely used as entrances and not as a security measure to keep off invaders because everyone coexisted amicably, and there was no concern about expansion. On the sides and approach elevations of the houses, there are likewise only a few very small window openings, leaving the interior spaces and the back side of the structure windowless. To generate designs with effective daylighting, which lowers the energy consumption of the building by requiring fewer artificial lights to attain the necessary illumination levels, building standards such as ASHRAE standards and CIBSE standards must be met. A ratio known as the daylight factor determines the amount of daylight in a room or space. The daylight factor is the amount of outdoor illumination at a place inside, typically on the working plane (Renei and Parand, 2008). Daylight factors can be measured in buildings; the claimed advantage of the average daylight factor (ADF) is that daylight factor values derived from measurements taken in an actual building can be compared with calculated/predicted daylight factors. The analysis of several daylight factors in existing buildings using different standards/rules of thumb displays the daylight values across multiple lighting parameters appropriate for designs/buildings with effective visual and thermal comfort. For instance, Table 2-3 below, taken from (CIBSE, 2015), displays the lighting settings recommended by various building evaluation organizations for a visually acceptable building.

Table 2-3: Daylight Factor Minimum Requirements

BREEAM	80% of floor area should have an average daylight factor > 2%.
BS 8206 Part 2: 2008	Average daylight factor > 2% across the office floor area for the space to appear predominantly daylit.
	For spaces with an average daylight factor > 5% then electric lighting will not normally be needed during the daytime.
LEED 2012/3	Maximum points: achieve spatial daylight autonomy, where at least 75% of the floor area is illuminated by daylight alone. A space is defined as being daylit alone if daylight exceeds 300 lux for at least 50% of the annual business hours.

Source: (CIBSE, 2015).

2.11.2 Rules-of-Thumb

The Rules of Thumb is a set of practical guidelines that a space or area must follow to be regarded as adequately day-lit. The building envelope, light admittance apertures, and light (luminance/illuminance) values distributed throughout the space serve as the foundation for these conditions. According to Rennie and Parand (1998), the guidelines for developing a visually comfortable space are listed below.

1. Effective daylighting can be obtained for any given space by varying the glass percentage of the window wall area within a particular room depth. The diagram below depicts different room depth conditions and the proportions of glass to window wall area required to provide successful daylighting.

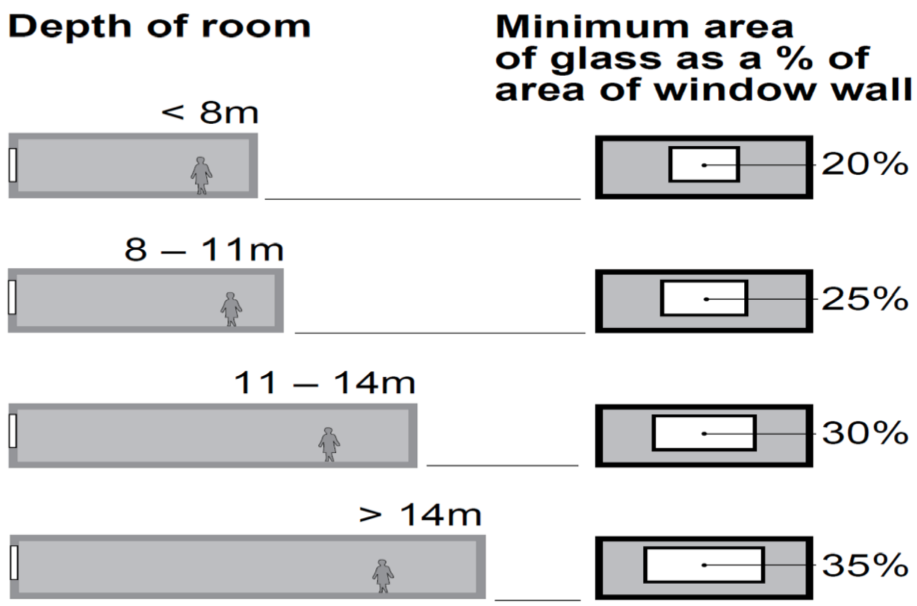


Figure 2-18: Rules of thumb: Depth of room. Source: (Rennie and Parand, 1998).

2. The ratio of perceived light in a space to ambient skylight illumination is known as the daylight factor. The diagram below depicts it as a percentage, and the required element for a suitably daylit space is highlighted in a circle, see Figure 2-19. According to Rennie and Parand (1998), deeper rooms have a worse uniformity ratio. Additionally, the average daylit factor is only an approximation and does not account for the room's shape. Thus, the rear of the room may still be dark.

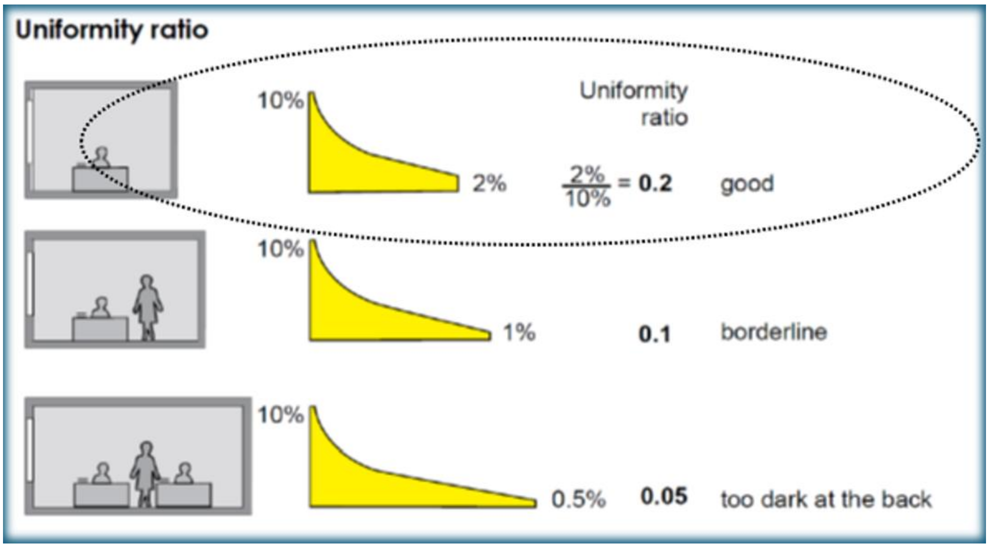


Figure 2-19: Rules of thumb: Uniformity . Source: (Rennie and Parand, 1998)

According to this rule (limiting depth rule), light can travel up to the deepest point of a room from an external source. In other words, it is a requirement to prevent the back of the room from becoming dark. Rennie and Parand (1998) predict a limiting depth rule where it states that: “A room will be lighter at the back if the following conditions are met:

a. Its depth is not much more significant than its width

b. Its dept is little more than twice the height of the window head
c. The surfaces at the back of the room are light". The diagram below highlights its state.

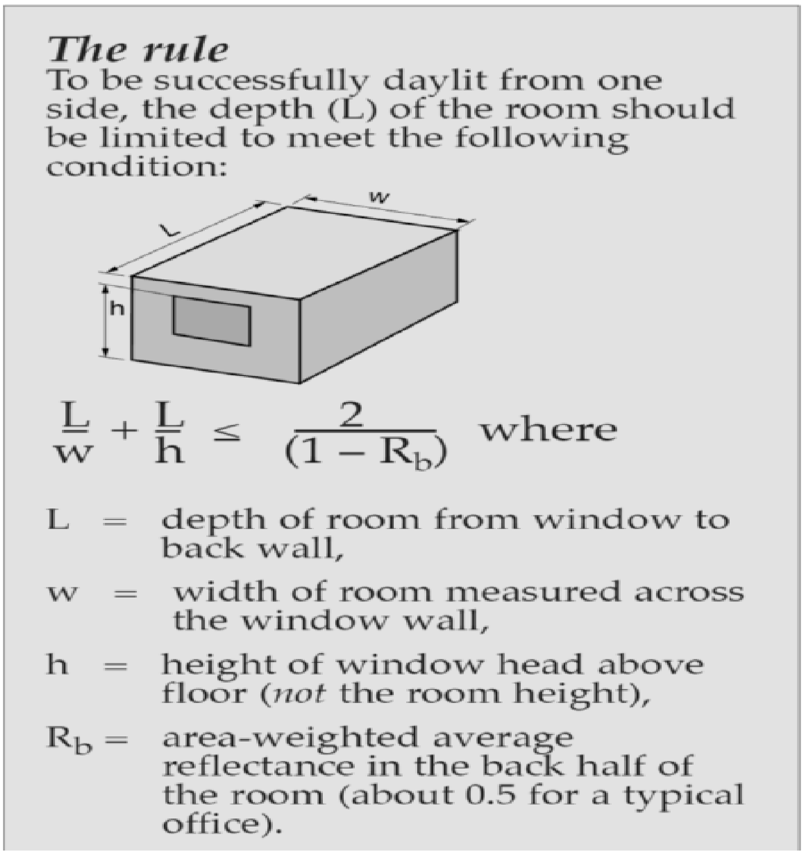


Figure 2-20: Rules of thumb. Source: Rennie and Parand (1998)

2.11.3 Thermal and Visual Comfort

Thermal and visual comfort are important for the health and productivity of building occupants (Cheong et al.,2020). According to the CIBSE guide (2014), Daylight must first meet functional demands, but it must do much more than this: It must create a pleasant visual environment leading to a feeling of well-being, which will stimulate individual performance. Factors that affect occupants' visual comfort in buildings are orientation, window-to-wall ratio, shading device, and material (Hosseini et al., 2018).

Mardaljevic et al. (2023) state that for every software simulation analysis, the approach assumes an overcast sky, indicating the ratio of daylight measured as a percentage independent of the time and season reaching an ideal work plane at a height of 0.70 meters based on the size of the windows. It is calculated by the *equation (2–3).*

$$DF = \frac{E_{in}}{E_{Out}} \tag{2-3}$$

Recommendation by CIBSE (1999), states that domestic buildings including living rooms and study areas should attain an average daylight factor of at least 1.5% and bedrooms with an average daylight factor of 1.0%. To determine if the daylight factor of traditional buildings is sufficient to support daily household activities, the daylight factor will be calculated manually and simulated in IESVE 2023 in chapter 5. The study will therefore investigate Ilorin traditional buildings where subjective responses on the perception of the satisfaction of both thermal and visual comfort and experimental validation processes will be conducted.

2.12 Discussion

Traditional Nigerian architecture, characterized by its rich historical and cultural diversity, offers valuable insights into achieving thermal comfort through sustainable design practices. Structures such as mud-brick dwellings in the North, compound homes in the Southwest, and artfully constructed mud houses in the Southeast exemplify the ingenuity of indigenous building techniques. Methods like adobe, cob, rammed earth, and wattle and daub utilize locally available materials, enhancing energy efficiency while preserving local craftsmanship and heritage. In warm, humid climates, maintaining thermal comfort can be particularly challenging due to elevated temperatures and humidity levels. However, traditional Nigerian buildings, especially those made with adobe, demonstrate superior thermal performance compared to many contemporary structures. The passive design principles inherent in these buildings promote effective temperature regulation, making them valuable subjects for research focused on optimizing thermal conditions. Key factors influencing comfort include indoor and outdoor temperatures, relative humidity, clothing insulation, metabolic activity, and airflow. Further exploration of traditional adobe buildings and their adaptation to various climates presents an opportunity to deepen the understanding of indoor environmental conditions. Researchers employ quantitative analysis techniques, such as Fanger's model and thermal sensation voting scales, to assess thermal comfort. As these studies progress, they have the potential to inspire sustainable architectural practices that not only enhance thermal efficiency but also celebrate Nigeria's rich architectural heritage.

2.13 Conclusion

The key findings emphasize that ensuring thermal comfort for building occupants in Nigeria is crucial and requires comprehensive strategies, including suitable design techniques and thorough research. Traditional Nigerian buildings, using materials like adobe, cob, rammed earth, and wattle and daub, provide sustainable and energy-efficient solutions while preserving indigenous traditions. These buildings perform better thermally than modern constructions, even in warm, humid climates. Effective strategies consider factors such as temperature, humidity, clothing, activity levels, and air movement, with researchers using models like Fanger's to quantify comfort. Further research on adapting traditional adobe buildings to various climates and indoor conditions will enhance knowledge in this area. This section lays the groundwork for investigating adobe buildings and their materials to ensure thermal comfort and sustainability.

Chapter 3: Research Methodology

3.1 Introduction

This chapter outlines the research methods used to achieve the study's objectives, focusing on a mixed-methods framework that integrates both quantitative and qualitative approaches. The study evaluates the thermal comfort performance of traditional adobe buildings in warm-humid climates, particularly in Ilorin, Nigeria. It examines how effectively these structures provide indoor comfort while addressing challenges related to vulnerable building materials prone to deterioration and extinction, cultural identity, and structural integrity. By identifying gaps in existing practices, the research aims to develop guidelines that enhance awareness of adobe's thermal potential and inform preservation strategies. Quantitative methods included field data collection on thermal comfort and environmental parameters using data logging instruments, questionnaires as well as computer simulations and model validations with IES-VE software, Optivent, and Andrewmash tools. Qualitative methods employed case studies and interviews to gather contextual insights and local perspectives across four selected Adobe case study buildings. Methodological triangulation enabled the integration of both data types, enhancing the reliability of findings. The research adhered to building regulations and ASHRAE standards on passive design, thermal comfort, and cultural heritage in tropical warm-humid climates. Ultimately, it aims to produce policy recommendations that promote the sustainable conservation of traditional adobe architecture in Nigeria, ensuring the longevity and cultural significance of these heritage buildings.

3.2 Methodology Overview

This chapter details the research methods employed in achieving the objectives of the study, why they were chosen, and any limitations in their use. The research methodology chosen for this study is mixed-methods research integrating qualitative data and quantitative data to address research questions. These methods were applied systematically in four purposefully selected adobe traditional case study buildings to address the project research objectives. The outlined research methodological triangulation, which involved using multiple methods to gather and analyse (primary and secondary data) to achieve a holistic understanding of the study, was supported by reference to current building regulations and ASHRAE standards on passive design strategies in buildings, thermal comfort, and cultural / heritage use implication, with a focus on tropical warm/humid climatic zones. See illustration of conceptual framework in Figure 3-1.

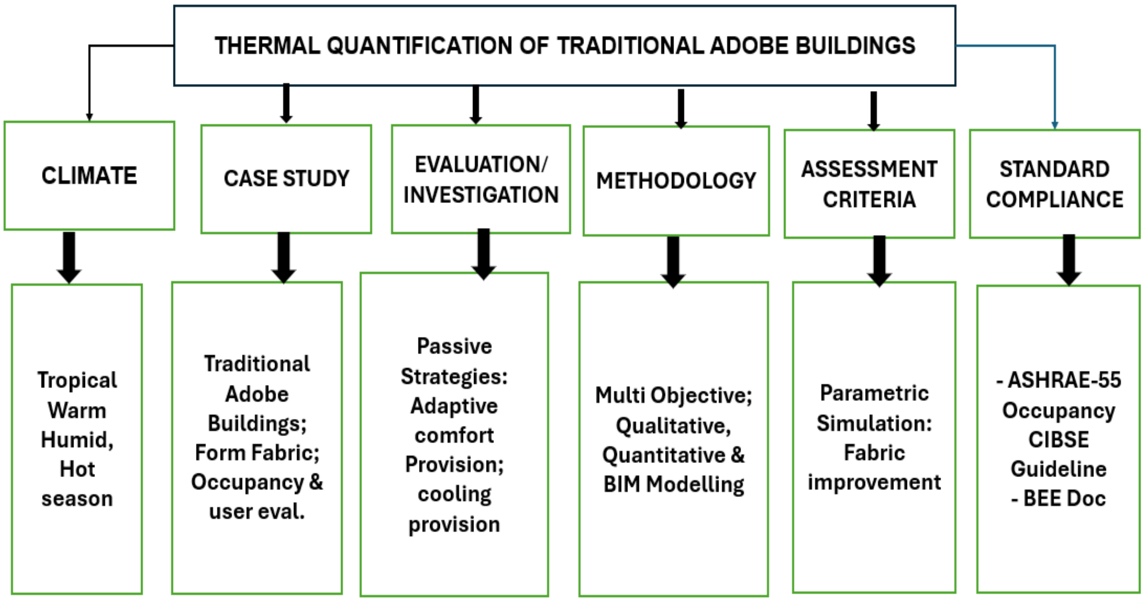


Figure 3-1: Conceptual framework of the research.

3.2.1 Research Philosophy

According to Maxwell (2011), a research paradigm is a fundamental philosophical framework that guides a researcher’s exploration and interpretation of the world, influencing the perception of reality. There are several existing research paradigms; two dominant paradigms are constructivism/interpretivism and positivism/post-positivism. They are typically seen as opposing methodologies, emphasizing objective measurements, statistical analysis, and the pursuit of generalizable truths. Positivism and post-positivism are strongly linked to quantitative research. Qualitative research is based on constructivism and interpretivism, emphasizing context, subjective experiences, and interpretation. According to Creswell (2007), another paradigm known as pragmatism relies on a mixed-method approach. Pragmatism employs a variety of techniques. However, the research problems/ questions being studied should always serve as the basis for applying methods. To achieve research goals, pragmatism values both subjective and objective knowledge. When taking a pragmatic stance, researchers can select the approaches or tactics that will best address their research problems. Considering the philosophical propositions of this research and the nature of data collection, this study is positioned within pragmatism. Pragmatism utilizes positivist and interpretivism philosophy and views both as a continuum rather than contradictions (Saunders et al., 2009). Researchers can address study concerns with adequate depth and breadth by using mixed methodologies, making it easier to extrapolate findings and implications of the concerns to the entire population (Enosh et al., 2014). The mixed method methodology employed in this study consisted of qualitative data, such as that obtained from interviews, which enabled the researcher to gain a deeper understanding of a phenomenon through narrative insights, thereby enriching the study. On the other hand, a quantitative approach (such as surveys and instrumentation) used for data collection allowed the researcher to gather information from a larger number of individuals across various aspects of the phenomenon, which was used to help broaden the scope of the study.

Literature reviewed showed that there are three types of mixed-method research design (Subedi, D,2016).

1. The convergent parallel mixed – method design.
2. The explanatory sequential mixed-method design.
3. The exploratory sequential mixed method design.

This study utilized mixed-method design throughout most chapters to thoroughly understand the significance of preserving Ilorin's adobe buildings and the capacity of these structures to provide thermal comfort in warm, humid climates. The mixed method design type employed was the explanatory sequential mixed-method which was carried out in two phases, where firstly the quantitative information was gathered – through a survey (administered questionnaires as seen in chapter 5) and secondly the qualitative information to provide full insight into the research and to support the results gotten from the quantitative data (interview as depicted in chapter 5) similarly, quantitative data was also gathered through a series of simulations as seen in chapter 7 and a second set of qualitative data as depicted in chapter 8). Moreso, according to Creswell and Plano Clark (2018), integration in this approach occurs in two ways: a) by linking the quantitative results to the qualitative data collection and b) by integrating two sets of results following the completion of the qualitative phase to produce integrated findings. Table 3-1, Table 3.2, and Figure 3-2 -3-4 show a pictorial representation of this method.

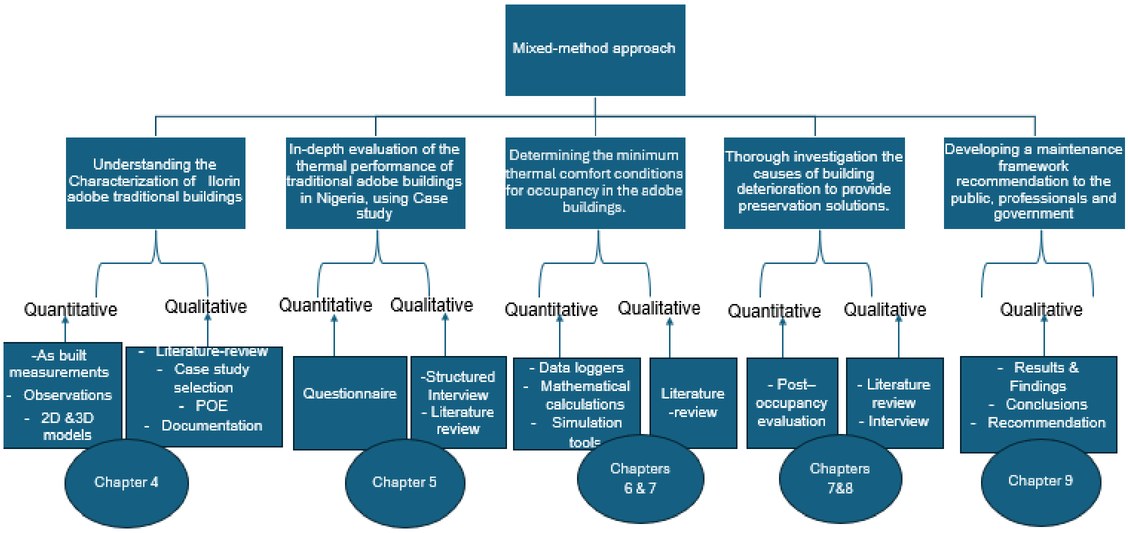


Figure 3-2: Schematic representation of quantitative and qualitative research approach

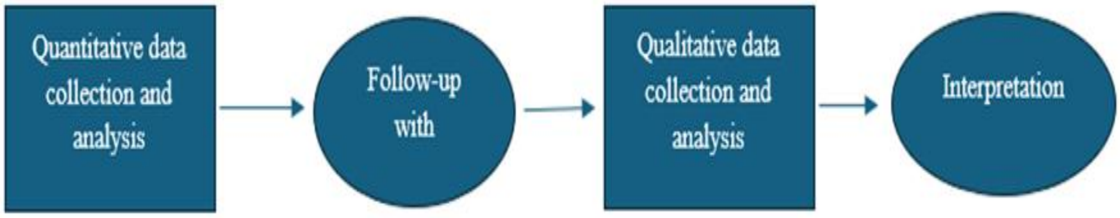


Figure 3-3: The Explanatory sequential mixed- method design.

Table 3-1: Research Methodology, Question in Relation to Objectives

S/no	Objectives	Research questions	Research Methodology	Type of Data Collection
1	Characterising the Ilorin adobe traditional buildings	RQ1	Literature review, survey/measurement and observation	Primary (qualitative) and Secondary Data (Quantitative).
2	Evaluation of the thermal performance of traditional adobe buildings in Nigeria, using Case study	RQ2	Occupant survey/ interview and Field instrumentation	Primary (qualitative) and Secondary Data (Quantitative).
3	Determining the minimum thermal comfort conditions for occupancy in the adobe buildings.	RQ3	Field Instrumentation Simulation and Parametric Analysis	Secondary Data (Quantitative).
4	investigate the causes of building deterioration to provide preservation solutions.	RQ4	Occupants survey Interviews/ and literature review	Primary (qualitative)
5	develop a maintenance framework recommendation to the public, professionals and government	RQ5	Parametric analysis, Interviews/ and literature review	Primary (qualitative) and Secondary Data (Quantitative).

3.2.2 Research Strategy

As outlined in section 3.1, pragmatic philosophy in research emphasizes the use of multiple methods to achieve research objectives by effectively combining elements of both positivism and interpretivism (Taguchi,2018) This approach typically integrates qualitative and quantitative methods, providing diverse perspectives for understanding the complexities of the world. However, it requires a high level of responsibility and skill in selecting or integrating methodologies that align best with the research aims (Creswell & Poth, 2016). Consequently, this study adopted a systematic approach to skilfully blend and utilize the most effective methods to achieve its research goals, as illustrated in the research methodology and approach flow chart in Table 3-2

Table 3-2: Methodology and approach flow chart

Objectives	Methods	Tasks
To examine and characterize Ilorin adobe traditional buildings.	Literature review, Observation Comparative analyses of layout, orientation, window placement, materials, shading, ventilation, etc_	- The literature was reviewed -Measurements and pictures were taken via walk-through post-occupancy evaluation. -The use of tables to classify buildings under general information, thermal properties, and architectural characteristics
To evaluate the thermal performance of traditional adobe buildings in Nigeria using the selected case study buildings in Ilorin.	Empirical data on temperature and humidity is collected using tiny tags, including surface temperature measurements and simulations to inform daylighting, form factor, ventilation, and solar ingress. Questionnaires/interviews	-A structured questionnaire was administered to willing participants of three selected Local government areas with a total of five communities in Ilorin Emirate as a means of rating various aspects of occupant satisfaction concerning building performance on a rating scale of 1 to 7 and a rating scale of 1 to 5. -A semi-structured interview was employed.
To determine the minimum thermal comfort conditions for occupancy in Ilorin adobe traditional residential buildings.	A thorough literature review Analysing readings from Data loggers installed Use of thermal comfort mathematical calculations. Simulation tools	Extensive literature was reviewed. - The occupant's perceptions from the post-occupancy evaluation were also analysed. - Aspects concerning occupant's sense of belonging votes from the questionnaire were analysed -Data loggers were installed in case study buildings. Use IES Simulation
To investigate the causes of deterioration in traditional Adobe building elements to provide preservation solutions.	Literature review Post occupancy evaluation	Conducted post-occupancy evaluation study in four adobe buildings. Gathered insights from household heads on building materials, preservation techniques, and other key information through walkthrough surveys and semi-structured interviews for strategic reviews.".
Develop a maintenance framework for the public and professionals-built environment and integrate it into the nation's building policy documents.	Collate information from above to illustrate the current status in a public-friendly way Describe strategies that increase comfort whilst preserving the buildings' characteristics.	The findings were used to create a framework to support the preservation of traditional adobe buildings in Ilorin.

3.2.3 Time Horizon

According to Saunders et al. (2009), time horizons in research refers to a study's timeframe. It could be cross-sectional studies that collect data at a single point in time, whereas longitudinal studies gather data over an extended period to track changes. A significant limitation encountered in the application of the explanatory-sequential mixed-methods design was that it was time consuming. Creswell & Plano Clark (2018) explained that this mixed-method approach takes too much time to implement the two stages in this design, and because it will be difficult to specify the qualitative phase in advance, the researcher may have trouble getting institutional board clearance. A researcher must also choose which quantitative outcomes to pursue, as well as who to study and what the sample criteria will be.

In this study, the quantitative phase was dominant, meaning more weight was placed on the quantitative phase. In the first phase, a survey was conducted with a population of 225 people who had experience living in adobe traditional buildings, producing 213 respondents. The data was analysed using SPSS. This phase was carried out within 2 weeks in August 2022 (1st – 15th) and 2 weeks in March 2023(1st – 15th). In the second phase, a semi-structured interview was conducted with a smaller sample of heads of households of people living in Ilorin adobe traditional buildings (n=128) for complementarity to the occupants' questionnaire and to obtain additional insights into the study. More details can be seen in Chapter 5. This was carried out within a month, in September 2022.

Prior to the survey, empirical data was gathered through data loggers installed in four case study buildings selected within a one-year duration (18th July 2022 to 31st July 2023). See chapter 6. This effort aimed to determine the standard effective temperature of Ilorin adobe buildings. This informed the Integrated Environmental

Solution virtual software (IES-ve) simulation process and validated the feedback on occupant perceptions collected from respondents. The explanatory – sequential design method was further employed to gain a holistic understanding of the thermal performance of Ilorin traditional adobe buildings and to provide a sustainable solution to protecting the building envelope of Ilorin adobe traditional buildings as recommended in chapters (8 and 9). In this phase, the simulation process was conducted over a period of five months, from August to December 2023. This was followed by a semi-structured interview with a smaller sub-sample consisting of five participants due to the availability of very limited time to conclude this study for submission, the participants included district heads, heads of households, and owners of adobe traditional buildings. The interview was done via phone calls (audio recording) on the 21st of June 2024 to validate the acceptability and affordability of the proposed building envelope framework/ recommendation to protect Ilorin traditional adobe buildings.

3.2.4 Research Survey Method

The explanatory-sequential research approach aimed to provide a contextual definition of Adobe traditional buildings in the warm, humid climates of Ilorin, Nigeria, from the experience of relevant stakeholders. Hence, the study population was within three local Government areas in the Ilorin emirate, including people living in traditional adobe buildings. The local government areas were Ilorin East, South, and West. The participants included Adobe traditional house owners/people renting and currently living in Ilorin adobe traditional buildings. This was carried out in stages as follows.

3.2.4.1 Sampling Method

The major sampling process adopted for this research was a probability sampling technique comprising a multistage simple random sampling through balloting without replacement. The sample population was identified as people above the age of 18 years living in the city of Ilorin central, particularly those living / have lived in Ilorin adobe traditional buildings. The first stage was carried out through a simple random sampling without replacement, this was done to select three local Government areas from Kwara central senatorial district area. The senatorial district chosen had four local government areas within it, this was done select the sample area for a thorough survey. To carry out the survey, the selected three (3) local government areas had a total of four communities where two local government areas had one (1) community each and third local government area consisting of two communities. Furthermore, it was preferred by the researcher to select one community per local government area to monitor the distribution of questionnaires properly considering time constraint. To be able to select one community from the third local government area, a simple random ballot sampling without replacement was done to give an equal chance to either of the two communities to be chosen. The next step was to gather information about the population size of each selected local government area from the Nigerian Government (National Population Commission of Nigeria (web), National Bureau of Statistics (web)) and calculate the sample size equation of each local government area using an online tool called Raosoft (Raosoft.com,2022) for accuracy and convenience, See full details in chapter 4. An online sample calculator is a web-based tool that helps researchers determine the required sample size for statistical studies or surveys. It is user-friendly, accessible, and convenient (Nyimbili and Nyimbili,2024).

The sampling criteria include identification of house types (adobe traditional buildings), historic value of the buildings (Ilorin traditional heritage buildings), cultural identity (prominent traditional buildings owned by district heads eligible to become the Emir) and the buildings cultural value (Buildings selected from three different local government areas within the traditional area of Ilorin). Approximately 100 adobe traditional houses were identified in each local government area; however, for this study, only 75 houses from each area were selected based on a calculated sample size (totalling 225). The selection of these 75 adobe buildings was also performed using simple random sampling without replacement, ensuring that each of the 100 initially identified adobe buildings had an equal probability of being chosen for the survey. This selection method also considered the participants' willingness to participate. In total, 255 questionnaires were administered, resulting in 213 completed responses. Data analysis was conducted using IBM SPSS (Statistical Package for the Social Sciences). Detailed information can be found in Chapter 5. The second sampling method employed in this study was purposive sampling to select interview participants with direct experience living in Ilorin adobe traditional buildings (Patton,1990: Nyimbili, and Nyimbili,2024).

3.2.4.2 Interview Types

Interview with the Head of households

The first step was to identify the people overseeing and managing the buildings/ rooms in their compounds. To obtain additional insights that would complement the occupants' questionnaire responses. It included two groups: heads of households who owned or rented these buildings, enabling cross-validation of their perspectives. This method was chosen because it ensures the collection of rich, relevant data by intentionally selecting individuals with specific knowledge and experience. Nyimbili and Nyimbili (2024) believed that a key advantage of purposive sampling is that researchers can strategically choose participants best suited to provide valuable insights, enhancing the depth and accuracy of the study's findings. the second step after identifying the specific group of people to interview was followed by a simple random sampling without replacement technique employed across the survey areas to select approximately 128 participants. According to Nyimbili and Nyimbili (2024), many people believe that if researchers want to use statistical analysis on their data, they should interview a minimum of thirty (30) participants. The participants from the three communities identified were individually interviewed. The data generated from this group of participants was analysed and prepared for discussion as described in Chapter 5 and Appendix V. The study was conducted to provide a framework for building maintenance and retrofitting procedures. It also offered details for the parametric process in Chapter 7.

Interview with Community heads (Daudus)

A second interview was carried out in a later stage of the study. However, only 5 people were selected through random purposeful sampling without a replacement method; this was due to the availability of extreme time constraints. The participants selected were prominent community heads living in adobe Ilorin traditional buildings as representatives across the four local government areas (Asa, Ilorin East, West and South) existing within the Kwara North central senatorial district also known as Daudus. This semi-structured interview was carried out via telephone audio recordings and analysed. The questions for the community heads were designed to elicit practical information on the proposed improved optimized Ilorin adobe traditional building to validate and verify the acceptability and affordability of the proposed adobe building model. The questions, which can be seen in Appendix VI and the full details discussed in Chapter 8, were aimed to describe the proposed Adobe traditional building envelope with optimised improvement, which is informed through an array of simulations to enhance the maintenance and protection of Ilorin traditional heritage buildings. They also helped to corroborate the importance of preserving cultural practices while ensuring sustainable housing in Nigeria through a maintenance framework that can be inserted into the Nigerian building policy. The selection process was deliberate to ensure the information was obtained for advancing the research objectives. Thus, the participants from the interview gave an understanding of the maintenance strategies of Ilorin's traditional heritage buildings. The analysis of affordability, practicability and acceptability of the optimised adobe Ilorin traditional buildings was driven by its experience to protect cultural Heritage with potentials of delivering good thermal performance in the warm humid climates of Nigeria.

3.2.4.3 The Context of Case Study Selection

In this study, Ilorin city located in the warm-humid region of Kwara state, Nigeria was chosen as the case study area for this research because its traditional buildings vividly showcase the architectural influences of both Yoruba and Hausa cultures, two major ethnic groups in Nigeria, along with other cultural influences. These adobe structures reflect the city's rich multicultural heritage, shaped by centuries of cultural fusion and social evolution. Hausa architectural elements such as curved conical shapes, separate courtyards for men and women, and intricate decorative patterns influenced by Islamic traditions are prominent. Simultaneously, Yoruba influences emerge in features like ornamental pillars, moulded balustrades, and rectangular mud houses, creating a unique architectural blend that tells the story of Ilorin's diverse community. Protecting this architectural heritage is vital, as these traditional buildings not only embody cultural identity but also offer sustainable design solutions perfectly adapted to the local climate. Their construction techniques, which enhance thermal comfort through natural ventilation and the insulating properties of adobe, present valuable lessons for improving vernacular architecture and modern architecture in the face of climate change. Preserving these structures safeguards the city's historical narrative while promoting climate responsive designs. Ilorin's rich architectural design makes it an ideal case study for exploring the intersection of heritage conservation and sustainable building practices, ensuring that the knowledge embedded in these structures endures for future generations and global research contributions.

Case study was adopted in this research to conduct an in-depth investigation of Ilorin adobe traditional buildings. This approach facilitated a comprehensive and contextual analysis of the architectural and thermal performance characteristics of these structures. This is similar to Flyvbjerg, (2006) support to the use of case study to provide a contextual based knowledge of a situation and for expanding knowledge to the level of expertise. The study integrated multiple sources of information, including literature reviews, thematic analysis, post-occupancy observation notes, and building measurements. According to Niezabitowsk (2018), in the field of architecture, case study approach is increasingly being used in historical studies as well as studies pertaining to function, form, typology, and other important topics related to architecture. Individual case studies, also known as the monographic technique in the literature, or comparative multiple case studies are two ways that research can be conducted. It is essential to use several case studies if research is to produce more comprehensive generalizations. Therefore, this study adopted multiple case studies that were conducted through multiple stages to obtain an in-depth investigation of existing Ilorin adobe traditional buildings. This is in line with research replication in many case studies to be primarily motivated by the development and validation of ideas. The data from a sample under investigation should therefore be expected to represent the "whole picture (Niezabitowska ,2018). The case study was conducted in multiple stages which included.

Stage 1: The identification of the case study buildings using a selection criteria comprising the following

a) The site location was Identified to be within the Kwara central senatorial district as discussed in section 4.2.2. In this case the four local government areas were considered.

b) A simple random purposive sampling method was adopted through balloting with replacement to select six case study buildings (Ilorin West - 1, Ilorin East – 2, Ilorin South – 1 and Asa – 2).

i. These buildings were considered to have historic values (Ilorin traditional heritage buildings) and cultural values / Identity (prominent traditional buildings owned by district heads eligible to become the Emir).

ii. The selection of case study buildings was also based on their symbolic attributes and architectural character, showcasing the indigenous use of traditional building materials in Ilorin adobe constructions. This process aimed to enhance the understanding of common architectural features defining typical Ilorin traditional adobe buildings or domestic compounds. Key attributes considered included the types of building materials used, overall design layout, entrance type, wall thickness, presence of wooden posts, fenestration design and materials, courtyard configuration, and roof design. These elements collectively illustrate the distinct architectural identity and construction techniques of Ilorin's traditional adobe structures.

Stage 2: The second step was a walk-through level post occupancy evaluation (POE), this included observation notes developed to systematically record firsthand observations of the current state of the buildings. These notes captured information on usage patterns, occupant interactions, and adaptive modifications made over time. This qualitative data provided insights into the ongoing relevance and sustainability of the adobe structures. Niezabitowska (2018) explained that to identify the most significant flaws in the building or faults that enable one to establish a course for more in-depth investigation, the walkthrough level is used in the building evaluation.

The third step illustrated a thematic approach, as described by Leach (2010), served as the primary method for exploring the architectural history of Ilorin adobe buildings. This methodology, rooted in poststructuralist thought, interprets architecture as a material manifestation of socio-cultural discourse (Groat & Wang, 2013; Adeyemo, 2019). By employing this approach, the study examined the cultural and historical significance of the buildings beyond their physical attributes, emphasizing their role within broader socio-cultural narratives. This method was used to obtain architectural data for building characterization.

The next step was to take proper building measurements and documentation. A systematic documentation guide, adapted from the Full Documentation Fiche (2011), was utilized to record architectural details. The documentation process included:

- Identification of Traditional Buildings: Traditional buildings were identified by their current names and locations.
- Classification Based on Typology and Architectural Variance: Buildings were categorized according to their architectural styles and structural distinctions.
- Historical Background Documentation: Each building's historical context was explored to understand its original function and evolution over time.
- Detailed Architectural and Physical Description: This included an assessment of historical, aesthetic, and cultural values associated with the structures.
- Visual Documentation: The study incorporated sketches, precise measurements, and photographs to capture external views, distinctive features, and internal layouts and to help inform the 3D and 2D models for analysis.

Lastly, a thorough comparative analysis of the characteristics of the case study buildings was undertaken to enhance the understanding of building typologies and to identify optimal components that contribute to improved thermal comfort. Although this comprehensive case study was rigorous, it enabled the researcher to achieve a deep and subtle understanding of Ilorin adobe traditional buildings, offering valuable insights into their historical significance, architectural integrity, and contemporary relevance.

3.2.4.4 In-depth Interview Analysis

Qualitative data analysis is a process that serves the purpose of interpreting, clarifying, and summarizing complex information in relation to a specific research topic or question (Smith and Noble, 2014). The approach chosen for analysis varies based on the objective of the study and the nature of the research question (Patton, 2002; Check and Schutt, 2017). For example, when the goal is to enhance understanding, provide fresh insights into existing knowledge, or explore broader themes within a particular context, an inductive approach proves beneficial. This method ensures objectivity by allowing researchers to identify emerging patterns and ideas without imposing preconceived assumptions (Patton ,2014).

As indicated in section 3.2.1 the quantitative research aspect of this study is based on Positivism and post-positivism while the qualitative research is based on constructivism and interpretivism, placing a focus on interpretation, context, and individual experiences. Patton, (2002) explains that qualitative analysis is based on two categories (Inductive and Deductive), Inductive involves discovering patterns, themes and categories in one’s data. Results are achieved through analyst’s interactions with the data while the deductive involves the analysis of the data using an existing framework. Furthermore, the descriptive qualitative approach is the most widely used method for data analysis, relying on coding, categorization, and thematic analysis to maintain a close connection to the original data (Patton, 2014). This study adopted the inductive analysis to identify and generate the themes, patterns and classifications from the information obtained within and across data in relation to participants' lived experience and views. According to Clarke and Braun, (2017), the process of finding, examining, and interpreting meaningful patterns also known as "themes" in qualitative data is known as thematic analysis (TA). Thematic analysis was considered highly appropriate for this research because the goal is to construct facts based on people's perspectives, knowledge, experiences, and values from a set of qualitative data. Thus, as a result, the extracted information from the interview were categorized as themes. The interview analysis was carried out in line with the 6-step guidelines provided by Braun and Clarke (2006). Where the following steps were taken into consideration.

- Familiarisation with the data (transcribing, reading re-reading and taking notes).
- Generation of initial codes.
- Searching for themes.
- Reviewing themes.
- Defining and naming themes.
- Producing the report.
-

Hence, the researcher carried out the interview process, recorded, and transcribed the interviews. A thorough review of the transcripts was done to provide a comprehensive understanding of the data and this aided in the identification of initial codes. Also, relevant data pieces were organized according to their corresponding codes and analysed using NVivo software. The recurring patterns of meaning were subsequently structured into themes, which were carefully reviewed, refined, and developed into distinct key themes. See Figure 3-4 for steps taken to analyse the qualitative research.

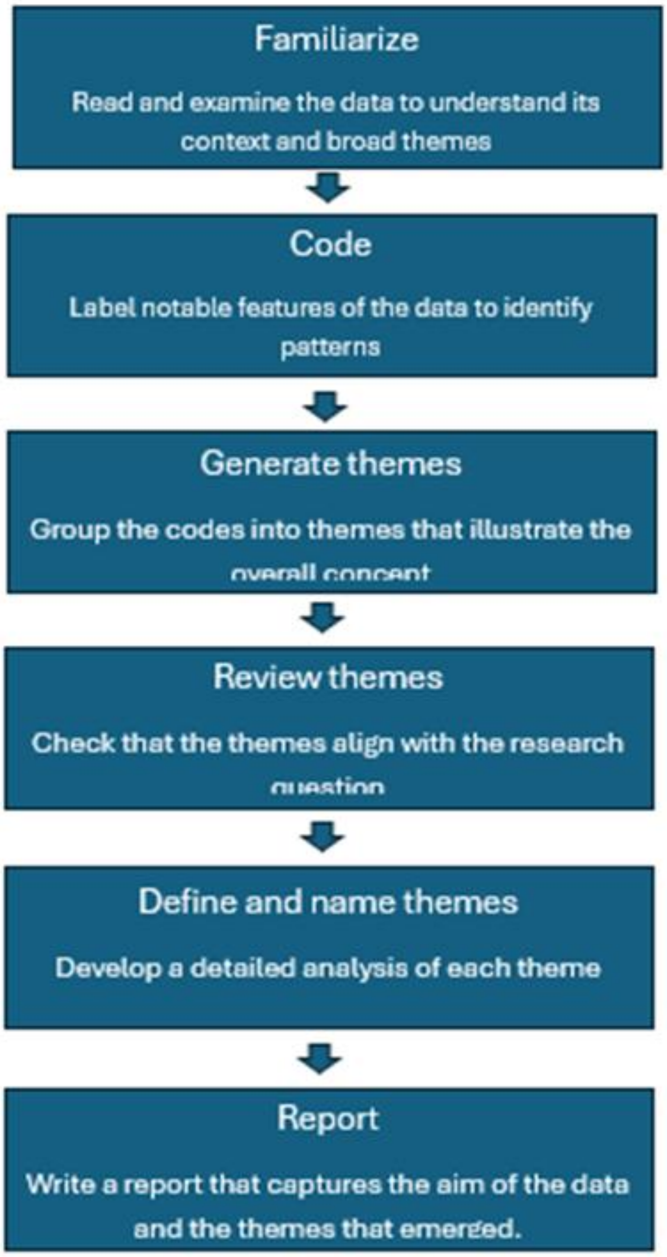


Figure 3-4 : Inductive analysis framework

3.2.4.5 Instrumentation

The research employed Tiny Tag data loggers to monitor indoor thermal comfort in traditional Ilorin adobe buildings characterized by zinc roofs and small windows. Four detached bungalows were examined, categorized into two sets: Set 1 included adobe walls that were plastered with cement, while Set 2 featured exposed adobe walls. Bedrooms were chosen for monitoring based on their representation of typical Ilorin adobe structures, the availability of maximum occupancy periods, their suitability for passive maintenance strategies, their potential for achieving thermal comfort, and their ability to facilitate natural ventilation.

The data loggers were suspended from the ceiling at heights between 1.3 and 2 meters to deter tampering and were strategically placed away from significant heat sources and direct sunlight in naturally ventilated rooms. Readings were recorded every 30 minutes over one year, after which the data were downloaded and analyzed using Microsoft Excel alongside established thermal comfort equations. For further details, please refer to section 6.3.2. The findings from this research were instrumental in establishing a standard effective temperature for occupants living in traditional adobe buildings located in the warm, humid climates of Nigeria. The instrumentation and setup complied with the ASHRAE 55 (2017) standard guide, ensuring that the data collected accurately reflected ambient conditions. This methodology aimed to evaluate the effects of building modifications, such as the transition from thatch to zinc roofs and the shift from exposed adobe walls to cement plaster, on indoor thermal performance.

3.2.4.6 Computer aided programs

Climate consultant 6.0

The Climate Consultant 6 software was utilized in this research to analyze the climatic conditions of Ilorin city and to improve thermal comfort strategies in naturally ventilated buildings. Its selection was based on its capability to graphically present a variety of meteorological data, utilizing the comprehensive EPW database endorsed by the World Meteorological Organization (WMO), which offers long-term hourly climate data from over 2,100 stations across 102 countries (Roradeh & Baaghideh,2024). The software's ability to categorize environmental parameters, including solar radiation, dry bulb temperature, soil temperature, relative humidity, and wind dynamics, facilitated a thorough climate assessment. Furthermore, it evaluated comfort levels and proposed energy-saving strategies tailored to various climatic zones. ASHRAE Standard 55 and the 2004 Fundamentals Model manual were employed to establish thermal comfort parameters, using the psychrometric chart to illustrate optimal outdoor conditions for indoor comfort based on air movement and seasonal clothing adjustments. See section for more details This tool complemented the study's emphasis on passive design methods aimed at enhancing thermal comfort, thus promoting climate-responsive design strategies in naturally ventilated traditional buildings in Ilorin.

Building Information Modelling (BIM) software

The case study buildings, comprising traditional adobe structures in Ilorin, were designed using Building Information Modelling (BIM) with Autodesk Revit 2023 and AutoCAD 2023. This approach was primarily adopted to fill the gaps in the non-existing building documentation and schedules of the existing Ilorin adobe traditional buildings from the Kwara State Ministry of Works and Housing. Employing BIM aligns with established professional practices that aim to enhance design accuracy, ensure consistency in construction data, and create detailed documentation (Zhao Ma et al., 2021; Ma et al., 2015). The design process began with a thorough survey and measurement of the existing structures during the post-occupancy evaluation period (details can be found in the corresponding section), which provided the foundation for the BIM model. The traditional building plans for Ilorin were developed in both 2D and 3D formats, encompassing floor plans, elevations, and other technical elements.

These detailed drawings and specifications were generated directly from on-site data, guaranteeing accuracy and serving as a reliable basis for the improvement of heritage buildings, future design analyses and integration (Sampaio et al., 2021). The decision to incorporate BIM in this research was driven by its capability to create a cohesive digital model that integrates diverse design elements while minimizing errors and conflicts. Additionally, its ability to produce interconnected, precise documentation made it an essential tool for achieving design clarity and supporting long-term planning.

Simulation software

Three simulation tools were adopted in this research, namely AndrewMarsh tool, Optivent 2.1 and Integrated environmental solutions (IES-VE) more details can be found in Chapters (6, 7 and 8). The first simulation tool utilized in this study was an online application called Dynamic Daylight on Andrewmarsh. This interactive interface calculates the daylight factor, which is the ratio of the light level inside a structure to the light level outside. It is defined as the indoor illuminance divided by the outdoor illuminance, multiplied by 100%. For this study, an overcast sky distribution model was assumed, and the weather file for Ilorin was sourced from onebuilding.org for the climate-based analysis. Next, room models were created using the dimension tool to input the actual measurements of the existing room. Two main rooms from each of the four case studies were modelled to perform the daylight factor calculations and the models visually represented building elements such as walls, windows, and the floor. This quantitative methodology was employed to validate the findings from the survey, which highlighted one of the significant challenges faced by occupants of adobe traditional buildings in Ilorin to be the presence of dark spaces that receive inadequate natural daylight. More details shown in chapter 6.

Optivent 2.1 tool

Envelope flow models are essential for solving airflow equations through building openings by considering internal density distribution and pressure differentials. These models enable accurate predictions of natural ventilation performance, which is critical for ensuring thermal comfort and indoor air quality (Adekeye, 2023). The Optivent ventilation tool is an online tool with a methodology grounded in fundamental airflow equations, particularly the calculation of airflow rates through openings based on the discharge coefficient and effective aperture area, Where key variables such as discharge coefficient, opening area, pressure difference, and air density dictate airflow behaviour (Mohammed,2022) as described fully in Chapter 6 and equations incorporating density differences as detailed in chapter 6 also. These equations account for the pressure drop due to hydrostatic pressure variations and gravitational forces, which are crucial in stack-driven ventilation. In this study, this software was used to predict how air moves under different ventilation strategies in envelope models of adobe traditional buildings.

The Optivent 2.1 was used as a computational tool to streamline airflow analysis in adobe traditional building design. The methodology involved:

1. Space Identification: The ventilation zone (single vs. multi-cell) and ventilation type (single-side or cross-ventilation) were defined.
2. Meteorological Data Collection: Weather data of Ilorin was inputted by gathering wind speed, outdoor temperature, and building orientation to establish boundary conditions.
3. Effective Aperture Calculation: The impact of window type (e.g., side-hung) on airflow efficiency, with percentage-based evaluations of opening effectiveness was determined.

4. Geometric and Material Properties: Floor area, volume, solar gains, and material properties like U-values to refine airflow models were considered.
5. Internal Gains and Comfort Metrics: Occupant loads and internal heat sources to assess necessary airflow rates for cooling and comfort was estimated.

This methodology was employed due to its ability to accurately predict natural ventilation by utilizing envelope model equations that considered key airflow parameters, thereby ensuring reliable results. It proved practical for the existing architectural design of Ilorin adobe traditional buildings, enabling swift yet effective assessments of ventilation to support informed decision-making. Moreover, the approach accounted for worst-case scenarios, including low wind speeds and high temperatures, while adhering to CIBSE standards, ensuring compliance with industry regulations and real-world applicability. Overall, its solid theoretical foundation, practical implementation, and adherence to engineering principles rendered it a robust and effective method for optimizing natural ventilation in building design.

Integrated Environmental Solutions (IES-Ve)

This study employed a parametric simulation approach utilizing IES-VE software to assess the thermal performance of Adobe traditional buildings. A dynamic simulation technique was selected to accommodate the diverse factors influencing indoor thermal conditions full details are illustrated in chapter 7. The methodology consisted of the following key steps:

1. Selection of Simulation Tool (IES-VE 2023)

The IES-VE software was chosen due to its advanced integration of multiple simulation models, which enabled a comprehensive thermal performance assessment of the buildings. The key advantages of using IES-VE included:

- Interoperability with various simulation applications.
- Graphical visualization tools for improved interpretation of results.
- Dynamic simulation capabilities, which allowed for real-time analysis of building performance under different conditions.

2. Development of Architectural Models

- Simplified 3D models were developed using ModelIT within IES-VE.
- The primary focus was on accurately representing thermal performance rather than overly detailed geometric complexity.

3. Simulation Input Parameters

- Meteorological data from Ilorin was incorporated to ensure climate-specific accuracy.
- The independent variables assessed included:
    - Building form and geometry
    - Construction materials
    - Surrounding environmental conditions

  The dependent variables measured were:
    - Indoor environmental quality metrics (Temperature, humidity ventilation, and overall thermal comfort).

4. Execution of Simulations

Multiple IES-VE simulation tools were used to address various aspects of building performance:

- SunCast – Analyzed solar radiation and its impact on indoor temperature.
- MacroFlo – Evaluated natural ventilation efficiency.

- VistaPro – Provided in-depth analysis of thermal comfort and energy consumption.
- Simulations were conducted across different parametric conditions to quantify the effects of passive design strategies on naturally ventilated adobe traditional buildings.

5. Validation of Results

- The results were compared with existing research (Yarely,2019; Kiamba 2016) to ensure the accuracy and credibility of the findings.
- Graphical outputs were used to better visualize and interpret the simulation data.
- The findings were consistent with previous studies carried out in similar warm humid climate zones (Kiamba, 2019) reinforcing the reliability of the chosen simulation approach.

The IES-VE software was selected for its comprehensive modelling capabilities, which span multiple domains, including lighting, ventilation, and thermal comfort. The software's dynamic simulation flexibility made it well-suited for adapting to the specific climate conditions of the study location, ensuring that the results would be relevant to the warm-humid climate of Nigeria. Furthermore, the study eliminated potential integration errors that could arise from using complex BIM models. The use of parametric analysis enabled the evaluation of various effects of building construction materials on the indoor thermal comfort temperature and passive design strategies under controlled conditions, providing valuable insights into the potential for improved indoor comfort. The methodology not only ensured the accuracy of the study but also had practical implications for improving building retrofitting and energy-efficient architectural design of optimised adobe traditional buildings in similar climates.

3.2.5 Ethical, Equality Diversity Inclusion (EDI), and Responsible Research and Innovation (RRI) Considerations

Research ethics is a vital field that focuses on the application of ethical principles and professional conduct codes throughout the research process, including data collection, analysis, reporting, and dissemination. It aims to uphold integrity, transparency, and respect for participants' rights, addressing issues such as consent and confidentiality. By providing ethical principles, research ethics guides researchers in responsibly navigating challenges with ethical conduct, ultimately contributing to the advancement of knowledge (Cox et al., 2023). Therefore, as a compulsory requirement in research, there are basic ethical guidelines that must be taken into consideration,these ethical guidelines require that researchers: (a) obtain informed consent from potential research participants; (b) minimise the risk of harm to participants; (c) protect their anonymity and confidentiality; (d) avoid using deceptive practices; and (e) give participants the right to withdraw from your research (Principles of research ethics, 2012). After receiving the University of Nottingham Ethics Review Committee's approval, data gathering began. Although the study was low risk and there was no expectation that participants would suffer any injury; yet all safety precautions were taken at all survey locations in compliance with the authorized risk assessment and management strategy. (See Appendix IX).

Participants in this study were selected through a multistage simple random process detailed in section 3.2.3.1 an information sheet detailing the study was shared with the potential respondents. Those interested confirmed their participation by agreeing to the preferred dates of survey and interview, forming the study's primary sampling method. Before each questionnaire was filled and interviews carried out, participants were provided with a consent form to review and sign, ensuring ethical compliance to the University of Nottingham privacy notice and the General Data Protection

Regulation (GDPR) guidelines that participants must agree to before proceeding to uphold confidentiality, pseudo names were assigned, and all collected data was strictly used for research purposes, securely stored as password-protected files.

This study investigates the functionality and preservation of Ilorin adobe traditional buildings through a survey based on lived experiences. It examines whether vernacular architectural strategies effectively address thermal comfort, cultural significance, materiality, and climatic challenges. By gathering insights from occupants, the research explores how these traditional design principles can inform the development of traditional adobe residential buildings with improved thermal performance and sustainability. This approach aligned with the principles of Responsible Research and Innovation (RRI) and Equality, Diversity, and Inclusion (EDI), emphasizing ethical considerations, social trust, and inclusive stakeholder engagement to enhance the credibility and impact of the study.

3.2.6 Summary

The methodology chapter adopted a mixed-methods approach to evaluate the thermal comfort of traditional adobe buildings in Ilorin, Nigeria. This approach integrated qualitative and quantitative methods, including a literature review, field data collection, simulations, surveys, and interviews. The objective of this study is to provide insights into sustainable conservation strategies while quantifying the thermal comfort benefits associated with traditional adobe buildings in Ilorin.

Chapter 4: Characterising Ilorin Architecture: Comparative Analysis

4.1 Introduction

This chapter presents the first stage of the core research. This involved the case study area of Ilorin adobe traditional buildings with historic values, an evaluation, and a comparison of these selected buildings, the architectural data is used to evaluate the performance of existing building envelopes concerning heat transfer and solar gains, The thermal properties of the building envelope used to identify the main parameters that influence the building fabric performance to explore them in the parametric study and approach to gain a greater understanding of the common architectural characteristics defining typical Ilorin traditional adobe building/ domestic compound and inform the design. In addition, the formation of the base case study to understand the major challenges, opportunities, and novel approaches being developed and deployed.

4.2 Method

This study utilised a multi-stage case study approach to examine the architectural and thermal performance of traditional adobe buildings in Ilorin. A variety of information sources were integrated, including literature reviews, thematic analysis, post-occupancy evaluations, and building measurements. The selection of six buildings within the Kwara Central Senatorial District was informed by their historical and cultural significance, ensuring a diverse representation. The literature review of prior research established a foundational understanding, aligning with Leach's (2010) historical method of investigation, which identifies six approaches to architectural inquiry. The thematic approach was considered most suitable as it examines the cultural context behind architectural forms, providing deeper insights into the socio-cultural narratives embedded within the structures. Post-occupancy evaluations (POE) documented the buildings' conditions, usage patterns, and adaptations over time. A documentation guide adapted from the Full Documentation Fiche (2011) facilitated the collection of systematic data.

The documentation process involved identifying each building by its current name and location, classifying its typology, and exploring its historical background to understand its original function and evolution. Physical and architectural features were carefully recorded to evaluate historical, aesthetic, cultural, and thermal performance values, ensuring a comprehensive assessment of architectural integrity. Visual documentation included sketches, precise measurements, and photographs capturing exterior views, distinctive features, and internal layouts, which contributed to the development of 2D and 3D models. Furthermore, a characteristics table was employed to classify the buildings based on general information, thermal properties, and architectural characteristics (Ghabra, 2017). A detailed comparative analysis of these characteristics was subsequently conducted, offering a deeper understanding of effective building design and identifying key elements that enhance thermal comfort. This approach not only emphasized the architectural diversity found within Ilorin's adobe buildings but also reinforced their importance as models for sustainable building practices.

4.2.1 Research Method: Qualitative and Quantitative Approach

During this research, there was no readily documented data to give an account of Ilorin adobe traditional buildings; therefore, the researcher obtained data through comprehensive fieldwork that entailed qualitative data (literature review, documenting, selecting case studies) and quantitative data by taking as-built measurements, observations, and photos to produce blueprints with the help of AutoCAD.

4.2.2 Case Study Selection Criteria

The scope of the study began with determining the case study locations, which were chosen based on the following criteria:

Stage 1: This involved the following:

i. Sites/locations within the Ilorin Emirate area.
ii. The historic value of the buildings (Ilorin traditional heritage buildings)
iii. Cultural identity (prominent traditional buildings owned by district heads eligible to become the Emir)
iv. The cultural value of the buildings (Buildings selected from different local government areas within the traditional area of Ilorin)

Stage 2: Case study buildings were selected based on the symbolic attributes and character that demonstrate the indigenous application of traditional building materials in their construction, which included basic building information, to gain a greater understanding of the common architectural characteristics defining typical Ilorin traditional adobe building/ domestic compound with the following attributes: Building materials, Building design layout, type of entrance, wall thickness, wooden posts, fenestration design/ material, courtyard, and roof design.

Stage 3: This is the assessment stage where the case study buildings were selected based on their potential and suitability to be carried out. The building thermal performance assessment (Adobe Buildings) and architectural data were used to evaluate the performance of current building envelopes in relation to heat transfer and solar gains. The thermal properties of the building envelope are used to identify the main parameters that influence the building fabric performance to explore them in the parametric study. Based on the afore mentioned criteria, six buildings within Ilorin and its environs were selected initially for building characterisation and in subsequent chapters four major case study buildings were focused on for thermal and visual comfort performance analysis to achieve the process of quantifying the potentials of these adobe traditional comfort in delivering thermal comfort to their occupants in their climatic zones.

4.3 Description of the Case Study Area

4.3.1 Climate and Average Weather in Ilorin, Nigeria

Ilorin is a city located in Kwara State, Nigeria and it is classified under the Warm-Humid climate zone as discussed in section 2.5. Koenigsberger et al. (1973) give notable and important characteristics of Warm-humid climates as; “a climate that exhibits high temperature (hot), sticky conditions and the continual presence of dampness”. A high relative humidity level of 75%, intense solar radiation as it is located close to the equator where the sun is usually at its peak. Also, heavy annual rainfall that provides some coolness, air temperatures between 21°C and 32°C, with negligible changes between days and night and moisture in the air is experienced in this climatic zone.

Moreover, according to global weather standards, the Nigerian city of Ilorin is in the Aw tropical savanna climatic zone of Nigeria. This region is within the tropical savannah region of a warm and humid climate zone. It is situated at an elevation of 320 meters above sea level. Thus, it is among the five Climatic areas in Nigeria that experience high temperatures during the day and substantially decrease at night. Summertime radiation is high all year round, especially in summer months but sunlight hours decrease in wintertime (Mobolade and Pourvahidi,2020; Adekeye et al.,2023). The predominant average hourly wind direction in Ilorin varies throughout the year, with the wind temperature and moisture determining its humidity for comfort levels. Ilorin experiences extreme seasonal variation in perceived humidity, with lower dew points making the body drier and higher levels making it more humid (Weather Sparks, 2023).

Average Temperature in Ilorin, Nigeria

From January 23rd to April 10th, Ilorin experiences the hot season, which lasts for 2.6 months, with an average daily high temperature of over 34 °C. The warmest weather occurs in March with an average high temperature of 34 °C and low temperature of 23 °C. See details in Figure 4-1. From June 22nd to October 10th, the chilly season lasts 3.6 months, with an average daily maximum temperature of less than 30°C. September is the coldest month of the year in Ilorin, with an average low of 21 °C and a high of 28 °C. The highest average solar energy reaching the ground is in March, with an average of 5.5 kWh, while the lowest average is 4.5 kWh in September.

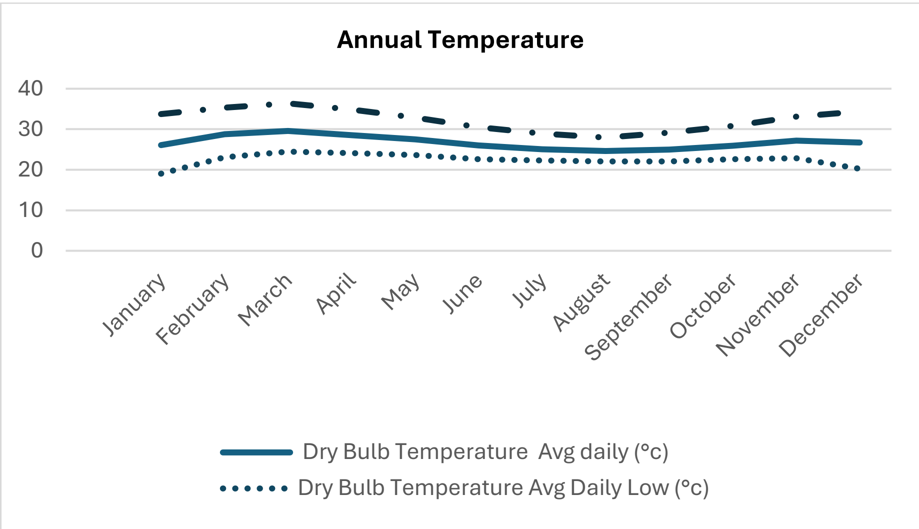


Figure 4-1: Illustration of outdoor Temperature by Climate Consultant 6.0

Relative Humidity

The annual relative Humidity is between 36-87 %, as shown in Figure 4-2, with the highest value recorded in August. This can be attributed to the high rainfall experienced during this period.

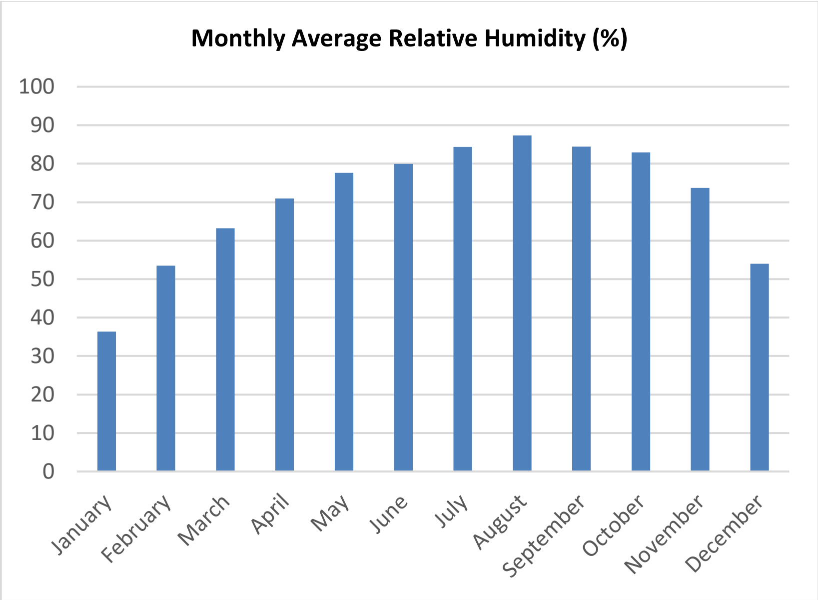


Figure 4-2:Illustration of outdoor Humidity by Climate Consultant 6.0

Wind Speed and Direction

Figure 4-3 shows an average daily wind speed of at least 1.8m/s is recorded throughout the year, with a peak value in June at 3.1 m/s.

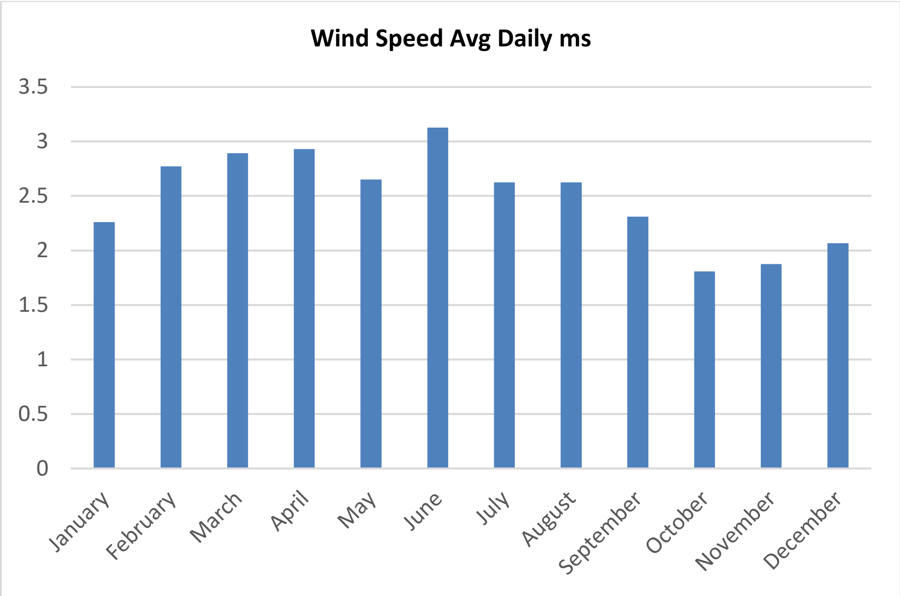


Figure 4-3:Illustration of Wind speed by Climate Consultant 6.0

Wind sources are predominantly Southwestern, with moisture at relative humidity above 70%. The southwestern wind is desirable for ventilation as its temperature is between 24-38 ˚C, see Figure 4-4.

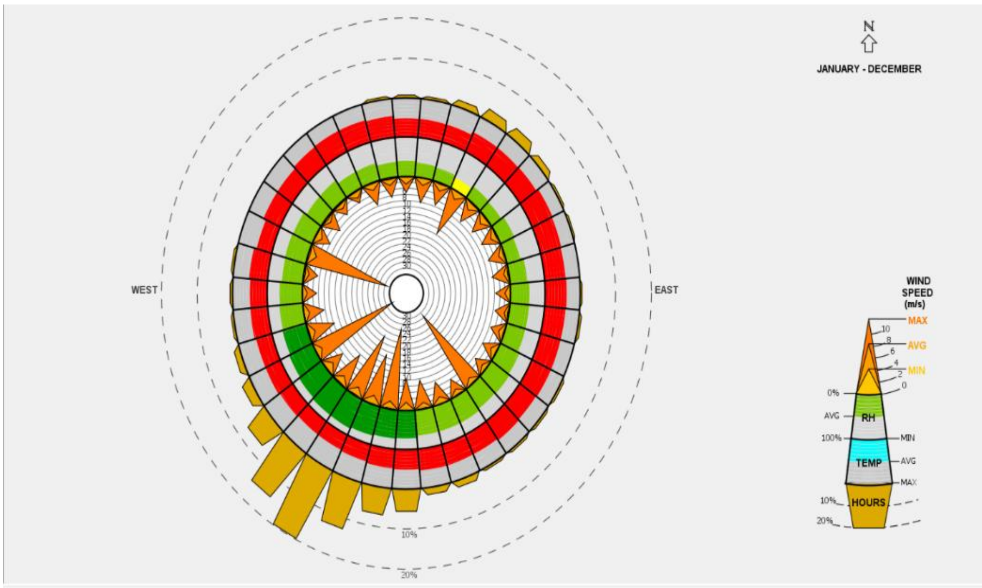


Figure 4-4:The direction of the wind by Climate Consultant 6.0

Sky cover and Solar radiation

The high level of sky cover was recorded between May and August and then from November to January, which signifies the tendency of overcast sky conditions in these months, as seen in Figure 4-5

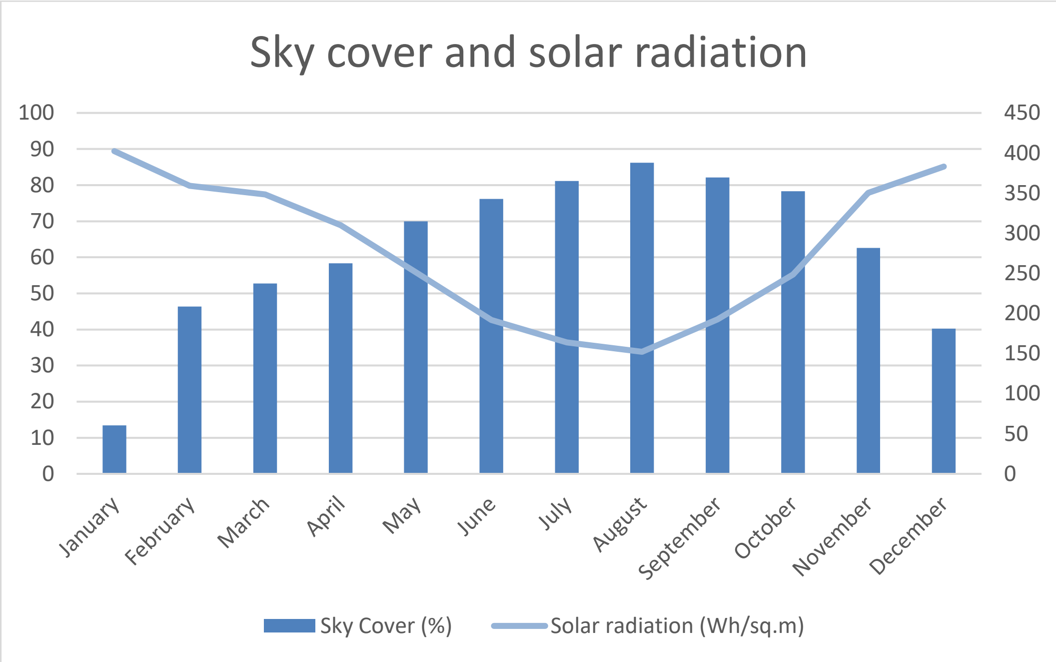
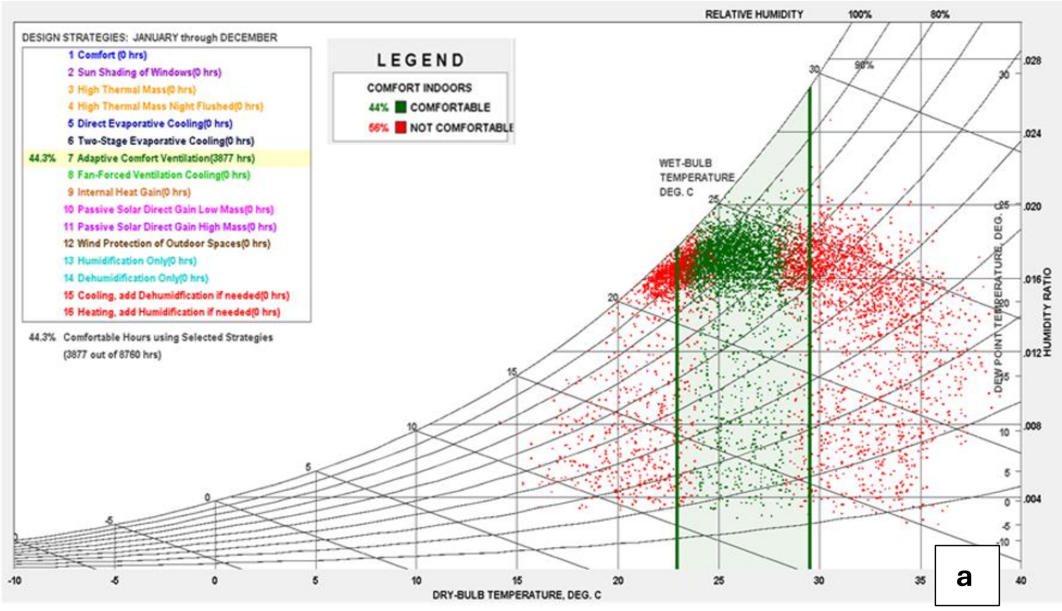
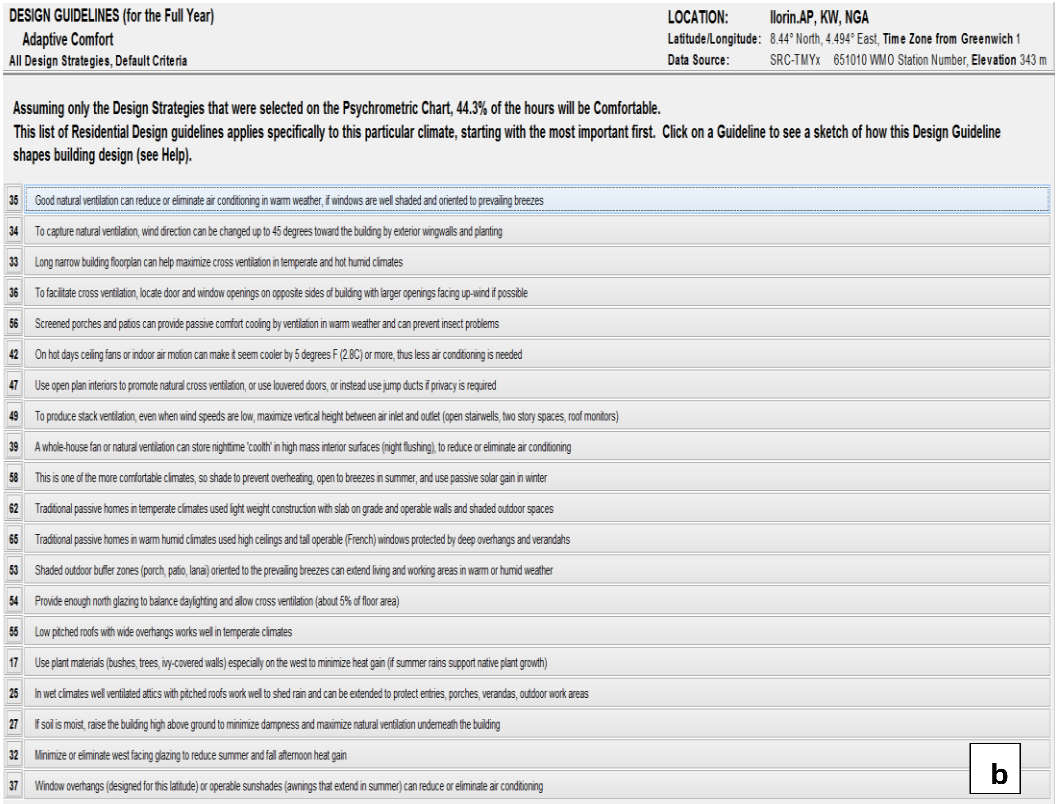


Figure 4-5: Sky cover and Solar radiation by Climate Consultant 6.0

4.3.2 Application of Psychometric chart in passive strategies





DESIGN GUIDELINES (for the Full Year)
Adaptive Comfort
All Design Strategies, Default Criteria

LOCATION: Ilorin.AP, KW, NGA
Latitude/Longitude: 8.44° North, 4.494° East, Time Zone from Greenwich 1
Data Source: SRC-TMYx 651010 WMO Station Number, Elevation 343 m

Assuming only the Design Strategies that were selected on the Psychrometric Chart, 44.3% of the hours will be Comfortable.
This list of Residential Design guidelines applies specifically to this particular climate, starting with the most important first. Click on a Guideline to see a sketch of how this Design Guideline shapes building design (see Help).

35	Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes
34	To capture natural ventilation, wind direction can be changed up to 45 degrees toward the building by exterior wingwalls and planting
33	Long narrow building floorplan can help maximize cross ventilation in temperate and hot humid climates
36	To facilitate cross ventilation, locate door and window openings on opposite sides of building with larger openings facing up-wind if possible
56	Screened porches and patios can provide passive comfort cooling by ventilation in warm weather and can prevent insect problems
42	On hot days ceiling fans or indoor air motion can make it seem cooler by 5 degrees F (2.8C) or more, thus less air conditioning is needed
47	Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required
49	To produce stack ventilation, even when wind speeds are low, maximize vertical height between air inlet and outlet (open stairwells, two story spaces, roof monitors)
39	A whole-house fan or natural ventilation can store nighttime 'coolth' in high mass interior surfaces (night flushing), to reduce or eliminate air conditioning
58	This is one of the more comfortable climates, so shade to prevent overheating, open to breezes in summer, and use passive solar gain in winter
62	Traditional passive homes in temperate climates used light weight construction with slab on grade and operable walls and shaded outdoor spaces
65	Traditional passive homes in warm humid climates used high ceilings and tall operable (French) windows protected by deep overhangs and verandahs
53	Shaded outdoor buffer zones (porch, patio, lanai) oriented to the prevailing breezes can extend living and working areas in warm or humid weather
54	Provide enough north glazing to balance daylighting and allow cross ventilation (about 5% of floor area)
55	Low pitched roofs with wide overhangs works well in temperate climates
17	Use plant materials (bushes, trees, ivy-covered walls) especially on the west to minimize heat gain (if summer rains support native plant growth)
25	In wet climates well ventilated attics with pitched roofs work well to shed rain and can be extended to protect entries, porches, verandas, outdoor work areas
27	If soil is moist, raise the building high above ground to minimize dampness and maximize natural ventilation underneath the building
32	Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain
37	Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning

b

Figure 4-6:(a & b) A psychrometric chart with environmental strategies for Ilorin city, Kwara state. ASHRAE-55 2004 using adaptive comfort model by Climate Consultant 6.0

The physical and thermodynamic characteristics of building air, such as humidity, enthalpy, air density, and dry and wet bulb temperatures, are visually represented in a psychometric chart (Aulicems and Szokolay, (2007). A psychometric chart is required to help determine the passive design technique used to provide year-round thermal comfort in buildings. These charts offer a summary of air conditions about the specific climate conditions and occupant comfort and subsequently it can be used to illustrate the passive design strategies that can ensure year-round thermal comfort provision in buildings.

The psychometric chart in this study, was created by importing the *epw*-weather file for Ilorin City into the Climate Consultant version:6.0 software. ASHRAE standard 55 and the most recent fundamentals model 2004 manual which indicates adaptive comfort model was selected to analyse this study area to guarantee cast of 100% of all strategies within the climatic zone as shown in Figure 4-6 (a).Also, the psychometric chart boundaries were defined to indicate the range of outdoor conditions that influence comfort provisions through air movement which has the potentials to render indoor conditions comfortable in naturally ventilated buildings. According to the analysis of ASHRAE-55 adaptive comfort via the psychrometric chart representing Ilorin, it was suggested that 44.3 % comfort hours was achieved in the entire year by keeping ambient temperatures within the predicted comfort range of 23.5 to 29.8 °C. However, it predicted that to achieve 100 % comfort hours would be possible, if the above passive strategies in the building design considerations and guidelines (see Figure 4-6 (b)) with full details in (Section 4.3.3) are adhered to to meet thermal comfort requirements for naturally ventilated buildings in Ilorin.

4.3.3 Building Design Considerations and Guidelines

A typical building may become uncomfortable due to high indoor temperatures, low perspiration rates, and high humidity from elevated temperatures. Similarly, low indoor temperatures can also lead to discomfort for building occupants. To address this issue, a climate-responsive approach to building design is essential. This involves understanding the local climate and identifying specific problems to create sustainable buildings. These buildings should keep occupants comfortable while minimizing energy usage and reducing the release of harmful gases into the atmosphere. According to Arup (2016), analysing climatic conditions using a psychrometric chart can help design passive cooling strategies to achieve comfort and meet building environmental design objectives. For instance, the requirement for the passive design of buildings in warm-humid climate zones, such as Ilorin and similar cities, should incorporate the following strategies obtained from the psychrometric chart analysed in Climate Consultant 6.0 software are as follows:

1. Consider the use of good natural ventilation, where windows are well-shaded and oriented to prevailing breezes. For instance, single-sided ventilation is achieved on one side of the wall, Cross-ventilation is when air intake and outlet openings are located at opposing walls across the room which creates a pressure difference across the space due to the openings at different heights, and Atria represents a ventilation chamber that improves the flow of air and enhances the stack effect with increased height difference.
2. Capture natural ventilation; wind direction can be changed to up to 45 degrees toward the building by external wing walls and planting.
3. Design sun-shading for a specific latitude to reduce or eliminate the need for air conditioning.
4. Minimize or eliminate west-facing glazing to reduce heat gain in warmer periods and in the afternoons.

5. Adopt the use of light-coloured materials for walls and roofs (with high emissivity) to reduce heat gain through conduction.
6. Ensure the use of open-plan interiors to encourage cross ventilation.
7. Select building materials with high thermal mass indoor walls to provide cooling and provide time lag.
8. Maintain and use passive design strategies developed by vernacular type architecture (where suitable).

According to the psychometric chart, ventilation is a crucial factor that improves passive energy efficiency and thermal comfort in naturally ventilated traditional houses. It is interesting to note that Ilorin's traditional adobe buildings are unique in that they primarily rely on adaptable comfort, as mentioned above, by utilizing passive cooling techniques through the creation of courtyards, small windows, and a combination of single-sided and cross-ventilation approaches.

4.4 Description of Case Study Buildings

The study area is situated in Ilorin, where the researcher identified six adobe traditional buildings within four local government areas: Ilorin East, Ilorin West, Ilorin South and Asa. These areas are illustrated in Figure 4-7 (A, B & C) depicting the maps of Nigeria highlighting Kwara State, and the map of Kwara State highlighting Ilorin Emirate/City. To evaluate the characteristics of Ilorin adobe traditional buildings in Ilorin, the researcher identified buildings with significant historic and cultural values constructed using adobe as the primary building material. These buildings include.

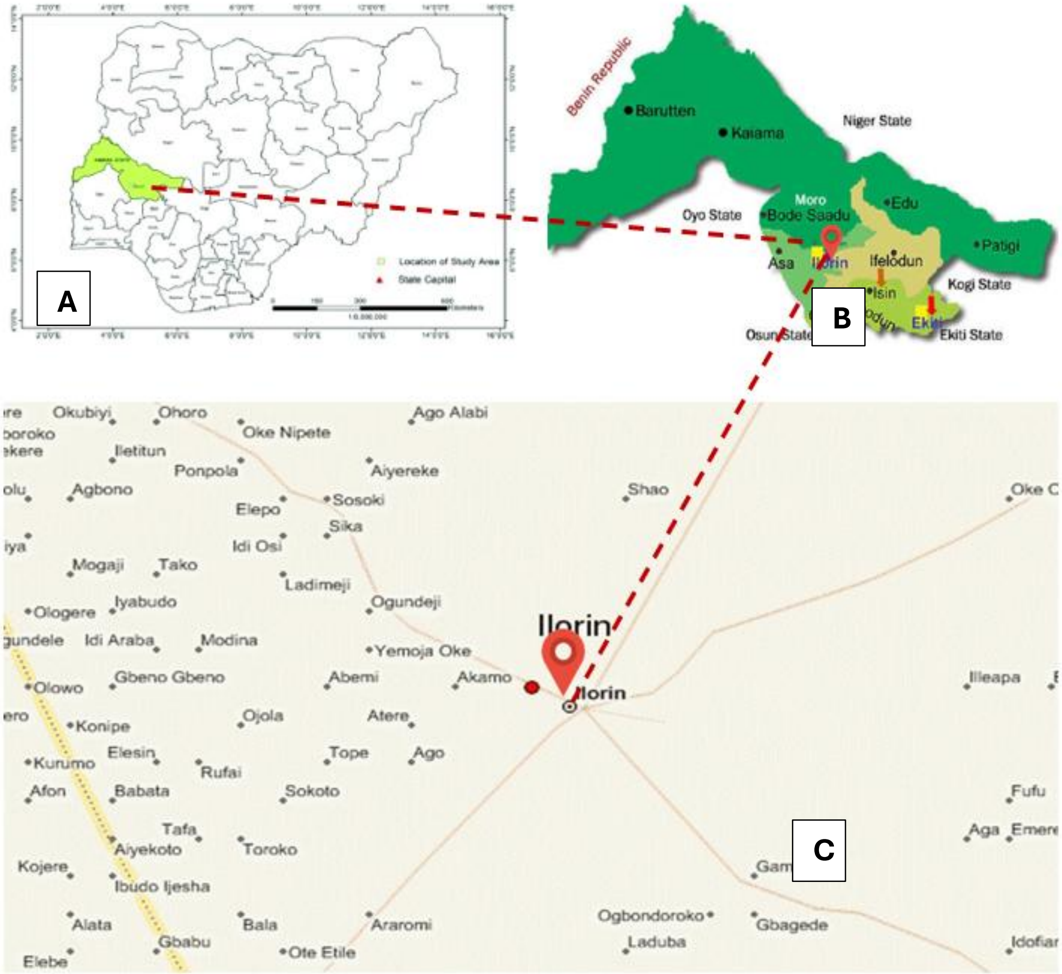


Figure 4-7:(A) Map of Nigeria, (B), Map of Kwara, (C) Map of Ilorin city

4.4.1 Case Study A

Case study A, also called the Judge's House, is situated in the Ilorin West local government area of rural Ilorin. Its coordinates are latitude 8°29'31.9"N and longitude 4°33'12.7"E. Built Circa 1920, this historic residential building stands as a remarkable representation of the unique cultural building styles of Ilorin, incorporating architectural influences from the Islamic faith and both Yoruba and Hausa ethnic traditions. The house was traditionally used as a venue for addressing minor disputes within the community. The central courtyards feature a well that supplies water to the compound and is surrounded by family rooms and the private quarters of the case study A. (Please refer to the appendix for additional photos).

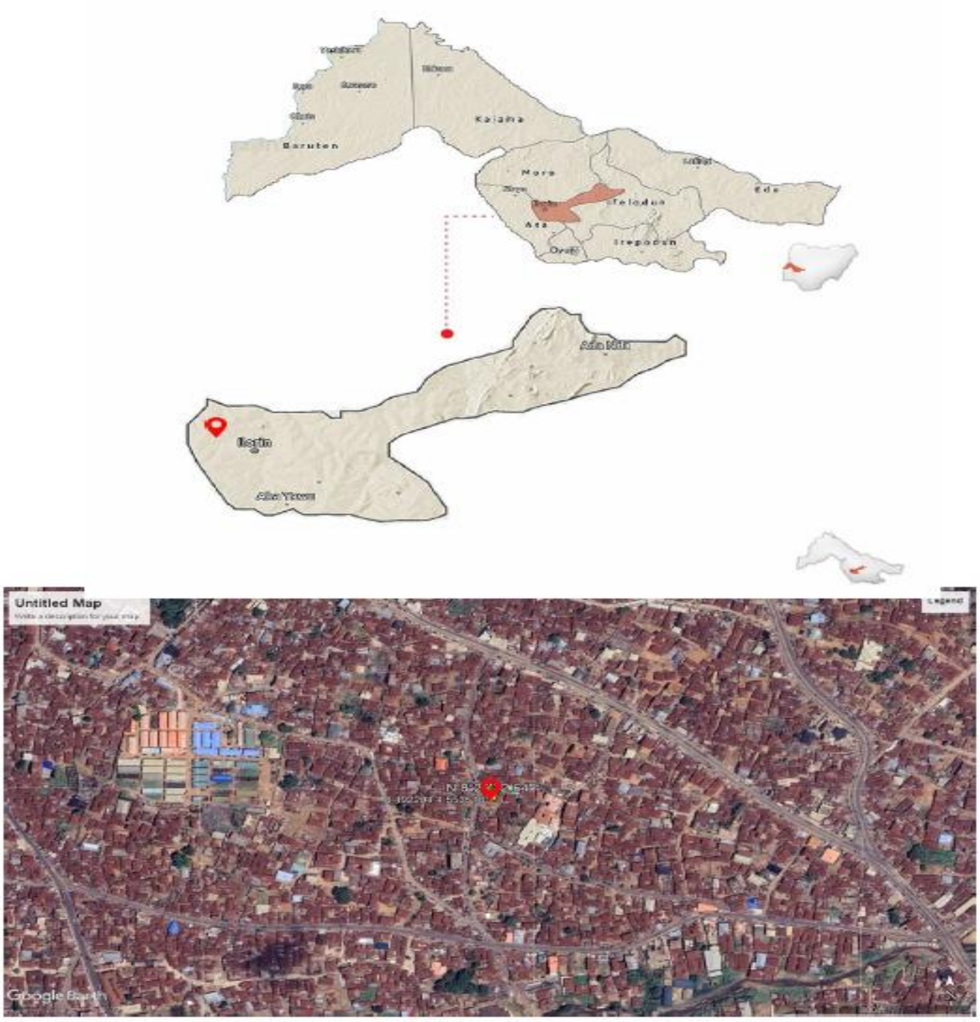
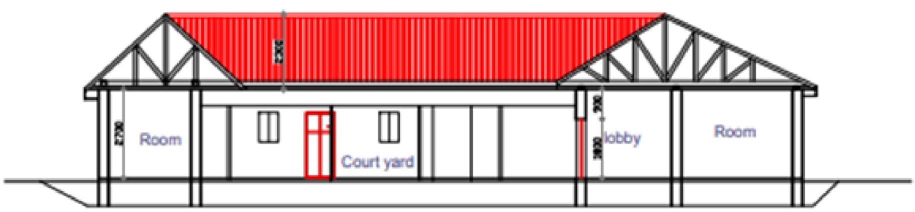


Figure 4-8:Google Earth view of Ilorin, showing the location of case study building A

FLOOR PLAN



SECTION A--A

Figure 4-9: Floor plan and section of Case study A by AutoCAD 2023

4.4.2 Case Study B

The case study building, Case Study B, is owned by a Daudu. It is located at latitude 8°29'50.1"N and longitude 4°33'09.4"E, off Princess Road in Ilorin South local government area (see Figure 4-10).

Figure 4-10: Google Earth view of Ilorin, showing the location of case study building B

Built around 1850, it is a significant old traditional residential building that showcases unique Ilorin architectural and cultural styles influenced by Islamic, Yoruba, and Hausa traditions. The building comprises different areas: The first courtyard serves as the men's court, where men and older boys entertain guests, including travellers visiting the Emir. Behind the men's court are the personal quarters of the Daudu, which include a living room, sleeping quarters, and storage rooms. Behind the

Daudu’s quarters is the women’s court, where the Daudu's four wives lived with their children. The family's burial place is behind the women's court, and the lavatory area is accessible from a passage to the left of the Daudu’s quarters. (Please refer to the appendix for additional photos).

Figure 4-11: Floor plan and section of Case study building B by AutoCAD 2023

4.4.3 Case study C

Case study C is situated in the Ilorin East local government area, with a latitude of 8°52'09.5"N and a longitude of 4°53'58.3"E (Figure 4-12). This is a significant traditional adobe structure with extensive cultural and historical relevance to the people of Ilorin, particularly those residing in the Okelele area. The pottery workshop in the courtyard adds to the structure's prominence. Built around 1850, the building is home to a pottery company owned by the current occupants, and the craft has been passed down through generations. The Yoruba ethnic group and the Islamic religion influence the architectural design of the building. It comprises of several bedrooms, a store, and a kitchen, all facing a central courtyard that separates the male and female sections. The family graveyard is located behind the women's court.

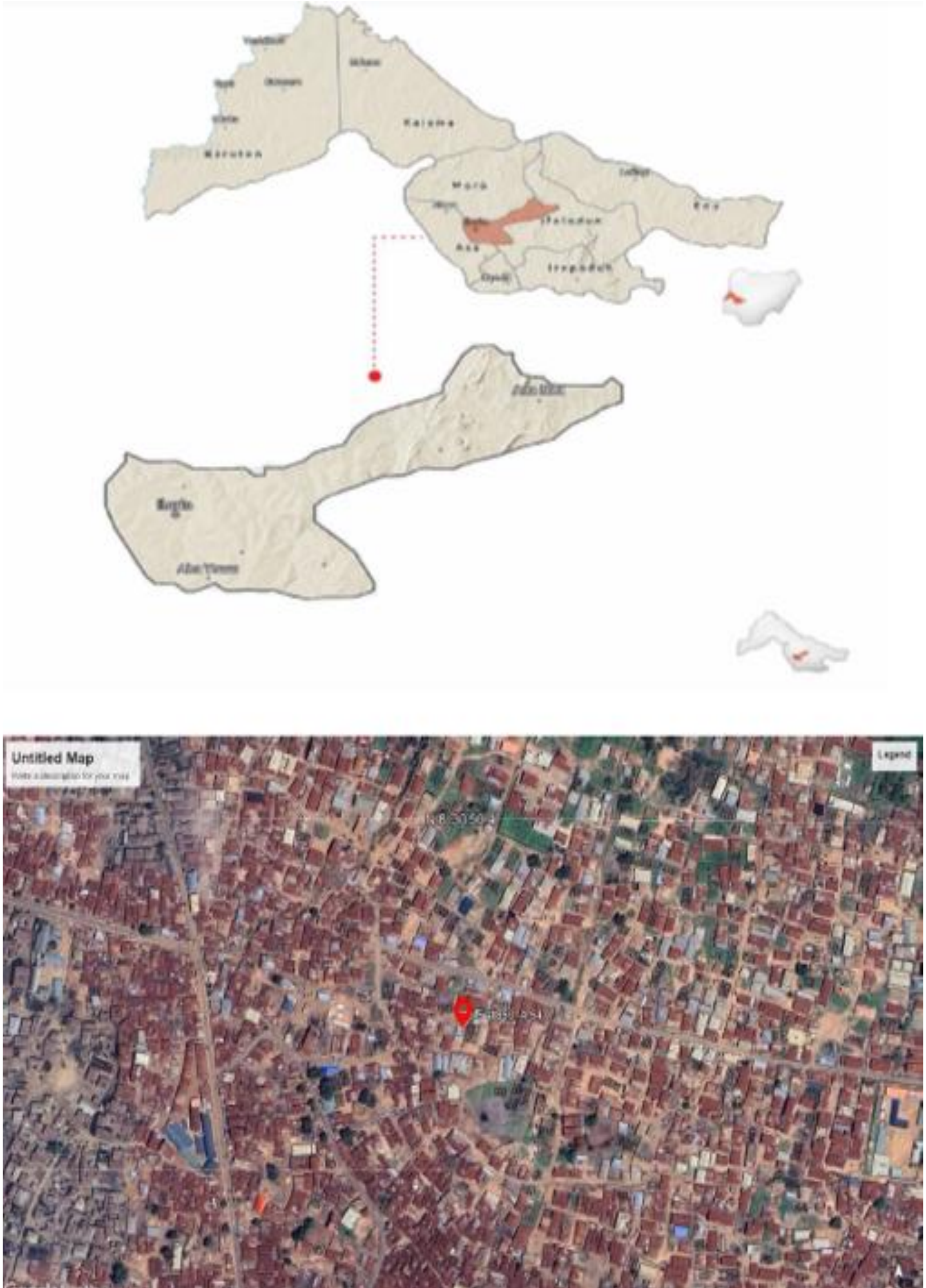


Figure 4-12: Google Earth view of Ilorin, showing the location of the case study building

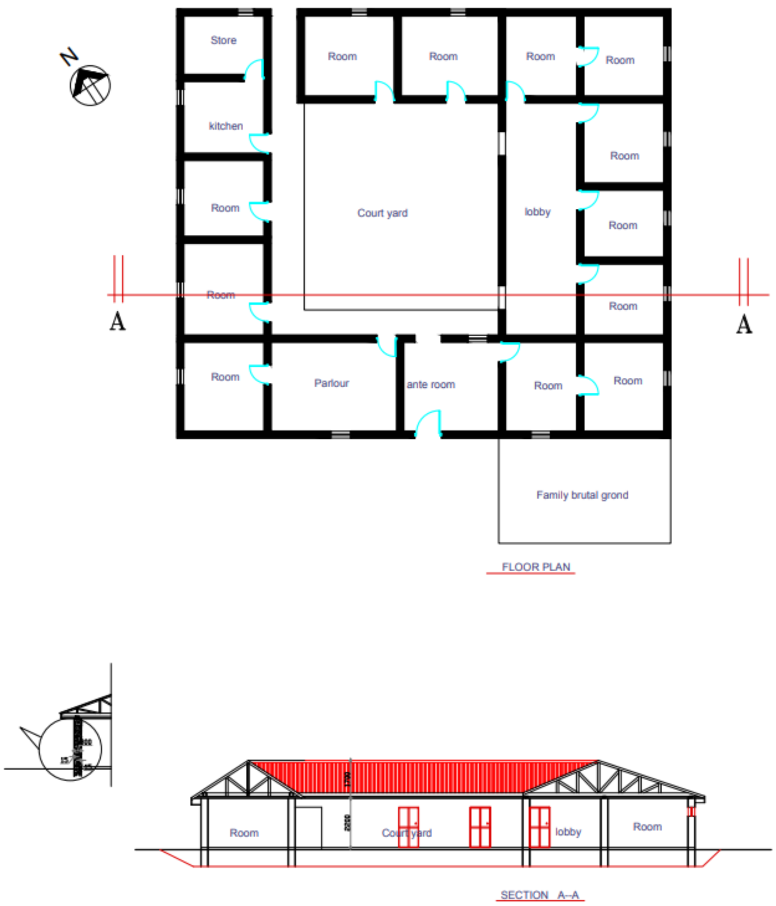
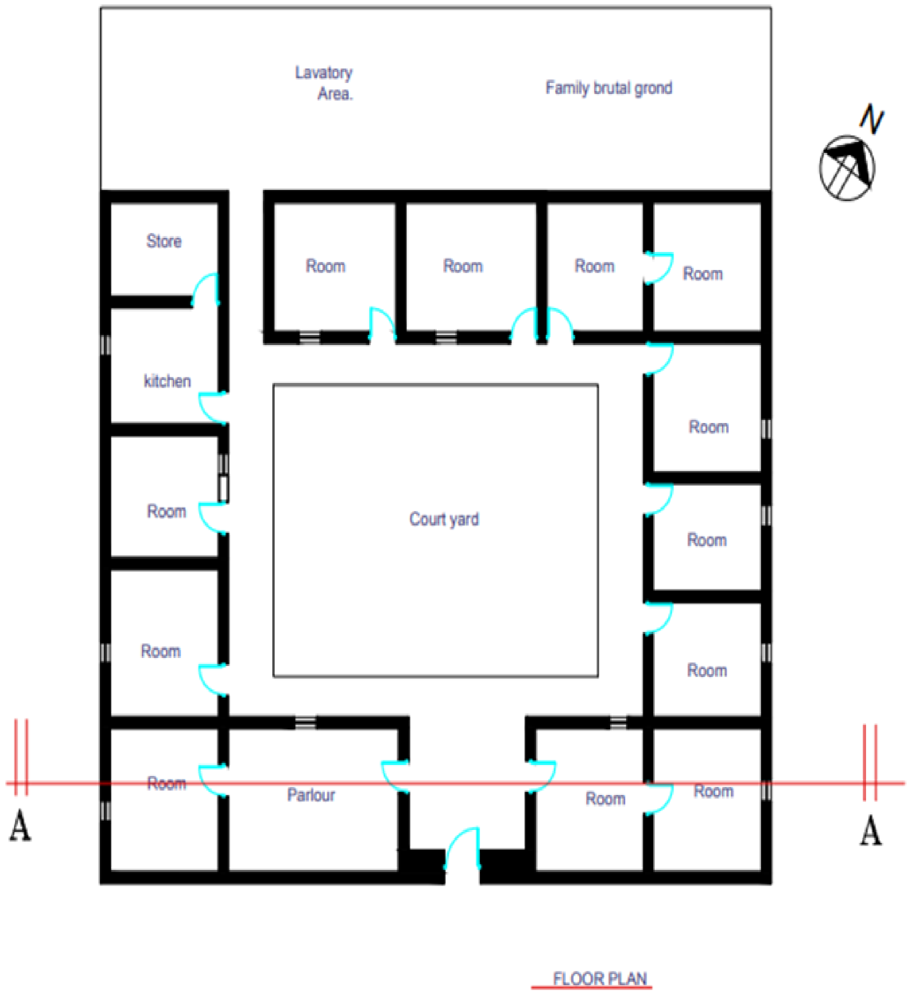


Figure 4-13: Floor plan and section of Case study building C by AutoCAD 2023

4.4.4 Case Study D

Case study D (House of the district head) is in Moya village situated in Ilorin East local government area and it is located at latitude 8°52’96.3"N and longitude 4°64’07.14"E. This building plays an important adobe traditional building with rich Historical and cultural values of the Moya people in Ilorin. It served as a mini palace that belonged to the district head, and it was built circa 1840; the building has been passed from generation to generation. The Islamic religion and the Yoruba ethnic group influence the architectural style of the building. The building comprises of several rooms and the private quarters of the Baale facing a central courtyard that separates the female quarters from the male quarters. Behind the court of the women was the burial place for the family members. (Please refer to the appendix for additional photos).

Figure 4-14: Google Earth view of Ilorin showing the location of case study building D



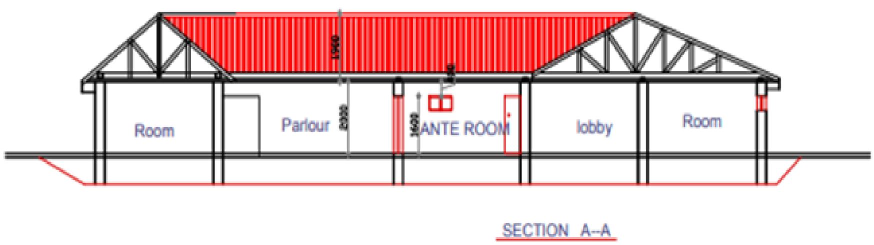


Figure 4-15: Floor plan and section of Case study building D by AutoCAD 2023

4.4.5 Other Case Study Buildings E & F

In this section, buildings E and F case study buildings were only studied to observe other traditional adobe building characteristics and building types that also exist in the Ilorin emirate. A compound located at Gaa Molari in the Asa local government area of Ilorin was identified, and it is located at latitude 8.6693382^{0}N and longitude 4.3996811^{0}E. The architectural styles showcase influences from the Islamic religion and the Yoruba ethnic group. The traditional buildings are made from hand-moulded adobe sun-dried bricks (Amoo) to design both round plans of detached units with a width equal to or slightly greater than the height of the building and the rectangular plans made to have a deep veranda extending for the width of the building in front. The thatch roofs of the buildings are made from elephant grass (Paasa) and are supported with sticks. The floors and walls of the adobe buildings are painted with cow dung (Boto)and supported with logs of wood as columns. All the adobe traditional buildings in the Molari compound were detached units arranged in multiple units built around large courtyards. (See Figures *4-16* and 4-17).

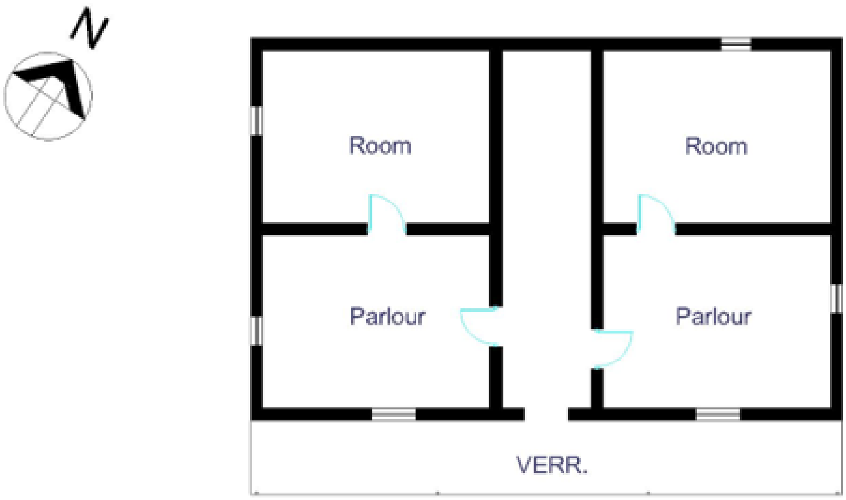


Figure 4-16: Floor plan of Case study building E

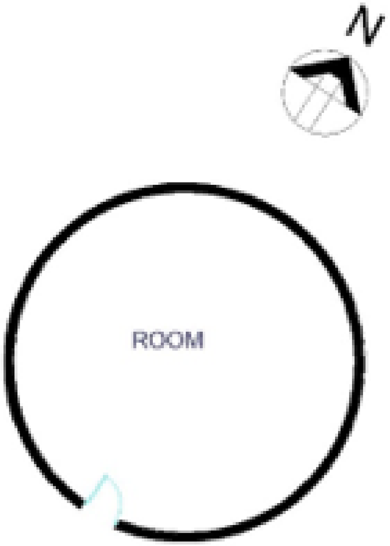


Figure 4-17: Floor plan showing Case study building F

4.5 Comparative Analysis of Traditional Ilorin Buildings

As previously indicated, the materials accessible in the warm, humid climate of Ilorin City, Kwara state, Nigeria, are used to construct the traditional buildings of Ilorin. These materials include sun-dried adobe bricks. Ilorin's indigenous population built their dwellings out of mud (*Amoo*), elephant grass (*Passa*), cow dung (*Boto*), and water, as a result, the distinctive traditional Ilorin adobe dwelling buildings were developed. It was observed that weather affects some of these traditional buildings, eroding the fabric construction materials over time, and the housing owners (locals of Ilorin) have devised various solutions for regular maintenance and enhancement of these old structures (Dmoschowski, 1990). To do this, adobe walls are plastered with cement to provide a protective layer against severe rainfall, and corrugated zinc roofing sheets are used in place of the elephant grass thatch roofs that were previously used. Typical Ilorin traditional adobe buildings have thick (300mm–450mm) external walls with small windows built deeply to provide shade and keep the interiors cool. The adobe material absorbs heat during the day and keeps the building cool, thus, the unique design of these homes aids in controlling indoor temperature. In the same vein, the thick walls then allow the stored heat to be released back into the house when the outdoor temperature drops and the nights become cooler, keeping the house's interior warm. The building envelope is the key to creating energy-efficient buildings; basic functional guidelines include combining elements like climatic conditions, building form, and material properties. In the warm-humid climate of Ilorin, where hot temperatures are encountered, this energy balance is highly influenced by the characteristics of the building envelope material, orientation, and window sizes.

A survey of existing traditional buildings in the city of Ilorin, Nigeria, was used to compile the "Ilorin adobe traditional Buildings Characteristics Table" to provide quantitative evidence of the composition and performance of the Ilorin adobe traditional building envelope. The primary goals in creating the table were focused on learning about and investigating residential architecture for two reasons:

I. To comprehend the primary architectural features of Ilorin's historic adobe structures.
II. To look at the architectural layouts of the old adobe structures in Ilorin that can be used to preserve thermal performance and energy efficiency without mechanical cooling aids. The findings show that all the buildings are almost of the same height (1-story), constructed using traditional building materials, and are all privately owned and occupied. An "Ilorin adobe traditional building Characteristics Table" was made for the study using the information on Ilorin's traditional adobe structures and their architectural features gathered over a year from other case studies from different local government regions of Ilorin.

To establish this, the elements of the characteristics Table were analyzed and divided into two groups: First, the architectural and design features of the case study buildings, and second, the thermal properties of the building envelope. The key findings in each area are described in the following sections, and how the goals above were achieved.

The characteristics table comprises basic building information, architectural characteristics/qualities, and thermal properties of the building envelope. The data compilation format was adopted from (Ghabra, 2018), and modified. The table was created as an Excel sheet consisting of 48 columns and 14 rows and was huge to be included in the body of this thesis, but you may find it in its full in Appendix (VIII).

4.5.1 General Information and Architectural Characteristics

Assessment of Architectural and Design Characteristics

The architectural features of the six case studies (traditional buildings) in Ilorin were analyzed concerning the primary design factors that affect the design of traditional residential buildings, and this includes the floor area, floor-to-ceiling height, plan geometry, courtyard location, façade, window ratio, and other elements that are also essential to traditional building designs such as lease span and floor plan efficiency which determine the occupied spaces. A typical adobe traditional building as previously mentioned in (Section 2.3.3) is usually a single storey (bungalow). This was observed during the post-occupancy survey visit. The floor plate efficiency of the buildings under investigation ranged from traditional buildings with rectangular plans: Case A (44.61%), Case B (41.44%), Case C (64.19%), Case D (44.63%), Case E (60%) to traditional buildings with circular plans: Case F (94.59%), it is established that large floor area is less efficient and compact floor areas are more efficient in cooling energy provision (Staszczuk at al., 2017).

The presence of courtyards in building design is an effective way of introducing passive cooling into buildings to enhance Passive energy efficiency, thermal comfort, ventilation, and lighting etc., this passive cooling method is known to be adopted into

Ilorin traditional building designs. According to Myneni (2013). The courtyard has a perfect climate for the tropics because it draws in cold air, which circulates inside the building and displaces stale air. Similarly, Soflaee (2004) explained further that when used as a passive cooling method, a central courtyard works as follows: as the day goes on and night falls, the air in the courtyard warms up. Natural convection layers of stored cool air in the courtyard flow into the rooms around it as the temperature in the courtyard gently rises in the morning, keeping the courtyard cool until solar radiation hits it directly. Having one or two central courtyards is the predominant system seen in the four structures investigated. As an illustration, one or two central courtyards are the predominant system seen in Case Study A and Case Study B; each has two courtyards. Case Study C and Case Study D each have one courtyard, while the other two, Case Study E and F, lack enclosed courtyards. Ilorin adobe traditional buildings have a lease span that varies from 1.5 meters (Case-studies A, C, and D, to 1.8 meters (Case-study B). All buildings studied had an average lease span of 1.57 meters. The tallest building has a floor-to-ceiling height of 2.7 meters, whereas the one from the rural area has a height of 2.0 meters. Furthermore, the introduction of wooden posts as an aesthetic and structural element in the design of Ilorin traditional adobe buildings; findings report that the use of wooden posts is a common design feature, where some are skillfully carved and decorated as seen in two Case study Figures 4-18 (A and B) while others were in form of sticks as shown in Case study D and F.

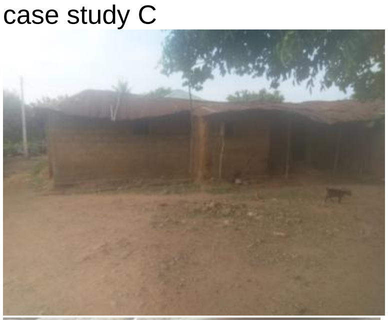
Figure 4-18: Carved and decorated wooden posts

4.5.2 Materials and Construction Method

The details of materials and construction methods are presented in Table 4-1.

Table 4-1: construction materials.

(a) Case study A 	• Construction materials**: Case A**, also known as Judge's House, is constructed of strong, 300 mm-thick adobe sun-dried bricks plastered with cement to preserve the walls. • The entrance of the building is adorned with wooden posts, windows, and doors that open onto a veranda that runs the length of the building's foyer. • The compound was originally roofed in thatch but now changed to a corrugated zinc roof which is supported by wooden frames, and it is designed to drain and harvest water for domestic use in the courtyard during the rainy season.

	
(b) Case study B  	• Construction materials: **Case study B** is made from 300 mm thick adobe sun-dried bricks with 15mm cement plaster that has a deep veranda extending through the width of the building in front. • The roof was originally thatch but now corrugated zinc supported by carved posts and raised to form a gable end at the entrance. • The entrance door into the compound is a large timber batten door large enough for the Daudu to ride into the compound on his horse; the raised roof in the entrance creates enough height for the main door. • The building has small sized windows for privacy.
(c) case study C  	• Construction materials of **Case Study C** building walls are composed of 300mm adobe sun-dried bricks, and the floors and walls are all plastered with cow dung. • The windows are small for privacy • The lintel, window, and doors are all made from wood, and the size of the main wooden door is 0.9 meters by 2.1 meters. • Corrugated zinc and hardwood frames support a zinc roof that drains and collects rainwater for use inside the home.

<table>
<tr>
<td>(d) case study D

</td>
<td>
Construction materials of case study D building is made from 300mm thick adobe sun-dried bricks with the walls and floors plastered with 7mm thick cow dung.
The main entrance is celebrated with thick adobe walls of about 450mm and a large wooden door measuring 0.9m by 2.1m.
All the posts, windows, and doors are of wooden designs.
</td>
</tr>
<tr>
<td>(e) case study E & case study F


</td>
<td>
Construction materials in Case study E and Case study F traditional buildings are made from hand-molded adobe sun-dried bricks (Amoo) to design both round plans (250mm thick walls) of detached units with a width equal to or slightly greater than the height of the building, the rectangular plans(300mm thick walls) made to have a deep veranda extending for the width of the building in front.
The curvilinear-shaped houses stand as single units.
The thatch roof of the buildings are made from elephant grass (Paasa) and are supported with sticks.
The floors and walls of the adobe buildings are painted with cow dung (Boto)and supported with logs of wood as columns.
The buildings have no or very few small windows for privacy
</td>
</tr>
</table>

4.5.2.1 Thermal Properties

Table 4-2 explains the thermal characteristics of the building envelope, including the thermal transmittance (U-Value) of the flooring, walls, and roofing materials and the Form factor.

i. The U-Value of Building Materials

The research revealed that the most common walling materials used on traditional buildings in Ilorin ranged from 300mm thick adobe sundried bricks plastered with 15mm thick cement on both the external and internal sides of the wall (U-value =0.64 W/(m^2K)) to only 250mm thick adobe sundried bricks or occasionally plastered with cow-dung (U-value =0.54 W/(m^2K)). In terms of the building's flooring materials, two of the case study buildings have floors made of 15 mm thick mud plastered with 10 mm thick cement (U-value = 3.49W/(m^2K)), while the other four buildings have floors made of 25 mm thick mud (U-value = 3.18 W/(m^2K)). CIBSE (2016) provided all the measured thermal conductivity values mentioned above, these values were further computed in the Passive House Planning package tool (PHPP) Excel worksheet and subsequently computed in the integrated environmental solution simulation software (IES-ve).

ii. The Form factor

Foundation, (2016) describes form factors as a building's design and shape that can have a big impact on its energy use. The type and shape of a building can generally be characterized as its "Form Factor," a property that can be quantified.

It is calculated as seen in equation 4-1

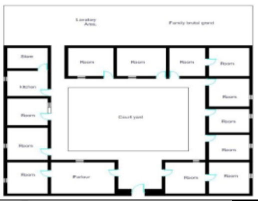
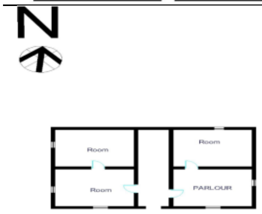
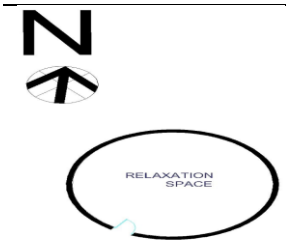
$$\text{Form Factor } (FF) = \frac{\text{Total heat loss area of walls,roofs,floors and openings (m2)}}{\text{Habitable floor area of all storeys (m2)}} \qquad (4\text{-}1)$$

This basically means heat loss from the ratio of thermal envelope surface area to treated floor area (TFA). The heat loss form factor is calculated to indicate energy efficiency and cost implications. The Passivhaus standard aims for a form factor of 3 or less, as higher values make efficient heating in temperate/ cold climates and cooling in warmer climates more challenging (Thorpe, 2018). The Ilorin adobe traditional buildings examined in this study showed varying form factors ranging from 2.2 to 3.4, where the least was 2.2 (case study B), 2.7 (case study D), 2.8 (case study A and case study C),3.15 (case study E) and the highest 3.4 (case study F).

iii. ***Energy consumption***

Ilorin adobe buildings demonstrate how energy-efficient passive controls can be; the monthly energy cost of traditional buildings was low compared to newly constructed conventional buildings, with most energy being used for artificial lighting. As the buildings are naturally ventilated, energy utilization for climate management was not a critical concern.

Table 4-2: Thermal properties

Case study	Typical Floor Plan	Occupancy	Wall fabric U-value	Roof Material U-value	Floor Material U-value	Form factor
CASE A		Private	Adobe sun-dried bricks with plaster cement. U-value = $0.64 (W/m^{2}. K)$	Zinc covering with wooden frame U-value = $7.14 (W/m^{2}. K)$	15 mm thick mud floor plastered with 10 mm thick cement U-value = $3.49 (W/m^{2}. K)$	2.8
CASE B		Private from forefathers	Adobe sun-dried bricks with plaster cement. U-value = $0.64 (W/m^{2}. K)$	Zinc covering with wooden frame U-value = $7.14 (W/m^{2}. K)$	15 mm thick mud floor plastered with 10 mm thick cement U-value = $3.49 (W/m^{2}. K)$	2.2
CASE C		Private	Adobe sun-dried bricks with plaster cow dung U-value= $0.54 (W/m^{2}. K)$	Zinc covering with wooden frame U-value = $7.14 (W/m^{2}. K)$	25 mm thick mud floor covered with a thin layer of cowdung U-value = $3.18 (W/m^{2}. K)$	2.8
CASE D		Private	Adobe sun-dried bricks with plaster cow dung U-value = $0.54 (W/m^{2}. K)$	Zinc covering with wooden frame U-value = $7.14 (W/m^{2}. K)$	25 mm thick mud floor covered with a thin layer of cowdung U-value = $3.18 (W/m^{2}. K)$	2.7
CASE E		Private	Adobe sun-dried bricks with plaster cow dung U-value = $0.54 (W/m^{2}. K)$	Zinc covering with wooden frame U-value = $7.14 (W/m^{2}. K)$	25 mm thick mud floor covered with a thin layer of cowdung U-value = $3.18 (W/m^{2}. K)$	3.15
CASE F		Private	Adobe sun-dried bricks with plaster cow dung U-value = $0.54 (W/m^{2}. K)$	Thatch covering with frames made from sticks U-value = $0.33 (W/m^{2}. K)$	25 mm thick mud floor covered with a thin layer of cowdung U-value = $3.18 (W/m^{2}. K)$	3.4

4.6 Discussion: Similarities and Dissimilarities

4.6.1 Some similarities of the Adobe traditional buildings examined

i. Ilorin's urban/city and rural areas include rectangular-shaped traditional adobe structures.
ii. The floor plate efficiency varies in both types of buildings, with some situations having better efficiency and others having lower efficiency
iii. In traditional Ilorin building designs, courtyards are a common element regardless of whether the buildings have circular or rectangular floor plans.
iv. All the case study buildings employ passive cooling strategies, with courtyards contributing to improved passive energy performance and thermal comfort.
v. The houses in all case studies are constructed using Adobe sun-dried bricks. The walls' thickness varies from 250mm to 450 mm. Additionally, wood is always utilized for the pillars, windows, and doors.
vi. Thatched Roof: Some of the structures originally had thatched roofs, but they were later replaced with corrugated zinc roofs to preserve the buildings. These roofs are now designed so that rainwater can be collected for use in the courtyards.
vii. Regarding privacy, all the buildings feature small or few windows, which suggests a preference for privacy.
viii. Many buildings have a veranda extending in front of the main entrance, providing a shaded outdoor space.
ix. Use of Traditional Plastering Materials: In some buildings, including Case study C and study D, the walls and floors are plastered with cow dung.

4.6.2 Dissimilarities of the Adobe traditional buildings examined

i. Buildings in urban areas typically have simpler geometry and rectangular designs, but those in rural areas typically have a combination of circular and rectangular forms.
ii. In comparison to traditional buildings with rectangular plans, which range in efficiency from 41.44% to 64.19%, traditional buildings with circular plans (Molari I) have far higher efficiency (94.59%).
iii. In contrast to the traditional buildings with circular plans (Gaa- Molari), which lack enclosed courtyards, traditional buildings with rectangular plans typically have one or two central courtyards as their primary feature.
iv. The buildings also have different floor-to-ceiling heights ranging between 2m to 2.7m and lease spans, each with different dimensions.
v. The window sizes of the buildings studied vary, with different window areas ascribed to differing cultural beliefs on privacy.
vi. The buildings have different ventilation strategies, some of which combine cross- and single-sided ventilation with others that only use cross-ventilation or single-sided ventilation.
vii. Roofing Material: Elephant grass thatched roofs are used on some traditional buildings, while others have corrugated zinc roofs.
viii. Entrance Design: The entrance designs vary amongst case studies, with variations in the size of the doors, the thickness of the walls, and the presence of raised gables.
ix. Building Plans: The buildings have a variety of shapes, such as rectangular, round, and curvilinear
x. Wall plastering: Some buildings use cement to plaster their walls, while others utilise cow dung.

4.7 Conclusion

This chapter concludes by thoroughly reviewing the first phase of the core investigation into the traditional adobe buildings of Ilorin that have historical significance. Ilorin City in Nigeria was used as the case study location, to identify the necessity of addressing the deterioration and destruction that these adobe traditional buildings are experiencing. The selection criteria of the case studies emphasise the relevance of their historical and cultural significance as well as the assessment of their thermal performance. In addition, the chosen traditional buildings showcase Ilorin's exceptional architecture and are notable buildings owned by district heads. Architectural data collected indicates the performance of building envelopes in terms of heat transfer and solar gains. Critical variables affecting the performance of the building were identified through the evaluation of the thermal characteristics of the building envelope. To comprehend the typical architectural features of the traditional Adobe buildings in Ilorin, building survey and measurement proved effective in understanding the design and construction details of fabric and would guide the parametric process in the subsequent chapters. The fieldwork which was undertaken to collect data on the traditional buildings aided a systematic documentation and characterisation by using a standardised guide to be accomplished. The chapter's conclusion highlights the architectural characteristics and thermal qualities of Ilorin adobe traditional buildings selected in the study. Also, the use of thick adobe bricks for wall construction, wood for structural and decorative purposes, planning the functional spaces around the central courtyards, and small windows as openings for ventilation are all characteristics of these buildings. Therefore, understanding the distinctive features of Ilorin's traditional adobe buildings can help to preserve their thermal performance and energy efficiency without the use of mechanical cooling. It also offers insightful information about local cultural heritage preservation in a way that ensures their long-term sustainability, good thermal performance, and cultural relevance, which sets the stage for the investigation of the occupant's perception of these buildings, which is thoroughly examined in the next chapter.

Chapter 5: Occupiers' Perception Questionnaire

5.1 Introduction

This chapter presents the second stage of core research. The fieldwork was conducted in Ilorin, Nigeria, during the months of August 2022 and March 2023 to investigate the thermal comfort and the compatibility of Ilorin's traditional Adobe buildings. The research hypothesis: Do the vernacular architectural strategies employed in Ilorin adobe buildings effectively address local thermal comfort, cultural significance, materiality, and pertinent climatic issues? Furthermore, can these insights inform the design of improved adobe residential buildings that enhance thermal comfort? This study addressed whether Ilorin adobe traditional buildings are fit for purpose and, therefore, worth preserving in their original form / improved form. Information was gathered and examined through a survey based on lived experiences. The chapter aims to study the influence of climatic conditions, building characteristics, and cultural values on the thermal comfort experienced by occupants of traditional adobe buildings in Ilorin, Nigeria.

5.2 Approach and Scope

This chapter discussed the second stage of the research methodology, which involves the subjective evaluation of post-occupancy documentation and occupants' thermal perceptions and preferences. This was achieved by administering 225 questionnaires to the population of the Ilorin Emirate across three local government areas, ensuring that all respondents had experience living in traditional adobe buildings in Ilorin. This section entails the occupier's perception and thoroughly examines the occupant's thermal comfort in traditional Ilorin adobe buildings. It employs a multimethod evaluation approach of the thermal comfort of traditional residential buildings in a warm-humid climate, focusing on Ilorin adobe traditional buildings.

5.3 Method

The primary aim of this chapter is to delve into the current state of traditional adobe buildings in Nigeria, particularly focusing on the Ilorin adobe traditional buildings in the warm-humid climatic zone. The focus is on understanding how these buildings offer thermal comfort and evaluating the satisfaction levels of the occupants living in these structures. To accomplish this, a mixed-method approach of post-occupancy evaluation was utilised to gather environmental and human data. This involved conducting a field survey to discern the users' perception of thermal comfort through two stages, as seen in Table 5-1.

Table 5-1: Links research goals and techniques used in the post-occupancy assessment.

Goals	Methods
To investigate thermal sensation and thermal preference experienced by the Ilorin traditional adobe residential building occupants.	self– administered survey
To Identify current architectural adobe traditional building design components associated with thermal comfort	Building measurement and design
To obtain in depth understanding of the maintenance strategies for adobe traditional building from lived experiences	Interview

1. Self-administered questionnaires comprised closed and open-ended questions related to indoor temperature, humidity, air velocity, and the thermal sensation and preference experienced by the occupants.

2. Building measurements and design.

3. Structured interview.

5.3.1 Sampling Technique and Sample Size

Ilorin Central is a city with three (3) senatorial districts. From these, one (1) senatorial district was specifically selected, and within this district, three (3) out of five (5) local government areas were also chosen. To provide further context, one selected local government area contained two communities, while the other had one community. At the time of this report, four communities within three local government areas were purposefully selected for questionnaire administration. The study employed transverse survey sampling to gather data on the thermal sensation vote, thermal satisfaction scale, and thermal preference of occupants in traditional residential buildings. This method involves collecting a single comfort assessment from a considerable proportion of the population, reducing bias and minimising disruption to participants' lives and work. It was crucial to determine the sample size to obtain representative information from traditional Ilorin adobe buildings. Therefore, data on the thermal sensation vote, thermal satisfaction scale, and thermal preference were collected using transverse survey sampling to assess indoor thermal comfort. The sample size for the total households of Ilorin (East, West, and South) local government areas was determined to obtain representative data from the Ilorin adobe traditional buildings. This information is presented in Table 5-2.

Hence, the sample size survey was calculated based on the following:

i. Population size of each local government area - Source: National Population Commission of Nigeria (web), National Bureau of Statistics (web)

   Ilorin East = 280,000 Population [2016] – Projection

   Ilorin West = 493,000 Population [2016] – Projection

Ilorin South = 282,500 Population [2016] – Projection

ii. Sample size equation of each local government area (Raosoft.com,2022).

Table 5-2: Survey sample

Local government survey area	Ilorin East	Ilorin West	Ilorin South
Margin of error can you accept	10%	10%	10%
Confidence level	90%	90%	90%
The population size	280,000	493,000	282,000
The response distribution	50%	50%	50%
Recommended sample size	68	68	68
10% non-response	7	7	7
Total Sample size for Ilorin East LG	75	75	75
The grand total sample size for the three Local Government areas = 225			

5.3.2 Data analysis with SPSS

Statistical Package for the Social Sciences (SPSS) is an extensive tool created by IBM in 1968 for statistical data analysis. It is used to examine survey responses and generate XML files. It also facilitates the construction of predictive models, computes mean and creates frequency distributions. In addition to measuring survey reliability, SPSS makes data processing and numerical representations of qualitative data easier. For this reason, SPSS was used to analyse all the occupants' responses in this chapter.

5.4 Semi-structured interview

Following a comprehensive building assessment, in-depth interviews were held with the heads of households. These key informants oversaw and managed the buildings/ rooms in their compounds. To obtain additional insights that would complement the occupants' questionnaire responses, an interview was conducted with household heads with interview questions that centered around the following subjects:

i. Building envelope character

ii. Building material degradation perceived/experienced

iii. Building construction

iv. Preservation techniques commonly administered

iv. Any other information

The information gathered from the interviews was utilised to create a framework for building maintenance and retrofitting procedures and offered details for the parametric process. Findings from the key informant interview gave insight into the maintenance of Ilorin traditional heritage buildings under the headings below; the following interview questions were levelled and responded to.

5.4.1 Interview Results

I. **Building envelope character**

Three significant building composition envelopes are commonly used for walls, floors, and roofs.

A). Adobe walls, mud covered with cow dung, and thatch roofs.

b). Adobe buildings with corrugated zinc roofing sheets and mud floors.

c). Cement-plastered adobe walls and floors with corrugated zinc roofing sheets.

II. **Building material degradation perceived/experienced**

During the interview, questions were asked about any building degradation, and an explanation of three major degradation agents was required.

a) Atmospheric agents caused problems associated with dampness and stains, chipping off walls around the base, cracks, collapse, and running water from rainfall and wind.

b). Biological agents cause problems, such as moulds and lichens, vegetation development, holes, and small cracks.

c). Human factors as agents as major contributors to introducing unsuitable elements in heritage buildings will be questioned and discussed.

III. **Building Construction**

Occupants shall be asked about the Adobe building construction method and elements used in traditional Ilorin buildings, such as wall, floor, and roof finish.

iv. Preservation techniques commonly administered

Questions on preservation techniques and how they were commonly administered will be asked during the interview. These questions for the interview will serve as a guide in setting the methodologies of research assessment chapters.

5.5 Questionnaire Process

The questionnaire was initially composed in English and then translated into Yoruba, the local dialect of the Ilorin people to ensure better understanding and avoid misunderstanding. This section outlines the process of occupant assessment and presents a subjective approach using an interviewer-administered questionnaire. The questionnaire was developed per the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) ANSI/ASHRAE standard 55. This ASHRAE guideline is applied to building performance designs and sets the minimum research requirements for occupant comfort. A total of 225 questionnaires were distributed among occupants of traditional adobe buildings in the Ilorin emirate, with 213 respondents received. These buildings were selected based on their habitability, and occupants agreed to participate in the survey. At the beginning of the survey, the participants were provided with documents that included a consent form outlining the purpose of the research, a brief introduction to the survey, information explaining the confidentiality and anonymity of their data under the University of Nottingham privacy notice, and general data protection regulations. Additionally, participants were asked to fill out and sign a document titled "Information and Declaration," indicating their agreement to take part in the survey.

5.5.1 Questionnaire preparation and application

The survey assessed the overall thermal and visual comfort of occupants living in traditional Ilorin adobe buildings. According to Subramanian et al. (2021), all occupants' well-being, health, productivity, and thermal comfort are crucial to be achieved. The survey is divided into two parts. The first section comprises six major questions that gather information about the survey's focus, survey area, general building details, occupants' personal information, occupancy and maintenance schedules, as well as participants' satisfaction with specific building components and overall building quality. The second part consists of seven major questions, including personal inquiries about the participants, such as sex, age, cultural attachment, and attire worn during the survey. Additionally, respondents were asked about their experiences with climate, indoor thermal and visual conditions. For additional details, please refer to the APPENDIX IV for the Questionnaire Model.

5.5.2 Questionnaire Structure

Part two of the questionnaire was specifically crafted to gather insights from occupants of traditional adobe buildings in Ilorin. The questions were tailored around the 7-point scale of ASHRAE-55, 5-point scale of ASHRAE-55, level of clothing, and cultural attachment. The primary objective was to assess the impact of environmental features on the comfort of the building occupants, particularly focusing on thermal satisfaction and heat sensation votes on the scale. (Please refer to Figure 4-1 and Table 5-3 for details).

Table 5-3: Questionnaire structure

S/No,	Question (variable) Levels	Question number	Objectives
		Part 1	
1.	Survey area	1	To examine and characterize Ilorin adobe traditional buildings.
2.	Building information	2,3,4,5	
3.	Occupancy and maintenance	6,7,8	To determine the minimum thermal comfort conditions in buildings. Develop an accessible maintenance framework and integrate it into the nation's building policy documents.
		Part 2	
1.	Personal information	1,2	To evaluate the thermal performance of traditional adobe buildings in Nigeria, for the selected case study buildings.
2.	Comfort, sensation, perception votes and comfort parameters; daylighting, artificial lighting, and visual.	3,4,5	
	Clothing	6	Determine the minimum thermal comfort conditions for occupancy in buildings.
	Cultural attachment	7	Create a maintenance framework for the nation's building policy documents.

5.5.3 Comfort Scales

Indoor temperature, indoor relative humidity, Natural lighting, ventilation and overall thermal comfort responses were sorted out using the subjective satisfaction scale of (-3 to +3) where -3 = extremely dissatisfied, -2= very dissatisfied, -1 = dissatisfied, 0 = Neutral, 1= Satisfied, 2 = Very satisfied and 3 = Extremely satisfied. In addition, a dissatisfaction scale (descriptive thermal sensation scale). .

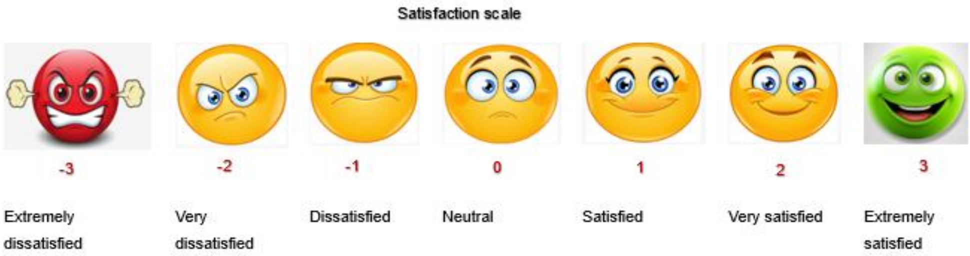


Figure 5-1: Thermal comfort scale

Table 5-4: Descriptive comfort variable sensation scale

1	2	3	4	5
Too dark	Dark	Neutral	Bright	Very bright
Too drafty	Drafty	Neutral	Stuffy	Too stuffy
Too noisy	Noisy	Neutral	Quiet	Very quiet
Too cold	Cold	Neutral	Warm	Too hot
Too humid	Humid	Neutral	Slightly dry	Too dry
Too breezy	Breezy	Neutral	Slightly still	Too still

Another subjective scale assessed metabolic levels were *clo* values (< 0.5,0.6-1.2, 1.3-1.7, 1.8 – 2.4, 2.5- <3.5). Lastly, a descriptive scale was employed to assess cultural attachment to Ilorin traditional adobe buildings in this survey: Prefer not to say (1), Not at all important (2), Not very important (3), Somewhat important (4), Very important (5). Furthermore, data on thermal perception was gathered from the responses obtained from the respondents, which covered both the hottest and the coldest months when discomfort due to overheating and extremely cold temperatures was experienced in March and August. See Appendix IV.

5.5.4 Questionnaire Results

Primary and secondary sources of information were used to gather data for this study. The primary data sources were household surveys, focus group talks, and key informant interviews with respondents who had experience living in Ilorin adobe traditional houses. The secondary data were books, various papers, and government publications. In Figure 4-2, the pie chart shows that 96% of the respondents were occupants of adobe traditional houses, which includes the four case study buildings. The remaining 4% of the respondents had previously lived in adobe traditional buildings.

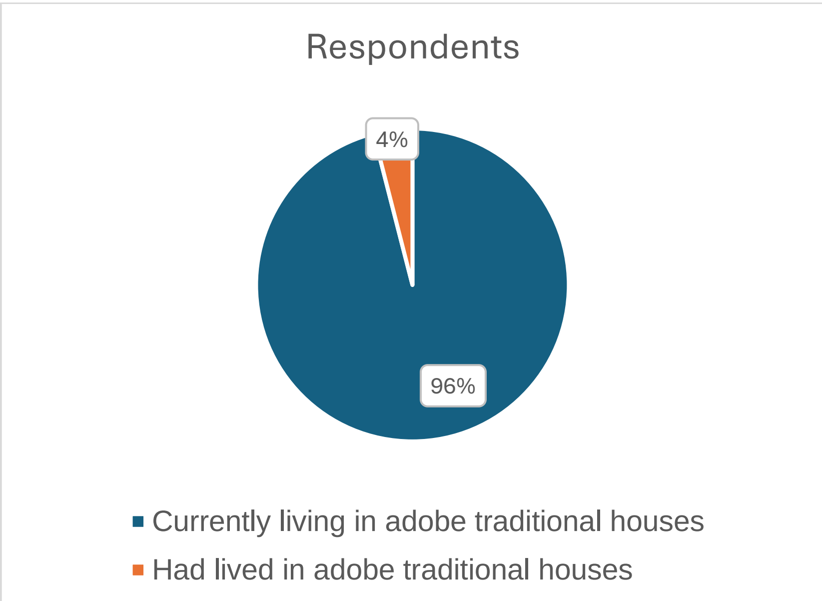


Figure 5-2: Distribution of respondents

5.5.5 Socio-economic Characteristics of the Respondents

As discussed in section 4.3.1, the study was conducted between July 2022 and August 2023 in 5 communities within three local government areas. A total of 213 respondents were obtained, and the occupants' responses were compiled using Statistical Package for Social Sciences (SPSS) version 19 and Microsoft Excel. The questionnaire population of 213 people was from the sample. The respondents were identified as occupants currently living and occupants who have lived in traditional Ilorin buildings at the time of the study; see Figure 5-2. The results consisted of 109 males (51%) and females103 (49%) out of a total respondent of 212 occupants (N = 212), as indicated in Figure 5-3. Also, Figure 5-4 revealed that the respondents were within the demographic age group of about 18- 50 years and above.

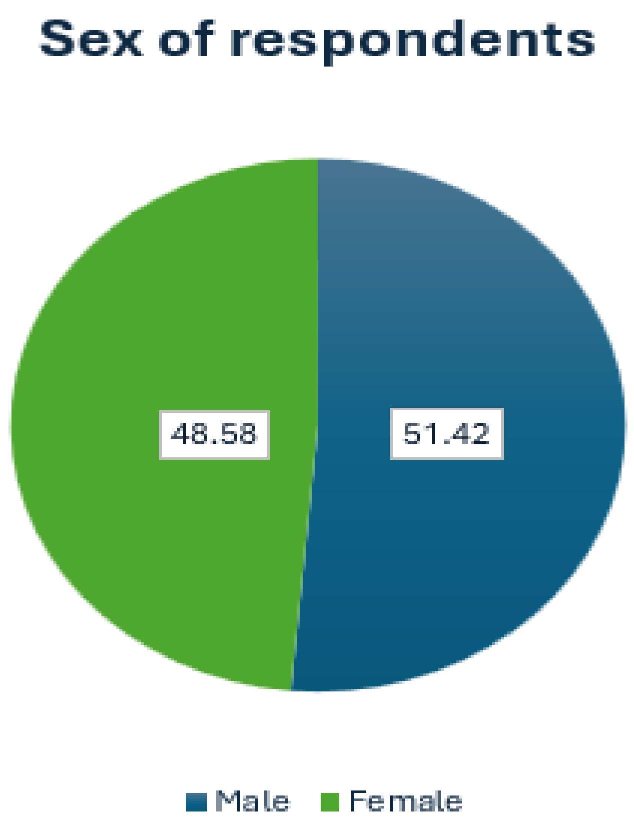


Figure 5-3: General characteristics of respondents, male & female

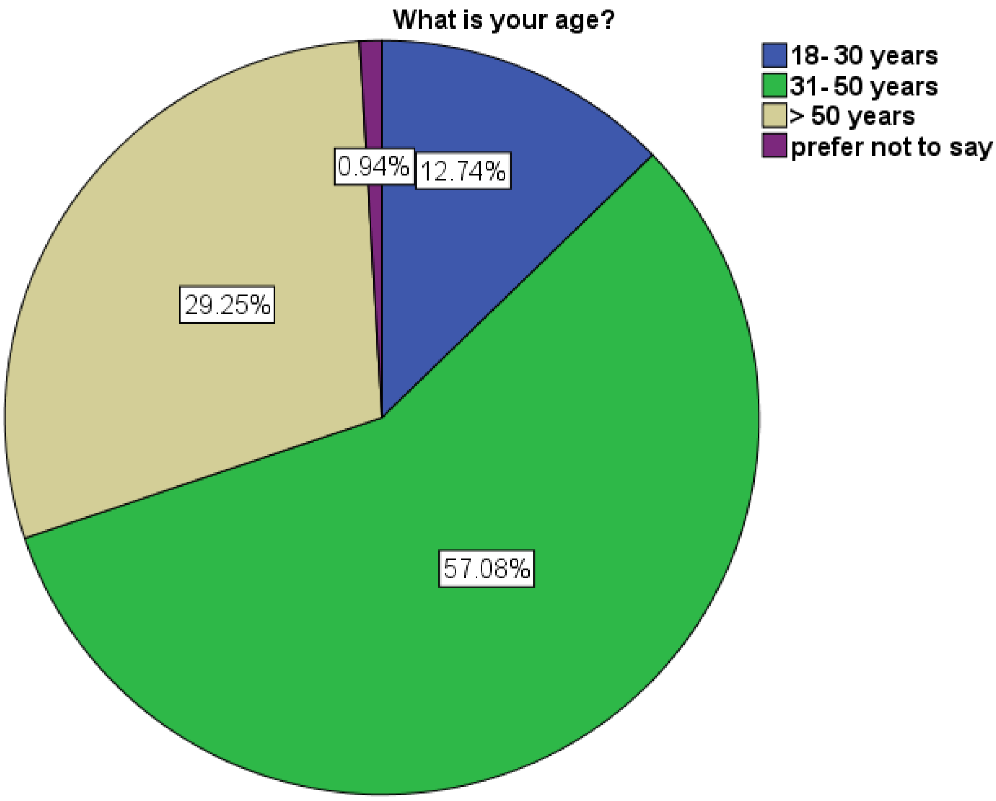


Figure 5-4: The age distribution of the respondents

5.5.6 Information on Building Usage

Participants were asked what local government area they belonged to. Results showed that about 33% (72 respondents) were from Ilorin West, another 32% (67 respondents) were from Ilorin South, and 35 % (74 respondents) were from Ilorin East local government area. See Figure (5-5).

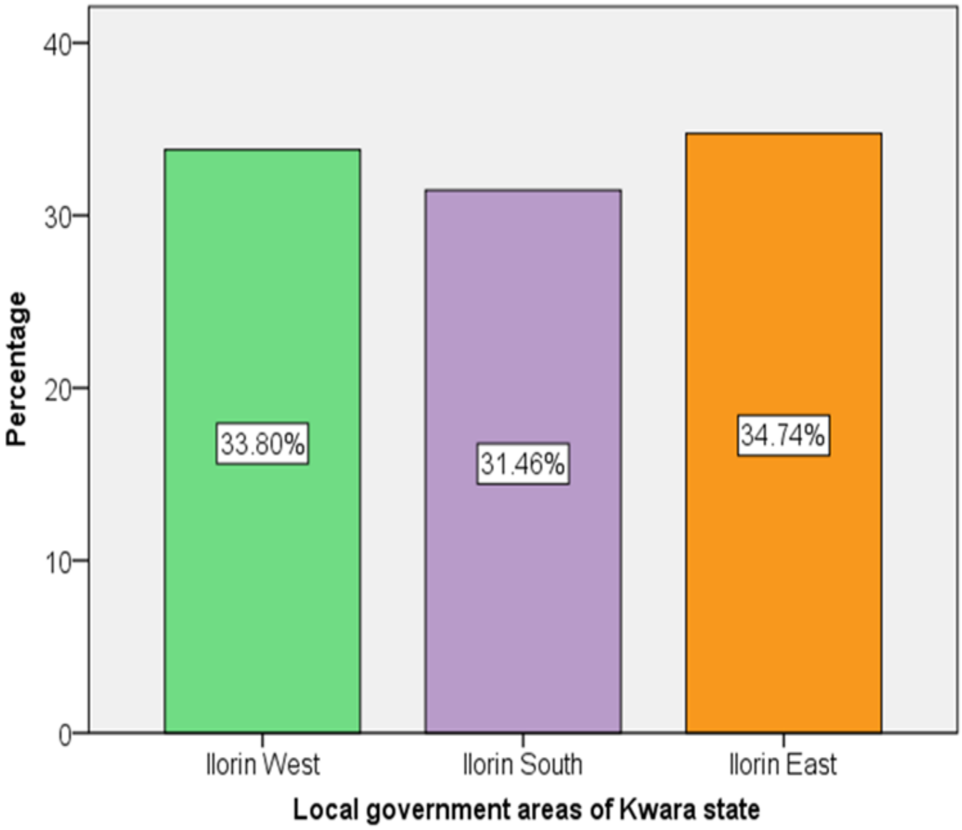


Figure 5-5: Local government population and respondents

The interviewer-administered questionnaires were conducted within Ilorin's three most populated local government areas. The questionnaires were administered strictly to respondents who have experience living in Ilorin adobe traditional buildings within the selected local government areas, and results indicated the number of years which the occupants have lived in their houses; this varied from about 1% who have lived in the building for less than 10 years to more than half of the respondents (51%) who have lived in the buildings for more than 30 years. See Figure (5-6).

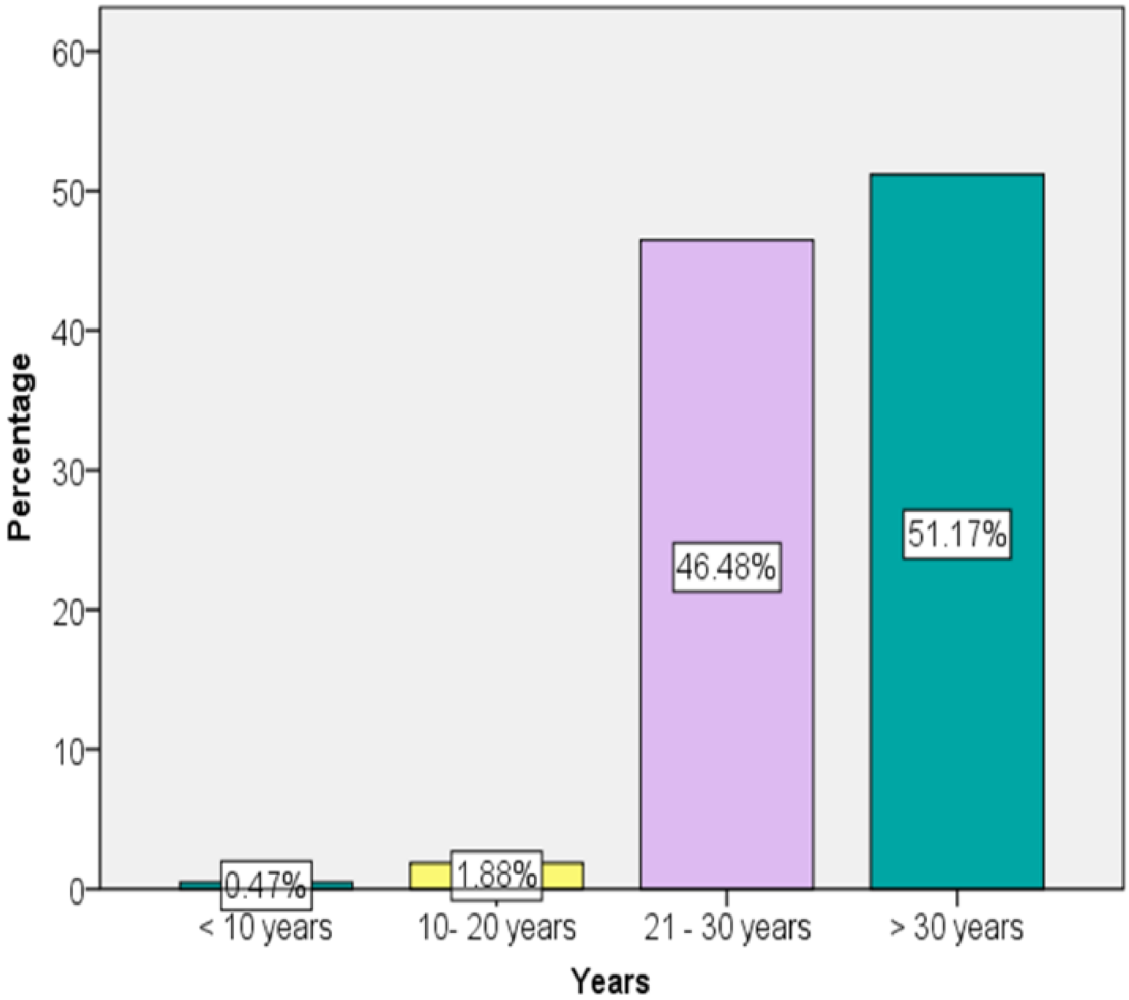


Figure 5-6: The frequency number of years respondents have lived in adobe traditional buildings.

The data indicates that most occupants prefer to construct and own the buildings they inhabit. This preference can be attributed to the fact that most buildings are constructed by family members of individual households and these houses are often passed down from generation to generation, preserving the family legacy and the area's cultural identity. The findings reveal that 59% of the respondents privately own the traditional Adobe buildings, while only 9% rent their homes, as shown in Figure (5-7).

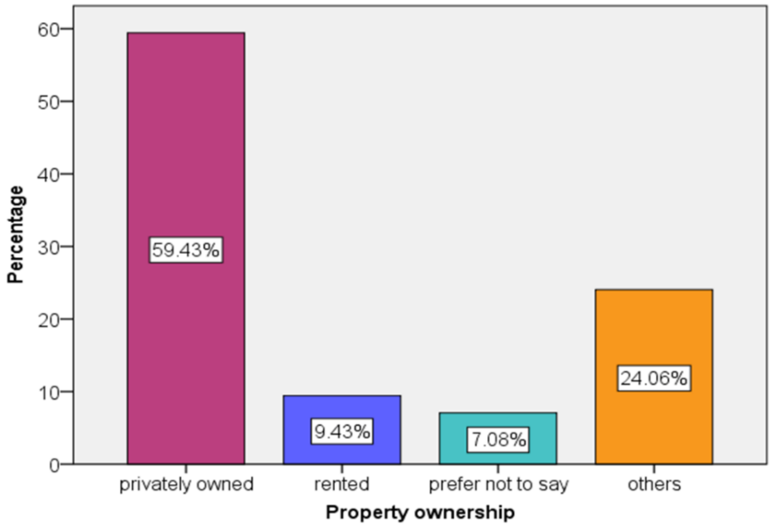


Figure 5-7: Distribution of property ownership

Furthermore, when the respondents were asked about the age of their buildings, the votes in Figure (5-8) indicated that 9% of the occupants lived in buildings that were less than 25years of age, 27% votes were considered within 25-50 years, 34% votes between 51 – 75 years, and 30% of the respondents believed that their buildings were above 75 years of age.

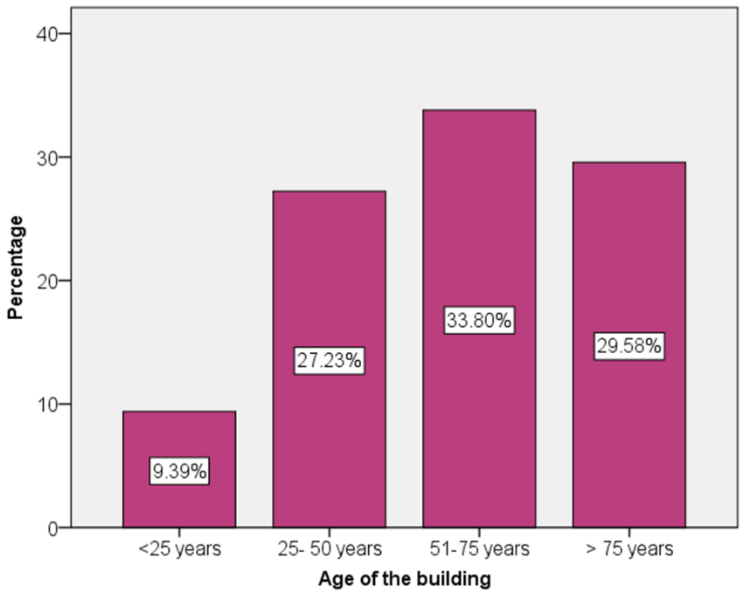


Figure 5-8: Building age distribution

The data in figure (5-9) illustrates the distribution of occupants per building as follows: 1-2 occupants: 1.4%, 3-4 occupants: 28%, 5-10 occupants: 47%, more than 10 occupants: 24%, and 1% of respondents were indecisive. Further insights from the respondents indicate that bedrooms are the most frequently occupied spaces, with an average of 2 occupants on weekdays (8 am-3 pm) and 6 occupants between the hours of (6 pm and 7 am) when they return home. There are typically 4-5 occupants per room on weekends, fluctuating throughout the day. The number of occupants reflects family sizes per household and often per room, influenced by Islamic practices that encourage polygamy and communal living.

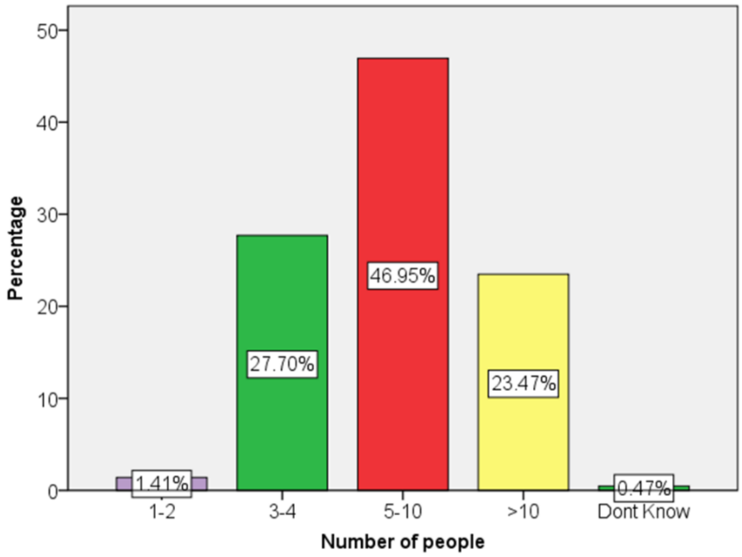


Figure 5-9: Number of persons per family in households

Respondents were asked about their home maintenance habits. Approximately 1% reported never carrying out any maintenance, while the majority (95%) stated that they perform maintenance periodically, typically within a span of less than 2 years. This maintenance included tasks such as replastering and repairing building envelope components during the dry season to address cracks before the next wet season. Around 2% indicated that they carry out building maintenance between 2-10 years. However, only 1% reported performing maintenance every 10 years or more, and another 1% responded "I don't know." For more details, refer to Figure (5-10).

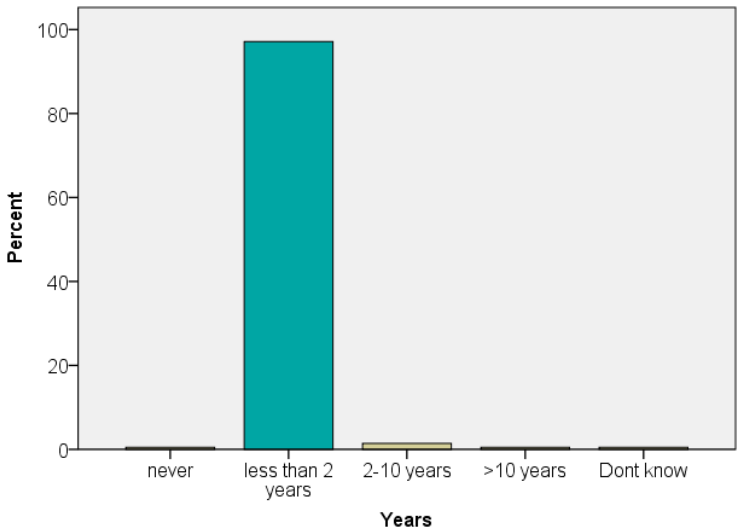


Figure 5-10: Frequency distribution of building maintenance

5.5.7 Cultural Appeal of the Traditional Buildings

As previously discussed in sections 1.6.4 and 2.4.1, the survey questions asked in this section were about cultural heritage, the significance of the built heritage in terms of cultural appeal to the people, and the comfort experienced by residents of the case study buildings. The results show a strong bond between the Ilorin people regarding their culturally built environment, cultural values, and the emergence of their housing.

i. Factors considered to be a true indigene of Ilorin

The respondents were asked to answer seven questions about factors to be considered a true Ilorin indigene using a 5-point rating scale provided to agree or disagree with the following statements: Extremely important, very important, somewhat important, not very important, not at all important or prefer not to say.

Question 1: How important do you appreciate Ilorin's traditional buildings?

Very few respondents (5%) negate the appreciation of traditional buildings, while almost half (48%) appraise their importance. The respondents believe that these buildings depict a strong affinity with the cultural identity of the people as true indigenes of the land (see Table 5-5 and Figure 5-11).

Table 5-5: Frequency distribution of the importance of traditional buildings in the Ilorin emirate.

How important are traditional buildings?	Frequency	Percent
Not very important	11	5.2 .
Somewhat important	92	43.2
Very important	102	47.9

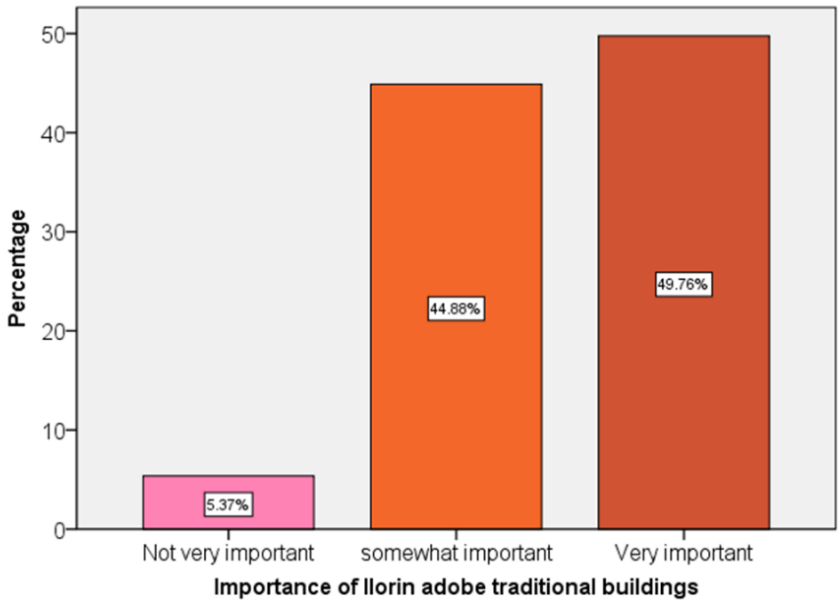


Figure 5-11: Frequency distribution of building appreciation and respondents living in traditional buildings

Question 2: What type of residence do you live in, modern or heritage?

The number of votes showed that few respondents (4%) lived in modern housing (buildings built of modern materials) as explained in section 2.7, 17% resided in semi-modern houses (traditional buildings that have adopted some modern strategies), whereas the majority (79%) lived in traditional buildings across the communities; this indicates that most of the respondent's population lived in the traditional housing units just like the ones under investigation. Figure 5-12 illustrates.

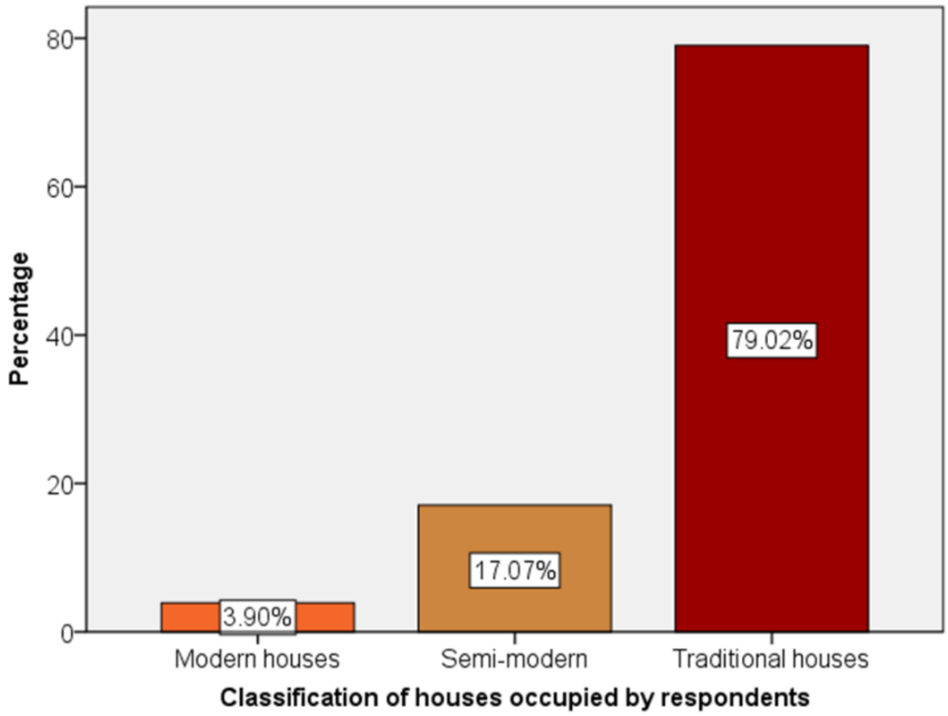


Figure 5-12: Frequency distribution of people living in a variety of house types.

Question 3: How challenging is living in traditional buildings?

Based on the survey, Figure 5-13 illustrates that 89% of the respondents find it challenging to live in a traditional building for a long time, while 2% think it's very challenging. Another 7% of respondents consider it somewhat challenging, and only 2% reported having no issues with long-term living in traditional buildings. The challenges could be associated with the level of dilapidation of these buildings and the urgent need for maintenance.

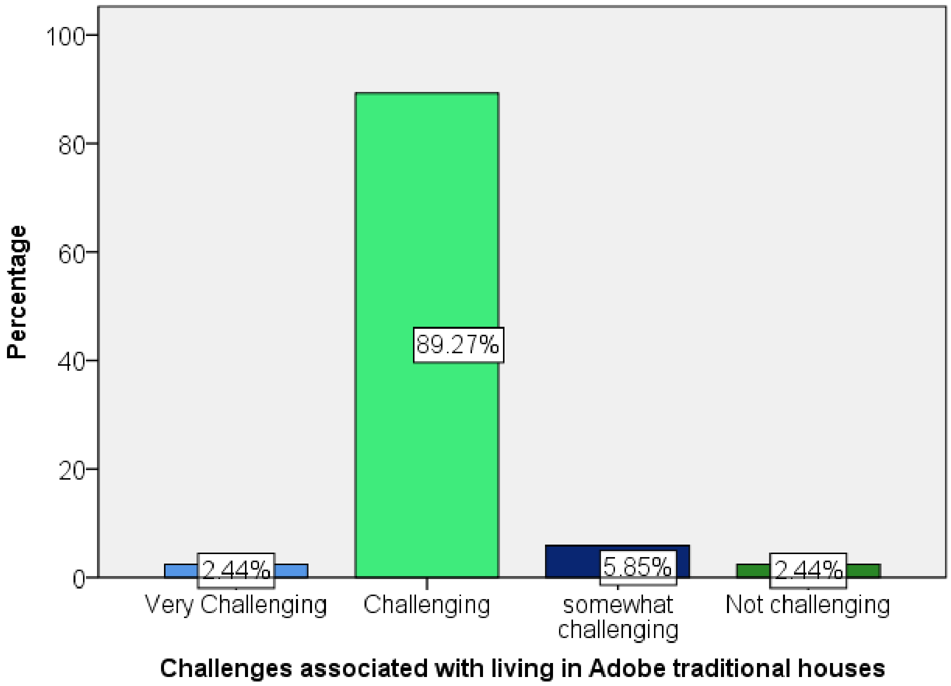


Figure 5-13: Frequency distribution for the challenges associated with living in Adobe traditional houses.

Question 4: How important is feeling Ilorin (Afonja/Alimi)?

The study shows in Figure 5-14 that almost all the respondents, 95%, concluded that having an Afonja or Alimi ancestral history or lineage to feel Ilorin as a true indigene is very important, and 1% of the respondents agreed that it is extremely important and somewhat important respectively. In comparison, another 3% believe it is not at all important to have an Afonja or Alimi ancestral history or lineage to feel Ilorin. The analysis indicates that cultural lineage was significant in the emergence of Ilorin architecture, and it is reflected in the planning layout of the building. This result supports the theory explained by Na'Allah (2008), which was discussed in Chapter 1 (section 1.7).

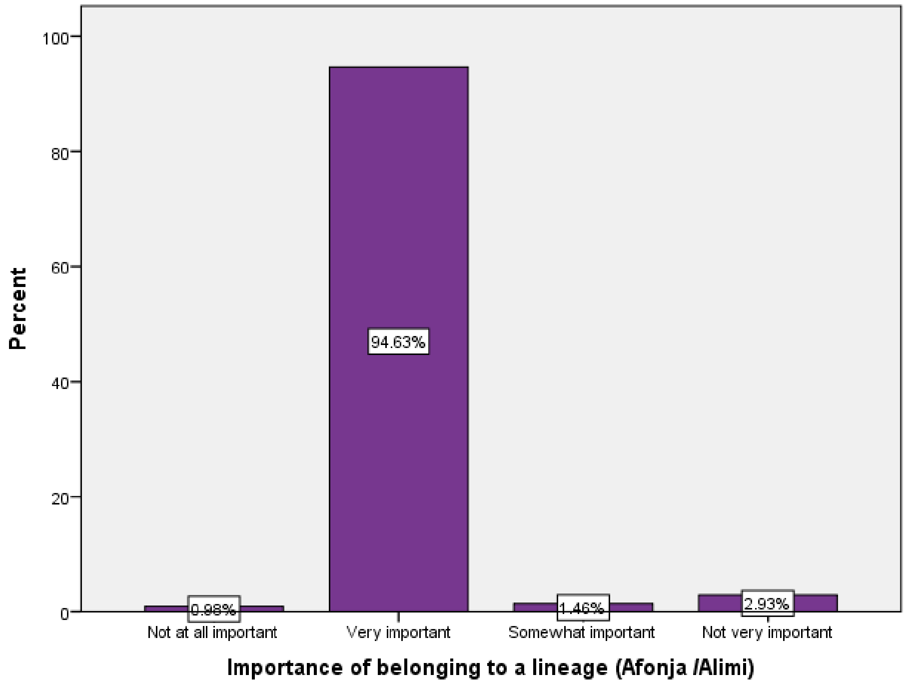


Figure 5-14: Frequency distribution for the importance of feeling Ilorin (Afonja/Alimi).

Yoruba is the predominant language spoken in Ilorin due to the familiarity of the Yoruba people with the majority. However, the Ilorin Yoruba accent is distinctly influenced by other languages, such as Hausa and Fulani, among others (Omoiya, 2005). The unifying factor of citizen oppression, particularly as it pertained to the group known as "Ilorin *Talaka Parapo", was cited by* Omoiya,(2008), *as* the association comprised individuals from various ethnic groups and social subgroups. The language and cultural unity is evident from the survey findings below.

Question 5: How important is it to be able to speak the Yoruba language?

The Majority, 91% of the respondents, agreed that it is not very important to know how to speak the Yoruba language in the Ilorin emirate. While 4% believed that it is very important, and another 4 % strongly believed that it is not at all important to know how to speak the Yoruba language to be considered a true indigene of Ilorin, as indicated in Figure 5-15.

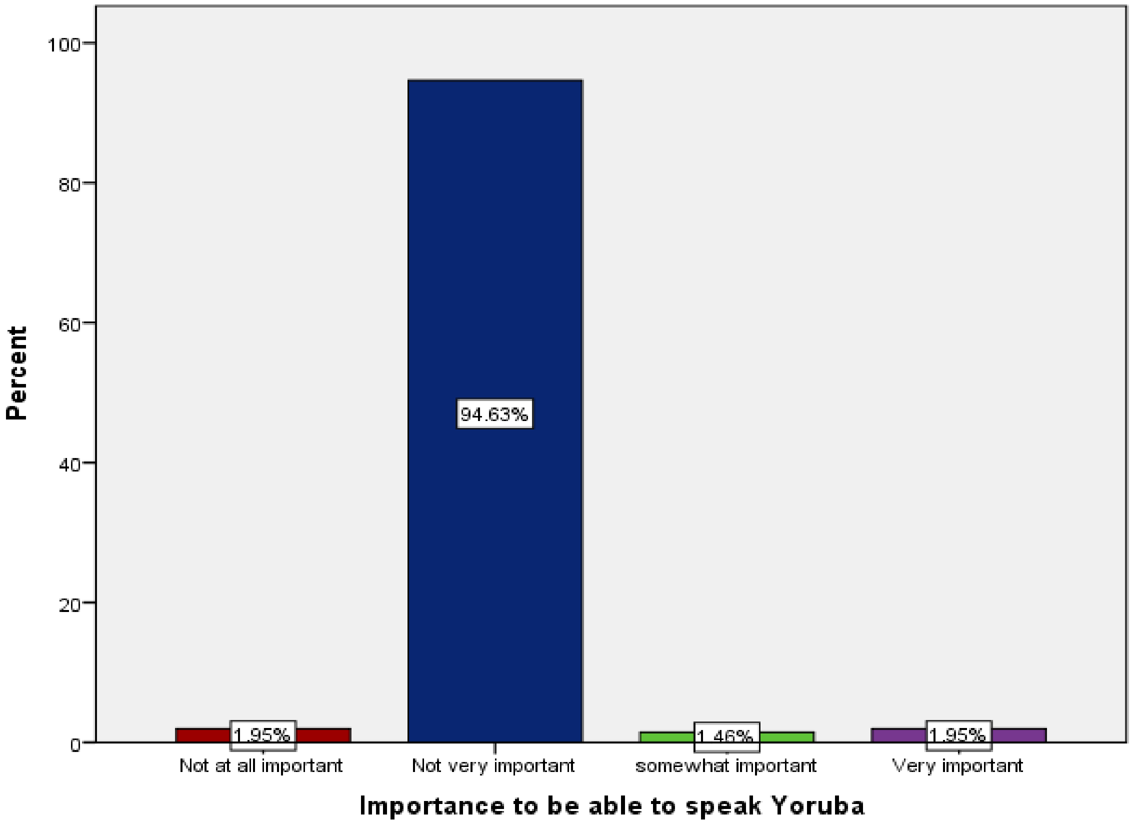


Figure 5-15: Graph showing the importance to be able to speak yoruba language.

Question 6: How important is it to be able to speak the Hausa language?

Findings in Figure 5-16 show that about 93% of the respondents attach little or no importance to knowing how to speak the Hausa language in the Ilorin emirate. 3% think it is somewhat important to know how to speak the Hausa language to be considered a true indigene of Ilorin.

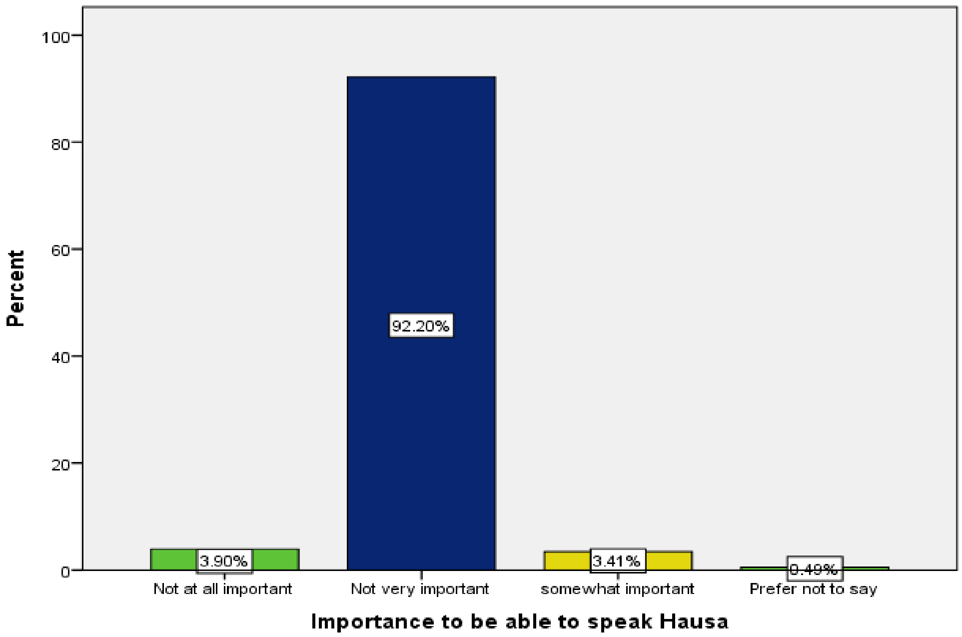


Figure 5-16: Graph indicating the importance of being able to speak the Hausa language.

Question 7: How important is it to be able to speak the Baruba language?

Also, about 83% of the respondents do not attach much importance to knowing how to speak the third most common language in Ilorin, which is the Baruba language in the Ilorin emirate. In contrast, about 1% think that it is somewhat important to know how to speak the Baruba language to be considered a true indigene of Ilorin, see Figure 5-17.

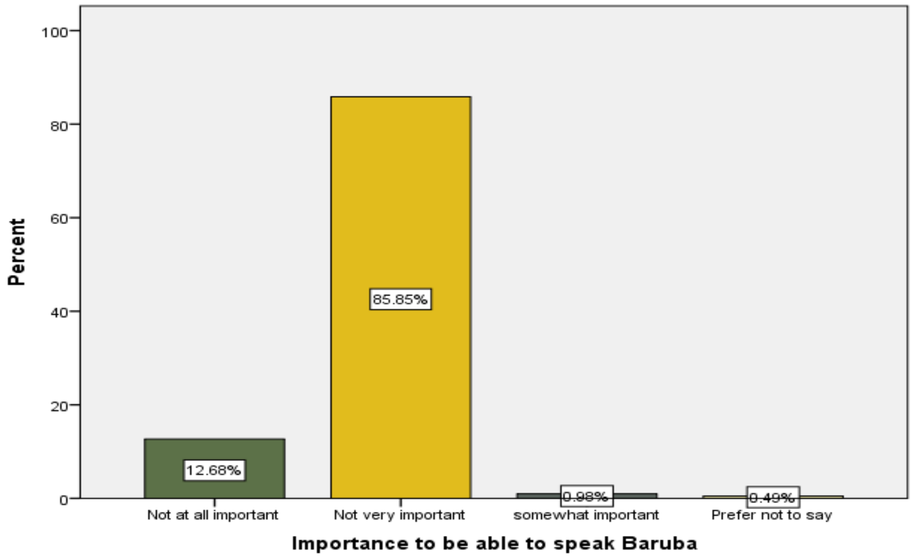


Figure 5-17: Graph indicating the importance of being able to speak the Baruba language.

a) Natural lighting

Findings reveal the occupants voted that the presence of few and small windows on Ilorin traditional buildings can be attributed to cultural values for occupant's privacy and the traditional method of building construction by the local builders. The analysis of the subjective preferences and disposition of the occupant's satisfaction of their building openings was based on a 7-point scale of being Extremely satisfied, very satisfied, satisfied, neutral, dissatisfied, very dissatisfied and extremely dissatisfied in accordance with ASHRAE 55. Among all the votes cast, almost half of the respondents (37%) indicated dissatisfaction with the size and type of the building openings (Windows and doors), only about 25% of the respondents could not decide on their choice. In comparison, the respondent's total satisfactory vote was 38%, see figure 5-18.

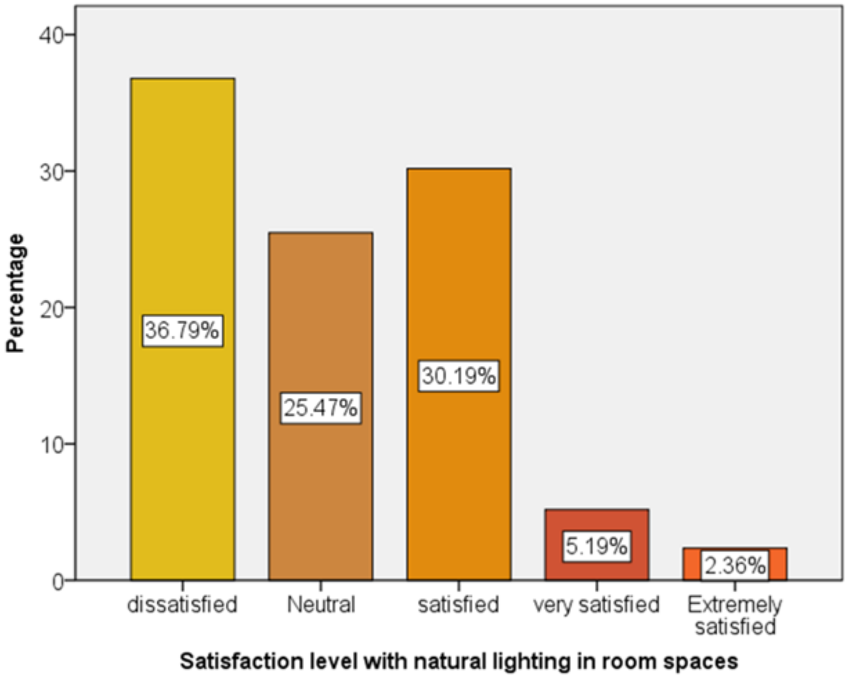


Figure 5-18: Graph showing occupant's satisfaction level with the natural lighting.

Based on the results obtained from respondents who were dissatisfied, a further investigation was carried out through a 5-point rating scale to find out the cause and the level of dissatisfaction of the occupants. The 5-point scale sensation scale measured the feelings as: Too dark, dark, neutral, bright, and very bright in accordance with ASHRAE 55. Out of the 213 valid responses, only 24% votes were indecisive about the cause of their discomfort with the building openings, and a total of 76% voted the interior spaces of the building as being dark and visually discomfortable, having the respondents vote of more than half (60%) as dark and (16

%) as too dark on the side of the scale as indicated below in Figure 4-19. This discomfort could be because of insufficient daylight reaching the interior of the building, which could be due to tiny window sizes (see Figure 4-20), low window-to-wall ratio, and window positioning with poor orientation.

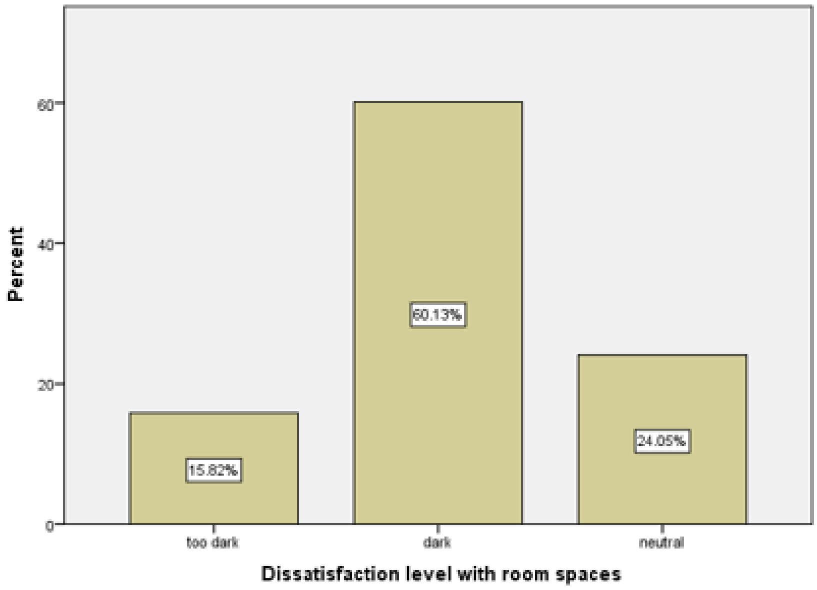


Figure 5-19: Graph showing the percentage of dissatisfied occupants due to visual discomfort.

Figure 5-20: Picture illustrating the tiny window (600mm by 600mm) on a typical Ilorin adobe traditional building.

Furthermore, Chapter 5 discusses in detail the analysis used to validate the occupants' responses and potential solutions.

5.5.8 Comfort (thermal and visual)

Based on the standards discussed previously in Chapter 2, the results of the thermal and visual comfort parameters assessment that affect the occupants include air temperature, relative humidity, ventilation, natural lighting, and occupant clothing levels. This was done through the administration of questionnaires with the aim of optimising visual and thermal comfort in indoor building environments while adhering to comfort and safety guidelines. The results were analysed and presented.

i. Clothing Level

The investigation of the clothing behaviour among males and females of Ilorin people in their daily traditional attires, as well as its relationship with thermal environments, was carried out. The method used was to observe the clothing habits of participants in three different local government areas of the Ilorin emirate. To begin, a cross-sectional study of people living in traditional Adobe buildings in each chosen local government area was conducted. Secondly, the buildings in which the research was carried out were chosen based on permission from the head of the household, house owners, and tenants. The cross-sectional study was used to look at average clothing insulation levels in a group of about 12 to 15 new participants per day for a month, choosing an age demography of 18 years and above.

According to Morgan and De Dear, (2003) and ASHRAE, (1997), clothing can be viewed from various angles. From a Physical point of view, it can be defined in line with thermal resistance or insulation. Clothing can also be viewed socially as a reflection of one's personality, mood, religion or other group affiliations. Morgan and De Dear (2003) explain further that clothing is also a code for identity expression and is widely used to portray socio-economic status. An approach similar to that used by Morgan and de Dear in their study of shoppers at a Sydney mall was used to estimate clothing resistance values. This study discovered that Ilorin men wore a variety of half/full sleeve shirts, t-shirts, trousers, and full traditional regalia made with matching cloth texture and colour that included a big gown (agbada), an inner long sleeve (Soro), and trousers (sokoto). Women wore a combination of long-sleeved long dresses, long-sleeved blouses (Buba) with wrappers (Iro), and matching headgear (gele) and veils (Iborun) or Hijabs. See Figure (5-21) for clothing images.

Figure 5.21 shows the results of the Clo values of the participants and the practical textile and apparel insulation values used in this study are shown in Table 4-6. The survey was conducted while the participants were sitting/relaxing, and the metabolic rate was estimated to be 1.0, corresponding to the value specified in ISO 7730-2005 for "Seated, relaxed". The survey asked the occupants to provide information regarding their clothing. Figure 5-21 illustrates the sex distribution of the survey. The responses from the male participants (51%) indicated that less than 10% wore T-shirts and jeans, 16% wore Long-sleeve shirts with full-length trousers, and more than half (71%) wore Long-sleeve shirts and full-length trousers with caps. Similarly, responses from the female participants (49%) revealed that less than 10% wore Short-sleeve ankle-length gowns with headgear, 14% wore Long-sleeve ankle length dresses with headgear and veil, and 66% wore Long- sleeve blouses with long skirts or wrappers, headgear and veil. It was observed that wearing these clothes has a cultural connotation regardless of seasons and time of the day.

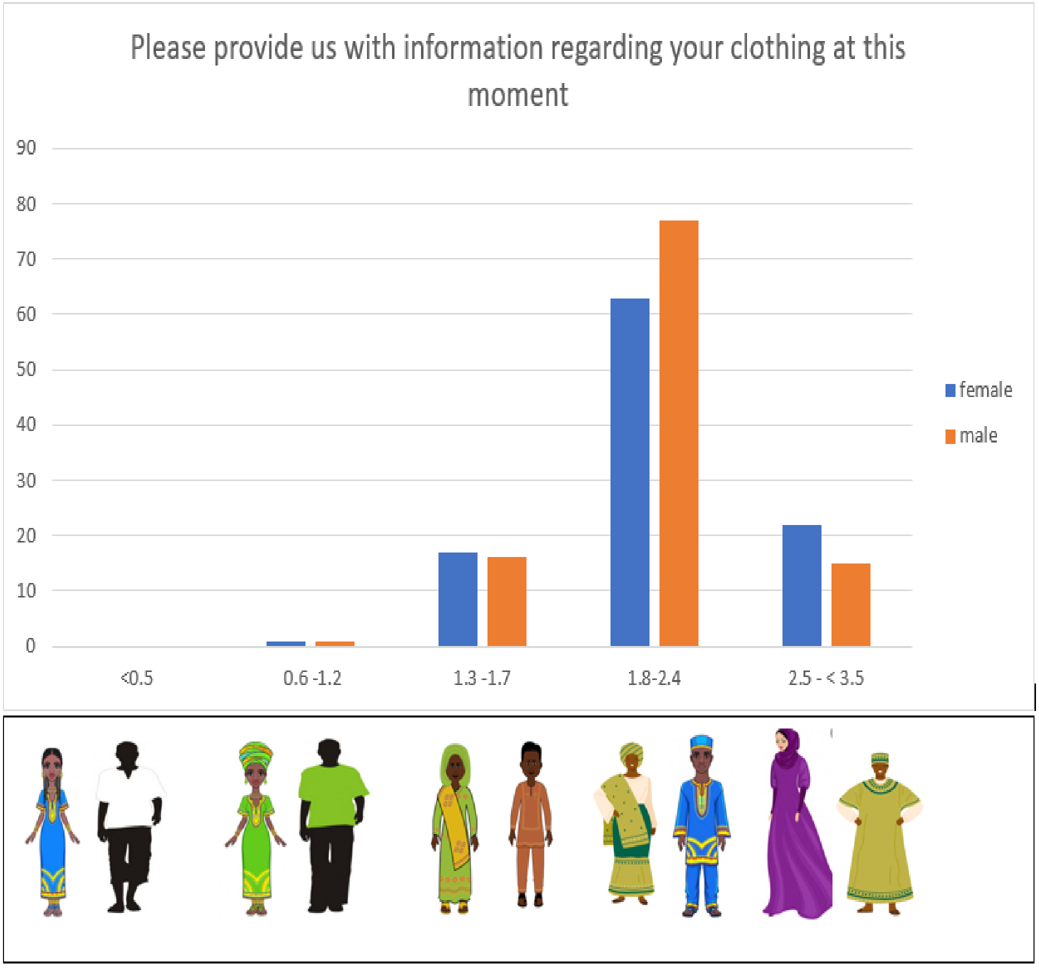


Figure 5-21: Frequency distribution for clothing (Ilorin men and women).

Table 5-6 shows where the integral insulation values of an ensemble are calculated by adding the practical insulation values of individual apparel following (ASHRAE Standard 55-92).

Table 5-6: Showing the practical insulation values of various clothing garments (Iclu,i, clo).

Apparel description for Women	**Apparel description for Men**	**Iclu,i, clo value**
Short-sleeve ankle-length gown	T-shirt and three-quarter trousers	< 0.5
Short-sleeve ankle-length gown with headgear	T-shirt and jeans	0.6 – 1.2
Long-sleeved ankle-length dress with headgear and veil	Long-sleeved shirt with full-length trousers	1.3 – 1.7
Long-sleeved blouses with a long skirt or wrapper, headgear, and veil	Long-sleeved shirt and full-length trousers with cap	1.8 – 2.4
Long- sleeve flared flowing gown, headgear and hijab	Overall, a big gown (agbada), an inner long sleeve-shirt (Soro), and trousers with a cap	2.5 - <3.5

Clothing Discussion and Findings

According to the study's findings, it is also believed that the observed day-to-day dress sense of Ilorin people, which consisted of full body covering clothes, is not only influenced by Islamic rites but also promotes good health and well-being of the people as it helps to protect their skin from heat and burns caused by direct sunlight in the warm-humid climate zone. Every subject was assigned a clo value based on observations on the ensemble he/she wore. In addition, dark-coloured clothing was observed to be predominant across both sexes, harmonising with the natural and the built environment with colours ranging from green, brown, blue, purple, and black. Clothing resistance values are typically the same all year; respondents' dark-coloured items of clothing demonstrate their adaptability to higher temperatures. Throughout the duration of the survey, the ensemble with the lowest clo value was (0.5 and 0.6-1.2) for both sexes. For men, it was a combination of a t-shirt and jeans or three-quarter trousers, and for women, it was a combination of a short-sleeve ankle-length gown with no head covering or hijab and a short-sleeve ankle-length gown with headgear but no veil or hijab. While the highest clo value (1.8 - 2.4) ensemble for men was a combination of a full-sleeve shirt, trousers, and a cap, the value ensemble for women was a combination of a full-sleeve blouse, ankle-length wrapper or skirt with matching headgear and veil or hijab.

Indoor Temperature

Figure 5-22 shows the indoor environmental conditions in various seasons (harmattan and rainy). The thermal sensation is the respondent's sensory perception of physical interaction with the immediate environmental conditions. The temperature in harmattan (TH) signifies a temperature sensation in harmattan, and Temperature in rainy/wet (TR) as Temperature sensation in the rainy season.

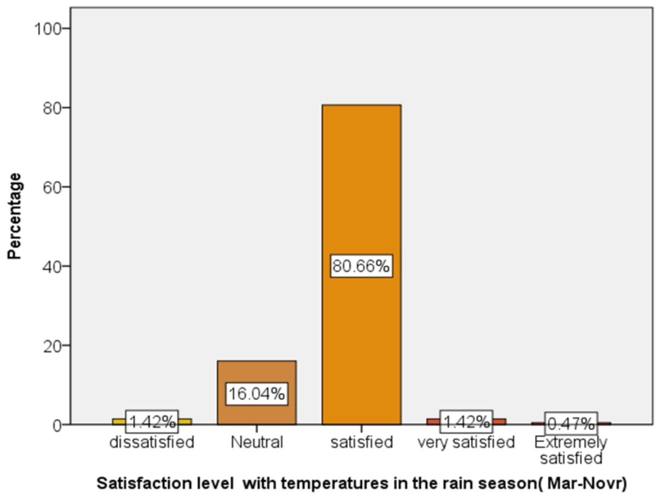


Figure 5-22: Graph showing occupant's thermal preference in the rainy season.

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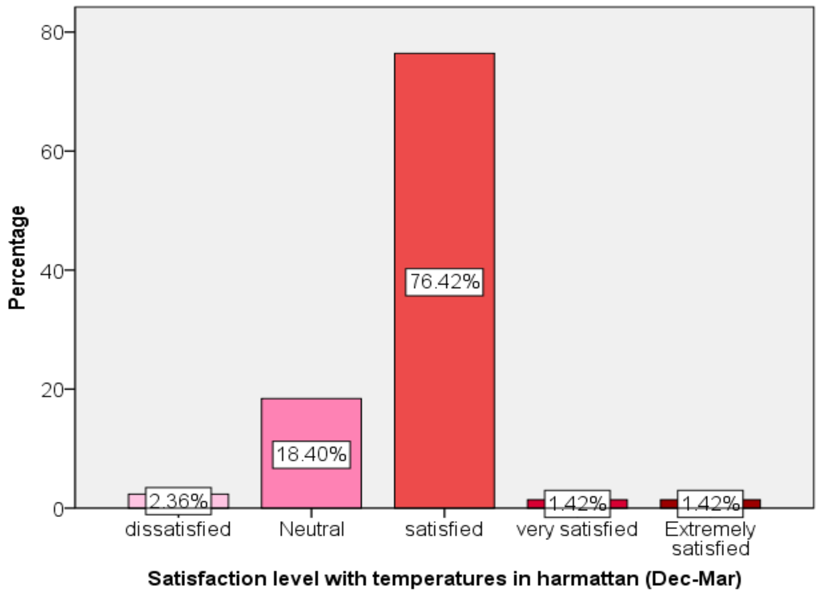


Figure 5-23: Graph showing occupant's thermal preference in harmattan season.

Figure 5-23 shows the distribution of subjective responses on temperature, and findings reveal that most respondents felt satisfied with their thermal conditions. 79.3 % votes of the total respondents expressed satisfaction in the harmattan season (TH = Dec to Mar) and 83% in the rainy season (TR = Mar to Nov), higher than the dissatisfaction votes of 3% and 1% respectively. The value for the rainy season is within the acceptable limit, while the value of the vote in the harmattan season is almost at the acceptable limits in line with the ASHRAE -55 standard that prescribes an 80% - 90% acceptability limit for which the environment is perceived as reasonably comfortable (PMV). According to the survey, 18.4% of respondents felt neutral during the harmattan season, while 16% felt neutral during the rainy season. The neural (0) scale indicates the position of respondents who remained indecisive. Based on findings from the 5-point scale, the indoor temperature growing cold, especially during the rainy season, was why almost half (41.1%) of all respondents expressed dissatisfaction. Similarly, according to ASHRAE Standard 55 and other studies, respondents in warmer conditions want cool, while respondents in cooler conditions prefer warmth.

ii. Relative Humidity

The distribution of the mean subjective response to the relative humidity in the Harmattan season is shown in Figure 5-24. The overall votes on humidity indicated that about 93% were satisfied with their dwellings in terms of humidity. While 2% of votes were dissatisfied, the remaining 6% of the respondents could not decide. Vote: However, the votes met the minimum requirements for the acceptable range PMV/ PPD in the harmattan season.

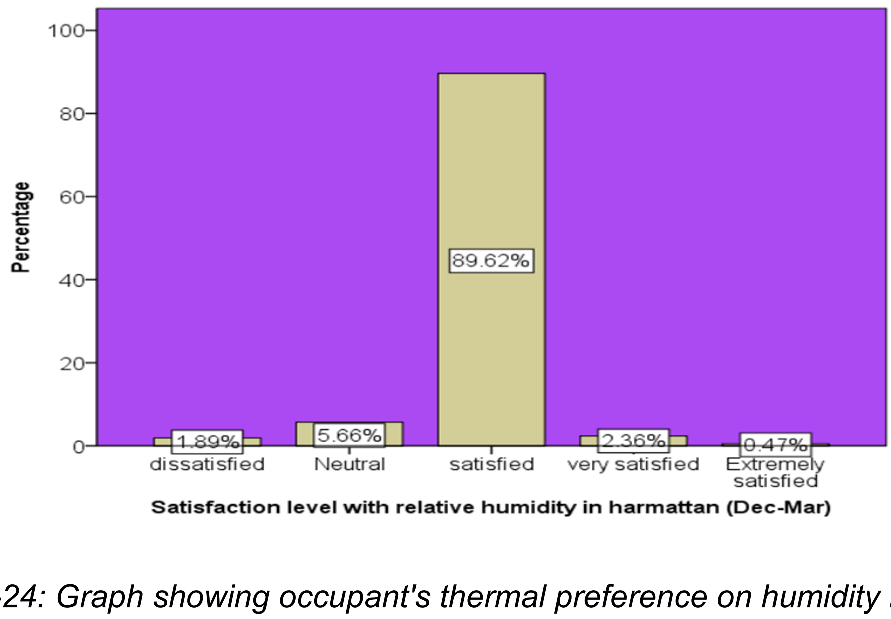


Figure 5-24: Graph showing occupant's thermal preference on humidity in the harmattan season.

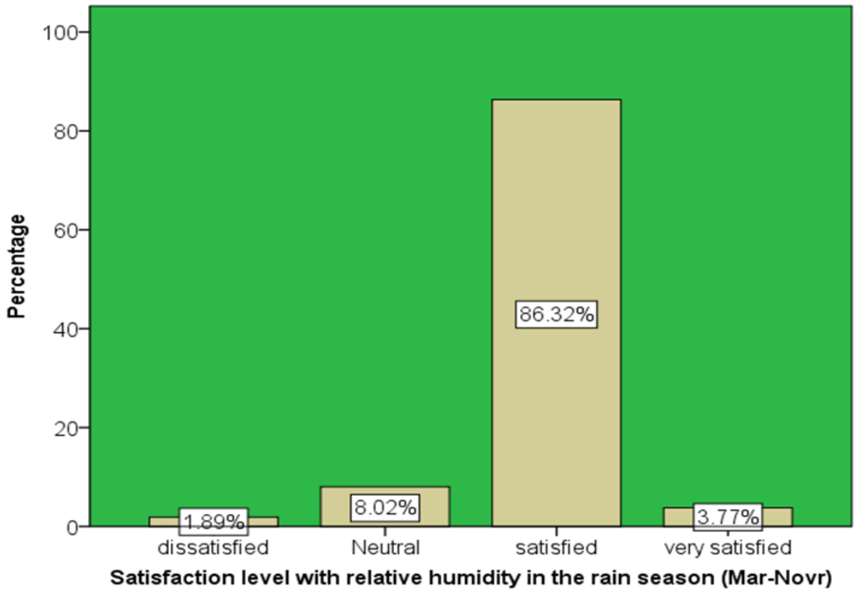


Figure 5-25: Graph showing occupant's thermal preference on the humidity during the rainy season

Figure 5-25 shows the distribution of subjective responses to relative humidity in the rainy season. Most of the respondents voted to be satisfied with a 90% distribution, while 8% voted neutral, and the remaining 2% voted dissatisfied.

iii. Ventilation

The residents in the naturally ventilated buildings expressed a 68% satisfaction level with the perceived fresh air. Approximately 6% reported dissatisfaction, while 26% were undecided. Upon further examination, it was found that those who were undecided mentioned issues with the air flow, such as increased humidity during the wet season and excessive dryness and dusty particles during the harmattan season. This led them to keep the windows closed during the day, resulting in reduced visibility and darker rooms.

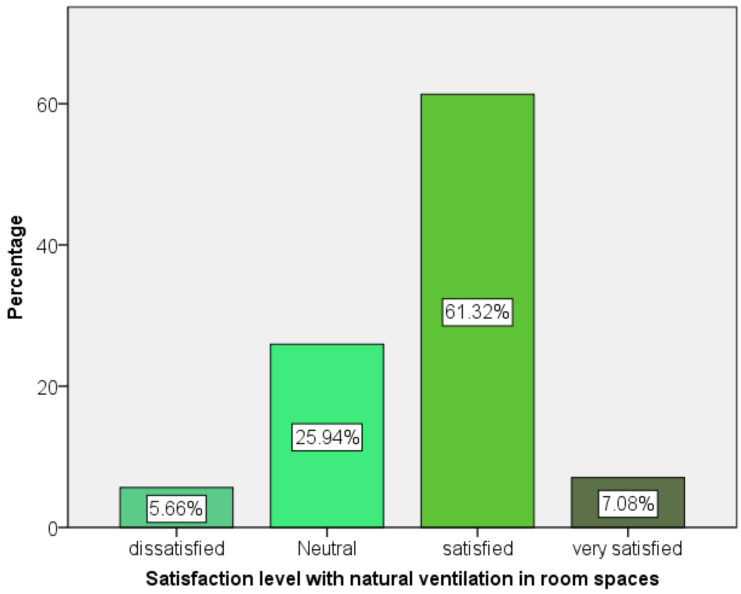


Figure 5-26: Graph showing occupant's level of satisfaction with natural ventilation in their buildings,

5.5.9 Overall Building Satisfaction

In this section, the respondents' building satisfaction scale was assessed in accordance with the ASHRAE seven-point rating scale (see Table 5-7). Regarding their satisfaction with their buildings, they were asked how satisfied they were with them under different subheadings, as discussed below.

Table 5-7: Rating scale

Satisfaction scale							
Extremely satisfied	Very satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied	Extremely Dissatisfied	Not Applicable
+ 3	+ 2	+ 1	0	-1	-2	-3	

a) Wall Finishing

A total of 71 % of the votes from the occupants indicated they were satisfied (more than half, 59%, were satisfied, about 11% were very satisfied, and 1% were extremely satisfied). On the other hand, only 4% indicated dissatisfaction, and 25% were indecisive, see Figure 4.27. However, when the respondents were asked why they were dissatisfied with the wall finish, they attributed it to the loose nature of the walling material (adobe) and its rapid dilapidation challenges in maintaining the wall fabric of the building envelope due to the loose nature of the walling material. Information derived from OS interview seen in Appendix IV.

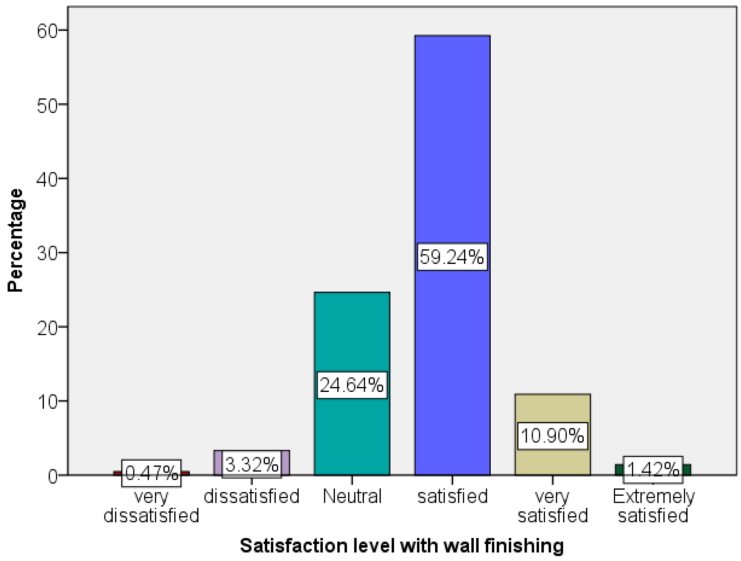


Figure 5-27: Occupants' level of satisfaction with the wall finish of their buildings.

b) Windows and Doors

Results revealed the overall satisfaction, and dissatisfaction votes of occupants on thermal and visual sensational preference, where almost half of the respondents (42%) voted dissatisfied with the existing type of windows and door openings towards the provision of ventilation and natural lighting. A total of 39% of the respondents were satisfied (37% satisfied, 1% very satisfied and 1% extremely satisfied). However, 19% were indecisive. Based on the results obtained from those dissatisfied, a further investigation was carried out through a 5-point rating scale to find out the root cause and the level of dissatisfaction experienced by occupants.

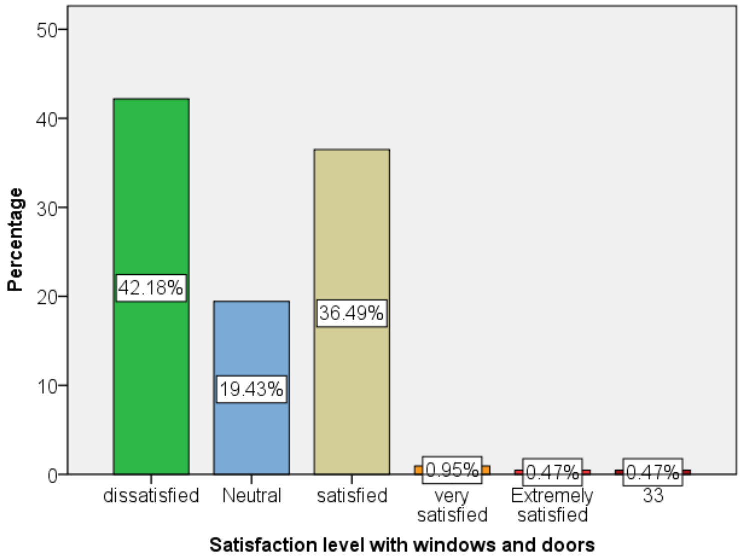


Figure 5-28: Occupants' level of satisfaction with the windows and doors of their buildings.

The 5-point scale sensation scale measured the feelings as Too dark, dark, neutral, bright, and very bright in accordance with ASHRAE 55. Out of 213 valid responses, only 24% were indecisive about the cause of their discomfort with the natural daylighting and the building openings in general. Meanwhile, about 76% of the respondents described the spaces as too stuffy and too dark. See Figure 4.28 and Appendix V for details on windows and door schedules.

c) The Roof of the Building

The occupancy survey evaluation, which involved interviews with key informants, provided valuable insights into the materials used for the building envelope of typical Ilorin adobe buildings. It was revealed that traditional Ilorin adobe buildings primarily utilized two types of roofs: thatch roofs and corrugated zinc roofs. The survey results also showed that 50% of the respondents expressed dissatisfaction with their building's roofs, with 1% very dissatisfied and 49% dissatisfied. Respondents indicated that the switch from original thatch roofs to corrugated zinc roofs had resulted in overheating due to poor heat insulation. Additionally, 21% of the respondents were undecided. For more information, please refer to Figures 5.29, 5.30, and 5.31, as well as the results derived from the occupancy survey evaluation interviews seen in Appendix V.

Figure 5-29: Photo showing an Ilorin adobe traditional building with a thatch roof.

Figure 5-30: Photo showing an Ilorin adobe traditional building with a corrugated zinc roof.

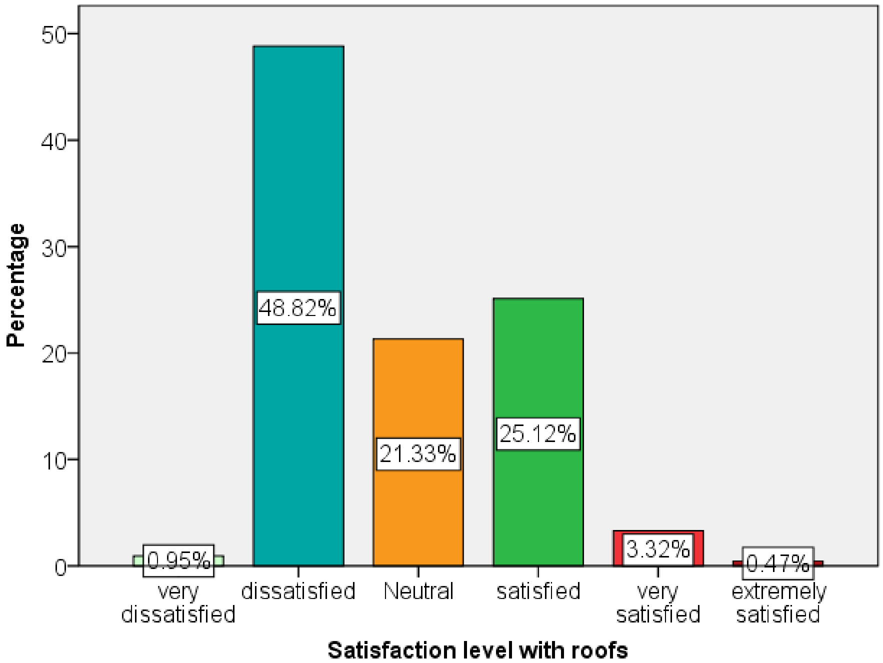


Figure 5-31: Occupants' level of satisfaction with the roof of their buildings.

d) Building Maintenance

The findings revealed that about 3% of the respondents were dissatisfied with the level of building maintenance when they complained about replastering the walls after every wet season, and 12% were indecisive as they were neither satisfied nor dissatisfied. 85 % of the respondents indicated satisfaction (74% were satisfied and 11% were very satisfied), as indicated in Figure 4-32 and explained that building maintenance was cost-effective as the building envelope was mostly made up of available natural materials. More insightful information was s derived from the occupancy survey, as seen in Appendix V.

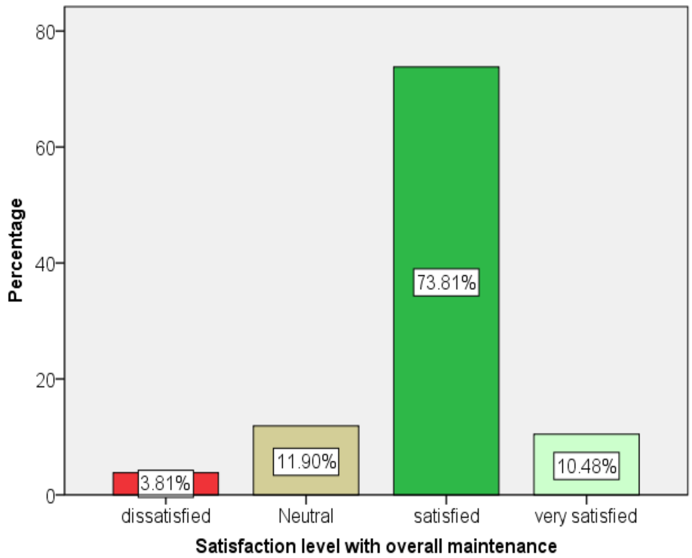


Figure 5-32: Occupants' level of satisfaction with the overall maintenance of their buildings

e) Quality of the Building

The research findings indicated that 1% of the respondent's expressed dissatisfaction with the overall quality of the building envelope, while another 1% remained neutral.

Conversely, almost all (98%) respondents reported being satisfied with the building's quality, as illustrated in Figure 5.33.

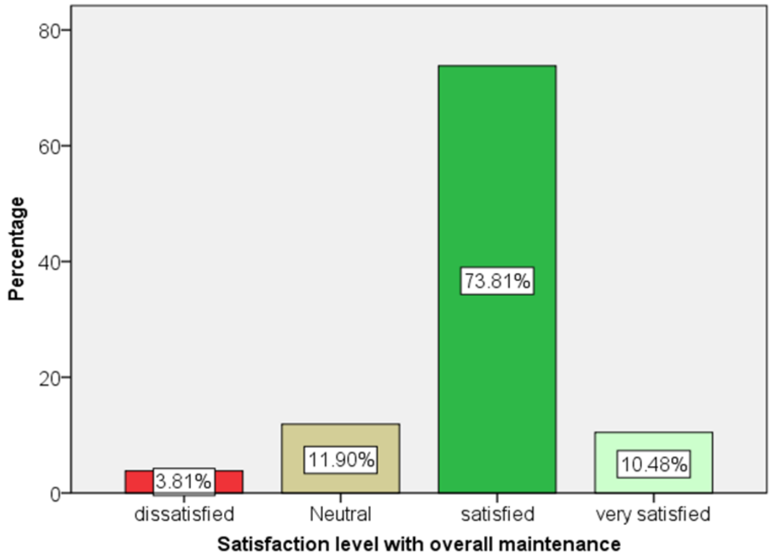


Figure 5-33: Occupants' level of satisfaction with the overall quality of their buildings.

5.6 Discussion: Dissatisfaction with Comfort Levels

Results revealed the overall satisfaction and dissatisfaction votes of occupants on thermal and visual sensational preference, where almost half of the respondents (43%) voted dissatisfied with the existing type of Windows and door openings towards the provision of ventilation and natural lighting. Based on the results obtained from those dissatisfied, further investigation was carried out through a 5-point rating scale to find out the root cause and the level of dissatisfaction experienced by occupants. The 5-point sensation scale measured the feelings as Too dark, dark, neutral, bright and very bright in accordance with ASHRAE 55. Out of 213 valid responses, only 24% were indecisive about the cause of their discomfort with the natural daylighting and the building openings in general. Meanwhile, about 76% of the respondents described the spaces as too stuffy and too dark.

The findings established that irrespective of the property ownership, the age of the building, and the local government area that the respondents were from, the overall occupant's dissatisfaction was predominantly geared towards the windows, doors, and roofs, as illustrated in Figure 5-34, 5-35 and 5-36 respectively.

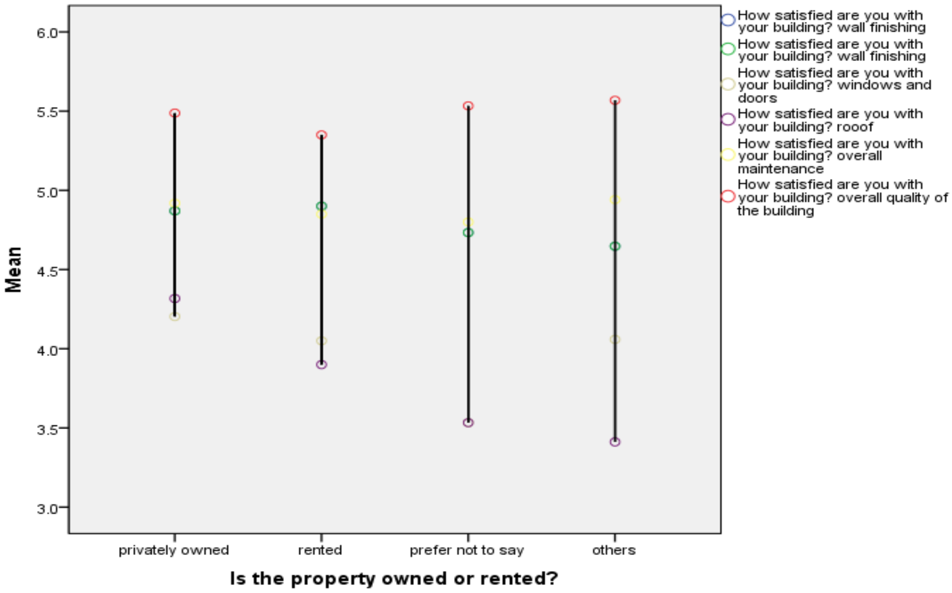


Figure 5-34: Occupancy property and comfort levels.

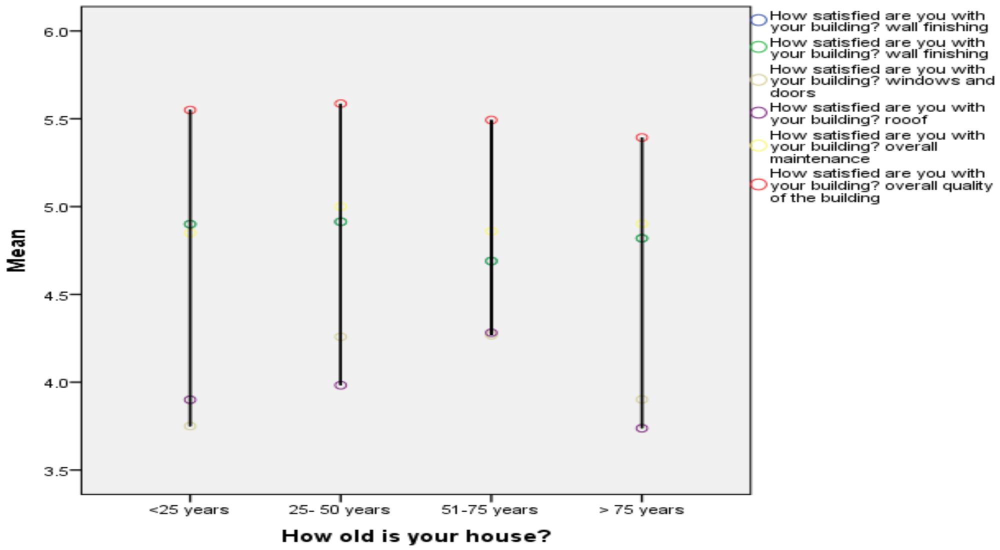


Figure 5-35: Graph showing age of property and comfort levels.

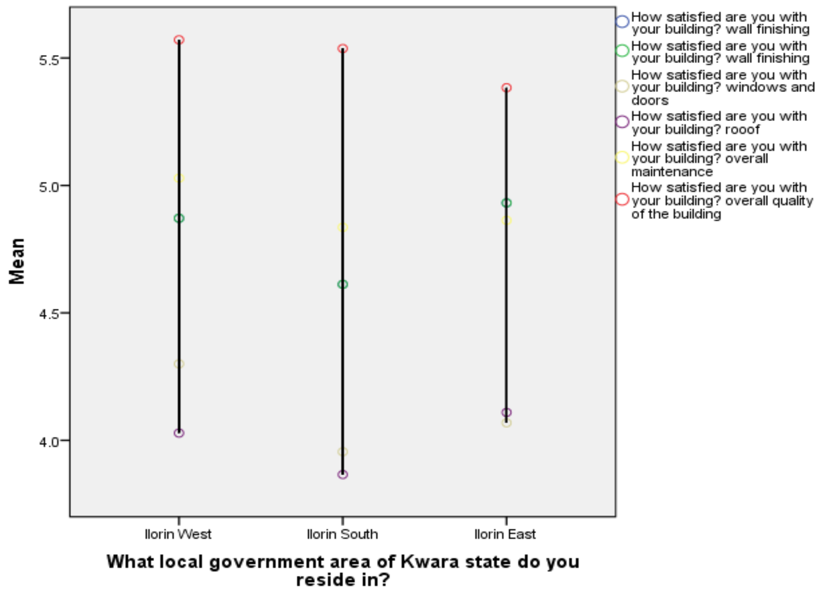


Figure 5-36: Local government areas and comfort levels.

Small windows of a 5% window-to-wall ratio are common features of Ilorin traditional adobe buildings, which could make it difficult for maximum natural ventilation to take place, especially if the windows are placed on surfaces with poor orientation, which can restrict the flow of fresh air and the removal of heat and humidity from inside the building. In the past, these smaller openings were designed to provide privacy and better protection against harsh climatic conditions such as solar insulation and to maintain a more stable interior environment. However, with the introduction of advanced building techniques and the insufficient accessibility of passive cooling technologies, the requirement for improved natural ventilation has become evident. From the survey, respondents' votes indicated darkness in the room's interiors, which could result from inadequate daylighting, causing visual discomfort to most occupants of these buildings. The prevalence of constructing traditional buildings with tiny windows also contributes to poor daylighting, which results in the interiors being poorly illuminated, and the well-being and productivity of the building occupants may suffer. These small windows have historically been utilised to reduce solar heat gain and glare while ensuring privacy and safeguarding against harsh environmental conditions and security threats, as explained in (Adekeye, 2014). However, it could be possible to reconcile the requirements for thermal comfort and natural light to provide visual comfort without compromising the cultural values of the occupants by using newer design techniques to increase the window sizes. This possibility is analysed in the following chapter through basic simulation tools. The daylighting factor is further investigated in Chapter Five. Furthermore, heat gain and retention are other major causes of thermal discomfort for occupants. Zinc roofing as a roof cover is identified to have low thermal insulation properties, and it is frequently adopted in most Ilorin traditional buildings, the conduction properties of the zinc roofing sheet exacerbate heat gain inside the buildings. These roofs can absorb and radiate heat, making indoor conditions uncomfortable and increasing energy use for cooling in warm-humid areas. In the past, thatch roofs, known as elephant grass (*passa*) in the Yoruba language, were extensively used for the roofing of most of these buildings. However, this research was informed from the semi-structured interview conducted with key informants (Head of households) that residents of traditional Ilorin adobe buildings enjoy and still wish to continue to enjoy the cool and calm indoor conditions that thatch-roofed buildings provide, but unfortunately, modernization and the fact that these thatch roofing materials are no longer available in abundance due to overgrazing issues in the region, hence one of the reasons for the change to zinc roofing sheets. Although the occupants adopted zinc roofs as their best strategy for several reasons, it may also have been chosen for their longevity and affordability. Regrettably, they do not meet the demands for adequate thermal comfort.

Innovative design solutions that combine traditional knowledge with modern understanding could be required to address the occupant's dissatisfaction with comfort levels. This could entail maximizing natural ventilation by adding larger windows in strategic locations and implementing passive cooling strategies like wind catchers. Lastly, to further reduce heat gain and improve thermal comfort, alternative roofing materials with improved insulation capabilities will be investigated in Chapter 6.

5.8 Conclusions

In conclusion, Traditional buildings in Ilorin hold significant cultural value as heritage infrastructure. Previous research has shown that adobe buildings are effective in regulating temperature, providing comfort, and preventing overheating. This study involved traditional adobe types of residential houses across three local government areas. The occupants' opinions were collected through questionnaires and interviews. The survey gathered information about building ownership, age, occupancy level, maintenance, occupants' perceptions, and satisfaction with the indoor thermal and visual comfort. Additionally, the study evaluated the cultural significance and importance of maintaining and preserving traditional heritage buildings. An evaluation of the building's construction materials indicated that the building was made of adobe sundried bricks for wall construction, which had a low u-value and high thermal mass. However, all the buildings investigated were found to be constructed with about 20% to 80% traditional building materials. It was observed that the occupants had to deal with year-round maintenance issues due to the prevailing weather conditions, especially during the rainy season, when there was persistent rainfall. The initial survey of the case study buildings revealed that they were particularly exposed to intense solar radiation during the summer months (January-April). The heat gain from the solar radiation affected the roofs and walls. The small windows helped prevent excessive heat from entering the indoors but also made the interiors dark.

The questionnaire and interview survey revealed that air movement was the main means by which the indoor spaces were ventilated in naturally ventilated spaces. Occupants could control ventilation through operable doors and windows, allowing them to adjust the indoor environment as much as outdoor conditions would allow. Out of 225 administered questionnaires, 213 (95%) survey respondents expressed some level of satisfaction with the building fabric, ventilation, and cultural significance of the building. However, only 68% of the respondents indicated they had direct access to natural ventilation through the windows in room spaces. Concerns were raised about the poor environmental conditions in the room spaces, with many users commenting that the rooms were dark. Corresponding occupant feedback revealed that users found indoor temperatures satisfactory even during the warmer part of the year. Also, it was suggested that opening both doors and windows encourages cross ventilation, significantly improving occupants' comfort conditions. Additionally, occupants living in buildings with corrugated zinc roofing experienced heat discomfort due to the high conductivity of the material and lack of roof insulation, especially during the warm months.

The survey on occupancy study gave valuable insights into the building's thermal performance in relation to occupant satisfaction. Generally, most of the occupants agreed that Ilorin adobe traditional buildings performed satisfactorily in accordance with the ASHRAE benchmark database. This was principally attributed to up to 78% of occupants finding temperatures in summer (warmer months) comfortable and about 93% finding the air moderately humid and comfortable. Up to 40% of users reported that the buildings get cold and that they changed their behavior to restore comfort in the cold months. The case study analysis of typical Ilorin traditional buildings enabled a detailed understanding of the building performance and the resultant occupant thermal and visual comfort. Evidence of overheating in the building and consequent occupant discomfort was apparent in a review of indoor conditions concerning occupant responses.

Overall, this chapter laid the foundation for understanding how the occupants of Ilorin adobe traditional buildings perceive thermal comfort and provided valuable insights that would be instrumental in the subsequent stages of the research. The information collected through questionnaires and subjective evaluation tools provided valuable recommendations and implications for improving the thermal comfort of traditional adobe residential buildings in the warm-humid climate of Ilorin. It could also potentially inform future building design strategies for improved occupant satisfaction and well-being. Lastly, the survey findings established that Ilorin adobe vernacular architectural strategies appropriately address local thermal comfort, cultural significance, materiality, and other climatic issues and Ilorin, inspired strategy could help inform the design of more adobe residential buildings with improved thermal comfort in the warm, humid climate of Ilorin. Further investigations on how the thermal comfort of Ilorin adobe traditional buildings can be improved will be covered in detail in the following chapters, using objective methods for quantifying indoor thermal comfort to indicate a thorough study approach to this research.

Chapter 6: Analysis of the Case Studies and Empirical data.

6.1 Introduction

This chapter presents the third stage of core research. It explains the instrumentation used for this research, and it presents validations and simulation results based on results discussed in Chapters 4 and 5 with the aid of detailed computer-based dynamic simulations. Selected Ilorin traditional adobe buildings located in the warm, humid climate of Ilorin, Nigeria, are investigated to quantify the effects of ventilation and Daylighting design methods on the thermal performance and the thermal and visual comfort of occupants. It also discusses various data logger readings from the data loggers installed in each case study building for this research.

6.2 Approach and Scope

The approach in the instrumentation process involves using specific tools, such as data loggers, to gather precise data for evaluating the impact of thermal comfort parameters by investigating and monitoring the indoor air conditions (Air temperature and relative humidity) to establish the thermal comfort limits in traditional adobe buildings in Ilorin. This encompasses setting up and calibrating the tools, analysing the gathered data, and assessing the thermal and visual comfort of occupants in the buildings. The results were employed for the parametric study discussed in Chapter 6. Furthermore, a simulation approach utilising software such as AndrewMash and Optivent 2.1 was employed to evaluate factors like daylighting and ventilation air exchange rate within the buildings. The results obtained from these simulations were validated using the IES-VE 2023 version. This approach offers valuable insights into optimising traditional adobe buildings in warm, humid climates to enhance thermal performance and occupant comfort through effective design methods.

6.2.1 Basis for Simulation

The construction of traditional Ilorin adobe buildings in Nigeria, using locally available materials, appears to have survived astonishingly well in most rural areas and some urban cities over the years. However, very little consideration is given to how these buildings affect thermal comfort. Nigeria is a country characterised by high temperatures and humidity values as it is in the tropics. Despite the adverse climate conditions, the country is currently facing an unstable supply of electricity and high energy bills, thereby causing people to depend primarily on natural ventilation for cooling in their homes but unfortunately, the efficacy of this is not adequate to provide thermal comfort in most of the recently built houses due to the fact that buildings of low thermal performance with design strategies that are less responsive to the climatic conditions are still predominantly being built. This is contrary to the benefits enjoyed in the past and presently in some areas of the country, such as Ilorin. In addition, climate change-related weather variations, the widespread adoption of non-eco-friendly building materials in contemporary buildings, and the use of mechanical cooling devices as temporary remedies for thermal comfort are all becoming increasingly common in Ilorin and throughout Nigeria. Nevertheless, there has been little or no research nor documentation on how these have affected Ilorin housing. Therefore, to bridge this gap, the empirical assessment for the thermal performance of Ilorin traditional adobe buildings is crucial since the data can validate the predictions of building thermal performance and, as a result, serve as a framework that can inform the housing policy document of Nigeria and the National building code. According to the recommendation in (Chapter 1), traditional adobe buildings in Ilorin must be safeguarded to preserve the nation's culturally rich legacy and inspire more practical climate-responsive design options that are appropriate for the region.

An examination of Ilorin Adobe traditional buildings has also disclosed the prevalence of small window openings in buildings that are used for ventilation and daylighting; their sizes can be ascribed to cultural values for privacy as well as the original good architectural practice by the people and method of construction as detailed in (Chapter 4 and 5).

Adekeye (2013), describes Ilorin adobe traditional buildings as built forms that have distinctive features and are distinguished by gothic-shaped doorways, which are solely used as entrances and not as a security measure to keep off invaders because everyone coexisted amicably, and there was no concern about expansion. In Chapter 2, According to climate consultant software, the recommended passive design strategies for Ilorin's warm and humid climate suggest that the planning layout should incorporate open-plan interiors in buildings. It is advised that buildings be oriented along the north and south axis of the cardinal points. Window openings in the east and west directions should be shaded. Additionally, light and natural ground colours should be used on walls and roof elements to effectively maintain a quality indoor environment for occupant comfort.

Based on the aforementioned, the case study buildings investigated in Chapter 3 revealed that the characteristics of Ilorin adobe traditional buildings do not fully comply with the local climate's plan, form, and fabric requirements. However, in Chapter 4, The analysis of the subjective preferences and disposition of the occupants' satisfaction with their building openings was achieved following ASHRAE-55. Insight from the subjective analysis shows almost substantial occupant dissatisfaction levels with the ventilation system in all the case study buildings. This necessitates further application of a quantitative (objective) approach in this chapter, based on the main objective of evaluating Ilorin Adobe Traditional buildings for thermal and visual performance using simulation and empirical research. Following the building measurement and post-occupancy evaluation study carried out in Chapter 3 and Chapter 4, the dynamic thermal computer simulations were undertaken to assist in drawing meaningful conclusions on the efficacy of the selected design strategies using the Andrewmash simulation tool (3D sun path and Dynamic daylighting), Optivent (version 2.1) simulation tool for ventilation validation and potential solutions via worst case scenarios and finally, the use of IES-ve simulation tool to validate results. In addition, this process helped quantify what could not be accurately measured during the on-site monitoring. For this chapter, the monitored buildings were chosen from four district regions of Ilorin City, Kwara state, Nigeria, for comparison and validation. The features of the buildings and the context of their climate are presented in Chapters 2 and 3. In this chapter, the simulation tools were used to analyse the main room in each case study building.The rooms were selected as the largest and most habitable rooms with adjoining living space in the buildings. The main rooms are rooms with the highest percentage of the window-to-wall ratio area, which was useful for evaluating the thermal and visual performance of the building. These rooms belong to the head of the house, and the space depicts a typical Ilorin traditional adobe room, which family members always occupy. The results obtained can serve as a replica of other rooms within the four case study buildings.

6.2.2 Software for Simulation

i. Andrewmash simulation tool (3D sun path and Dynamic daylighting)

The Andrew Marsh dynamic daylighting calculation tool is a deeply interactive software designed to address complexities in the design and analysis process. The software focuses on real-time dynamic daylight analysis within a rectangular room. It has several characteristics, including room size, windows, exterior shading devices, work plane height, etc., and instant updates on internal daylight distribution. Its main objective is to model the relationship between daylight distribution and factors like room size, window configuration, shading devices, and external obstructions in an engaging and user-friendly manner. The calculations are optimized for speed and accuracy, resulting in speedy and responsive interactions(Andrewmarsh.com).

ii. Optivent (version 2.1) Simulation Tool

Envelope flow models are used to solve the equations that govern how air flows through openings in a building's envelope. They rely on assumptions about the distribution of internal density (temperature), considering an opening in the envelope to reveal the fundamental equations for a single cell. The airflow rate through each opening is calculated using the discharge coefficient and effective aperture area. Equation 6-1

.

$$q_i = \frac{C_{di}\ A_i \pm \sqrt{2|\Delta\, p_i|}}{p}$$

(6-1)

Where i = identifies the opening/ inlet

q_i= is the flow rate through the opening (m^3/s)

C_{di} = is the discharge coefficient

A_i = is the area of the opening (m^2)

$\Delta\, p_i$ = is the pressure difference (Pa)

P= is the air density (kg/m^3)

The discharge coefficient is defined and measured under still-air conditions with uniform density flow being generated by wind. When the flow is generated by a density difference (i.e. in the absence of any wind effects), the pressure drop in equation (1) is given by Equation 6-2

$$\Delta p_i = P_{E0} - P_{I0} - \Delta P_0 gZ_i \qquad (6\text{-}2)$$

Where:

$P_{E0} - P_{I0}$ = are the external and internal hydrostatic pressures, respectively, at the ground level (Pa)

ΔP_0 = is the density different at the ground level (kg/m^3)

g = is the gravitational force per unit mass m/s^3

Z_i = is the height of the opening

The density differences are defined by

$$\Delta P_O = P_E - P_I$$

(6-3)

Where:

P_E and P_I are the densities of the external and internal respectively (kg/m^3)

Equation 6-2 is applied to an opening aligned in any direction, irrespective of whether the flow is inward or outward and whether the indoor temperature is higher or lower than outside temperatures. However, it is important to note the height where the flows leave the opening. Zi i.e. the height of the outlet. This follows from the outlet boundary condition, namely that the pressure at the outlet is determined by the pressure of the surroundings and the assumption that the temperature of the air remains unchanged as it flows through the opening. This means that for a long opening in the vertical direction, such as chimneys, z will change with the flow direction (Adekeye et al., 2023).

In this section, Optivent 2.1 is a straightforward natural ventilation steady-state tool designed to expand the range of generic airflow techniques for clear analysis and informed strategic decision-making during the early design stage. To analyze the ventilation techniques using the Optivent simulation tool, the following steps were followed: The first step involved identifying and determining the single and multi-cell space for single-side ventilation and, in some cases, cross-ventilation. Secondly, the meteorological wind speed for the terrain, prevailing mean outdoor temperature, and building orientation were determined. Thirdly, the effective apertures and windows beyond the stack height between inlets and outlets were located to calculate the volume flow rate displayed as a percentage between 0 and 90% on the Optivent interface. This step also considered the side-hung window type (depicted in red) with an effective area of 0-90% of each opening to be the most relevant for all the case studies as in Figure 6.1 and Table 6-1 Ventilation relies on buoyancy, which is driven by the temperature differential between indoor and outdoor air.

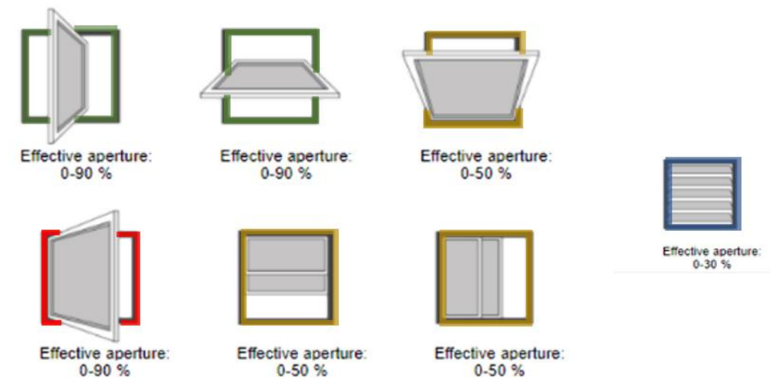
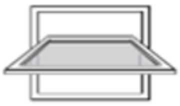
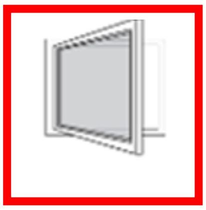
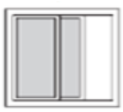
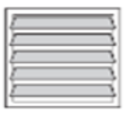


Figure 6-1: Effective aperture according to the optivent simulation.

The next step involved identifying the space geometry for the floor area, volume, and direct solar gain. In addition, the properties of construction materials were calculated based on surface absorptance, transmittance, glazing transmittance (glazing) and U values.

Table 6-1: Main Window types (CIBSE,2005)

Window types	**Actuator options (if automatic control is required).**	**Comments and eligibility**
Horizontal pivot 	Linear chain	The window has a high ventilation capacity; geometry promotes a good air supply distribution. Internal blinds are not practical. For an opening of 22^0 = 34% of the effective structural area. Not eligible
Vertical pivot 	Linear chain	This provides a similar effective area as the horizontal pivot. Blinds are not practical, and they are vulnerable to driving rain. Not eligible
Top/bottom hung 	Linear chain Rack and pinion Lead screw Lever arm	A wider range of actuator options. The length of the throw is significantly increased relative to pivot windows (which are more costly and vulnerable under high winds). Not eligible
Side hung (Casement) 	Chain Rack and pinion	It is difficult to link to the automatic opening gear (the lever arm must rotate as it extends). Also, ventilation characteristics are strongly influenced by winds, speed, and direction. Eligible
Tilt and turn 	It cannot be linked to the actuator.	These ventilation characteristics have been studied in several buildings. The tilt provides too much ventilation. Not eligible
Sash (sliding) 	Linear Linear-sleeved cable or rod	These windows have ventilation characteristics like horizontal and vertical pivot windows. The effective area is a maximum of 50% of the structural opening. Not eligible
Louvres 	Rotary Linear	Usually glazed or aluminium. The advantages are that they can be made secure and still function satisfactorily, which has the potential for night ventilation. However, when closed, louvers generally have a poor seal. Not eligible

Lastly, the estimation of internal gains, which comprises the number of occupants and lights, was carried out to calculate the flow rate of air needed to cool the building and make occupants thermally comfortable. According to Mohamed (2022), who also used a similar method, states that the worst-case scenario where space is completely occupied and experiences low windspeed and relatively discomforting high outdoor temperatures must be established through a baseline case study that addresses CIBSE standards to provide the optimum design solution for the specific building space. The author further explained that the temperature and wind speed must be fixed prior to the start of simulations.

i. IES-VE Simulation Tool

Simulation work was performed using a commercially available tool known as IESVE software (version 2023). The software has important interphases, which include ApacheSim, Macroflo, and RadianceIES programs for running parametric analysis. the purpose of ModelIT in IESVE is to design building models with varying degrees of complexity to be included throughout the whole design range as utilised in the comparative studies of building performance simulation tools for the thermal and daylighting outputs of different building performances. Erdogan (2019) suggested researching the process of implementing modern shading and daylighting strategies using IES-ve generative design, which shows a stronger correlation with the results of the indoor air temperature. Sun cast program does computations for sun path tracking for shading; Ibrahim and Hassan (2023) used the Suncast tool for solar analysis of the building model to determine solar shading needed and predicted the elements of the outer shell most exposed to solar radiation and gave an insight into the highest heat gain inside the building investigated. The thermal analysis programmes in IESVE, such as Apache, compute heat gains and losses by conduction and infiltration. RadianceIES and Macroflo in IES are used to simultaneously solve interdependent daylighting visualisation shown on the working plane within the ModelViewer. by calculating the daylight factor and airflow balances. MacroFlo simulates airflow via the building envelope windows and interactively connects data with Apache. RadianceIES can estimate the anticipated requirement for artificial lighting within the building during the day to find the daylight factor of the indoor space. However, parametric simulations would provide an opportunity to investigate daylight performance within the building based on new perspectives (Hosseini et al., 2018). Therefore, in this study, the IES simulation results are crucial for assessing whether the room space receives adequate lighting through the designated window sizes and placement.

6.3 Method of Simulation

This research section analyses several daylight factors in four existing case study buildings using different standards/rules of thumb and displaying the daylight values across multiple lighting parameters appropriate for designs/buildings with effective visual and thermal comfort.

6.3.1 Assessments of Natural Lighting Conditions in the case study Buildings using Rules-of-Thumb.

This section of the research analyses several daylight factors in existing case study buildings using different standards/rules of thumb and displays the daylight values across multiple lighting parameters appropriate for designs/buildings with effective visual and thermal comfort. For instance, the Table in section 2.9, which is taken from (CIBSE, 2015), displays the lighting settings recommended by various building evaluation organizations for a visually acceptable building.

ii. Rule of Thumb analysis

Rule of Thumb 1; Average Daylight Factor (Manual calculation) using Equation 6-3

$$\overline{D} = \frac{W}{A} \cdot \frac{T\Theta}{(1-R^2)} \qquad (6\text{-}3)$$

Where:

$\overline{D}$ = average daylight factor

W = net window area (Subtract 10% for frame)

A = area of all surfaces of the room, including the window

T = visible transmittance for the glass (subtract 10% to correct for dirt)

Θ = visible sky angle, in degrees

R = R = average reflectance of room Surface

(Rennie and Parand, 1998).

Rule of Thumb 2: Depth of Room (Manual calculation)

Scenario 1 $Depth\ of\ room < 8m\ = 20\%\ WWA$ *(6-4)*

Scenario 2 $Depth\ of\ room\ (8m - 11m) = 20\%\ WWA\ldots$ *(6-5)*

Scenario 3 $Depth\ of\ room\ (11m - 14m) = 20\%\ WWA$ *(6.6)*

Scenario 4 $Depth\ of\ room > 8m\ = 20\%\ WWA$ *(6.-7)*

Where: WWA = Window to wall area.

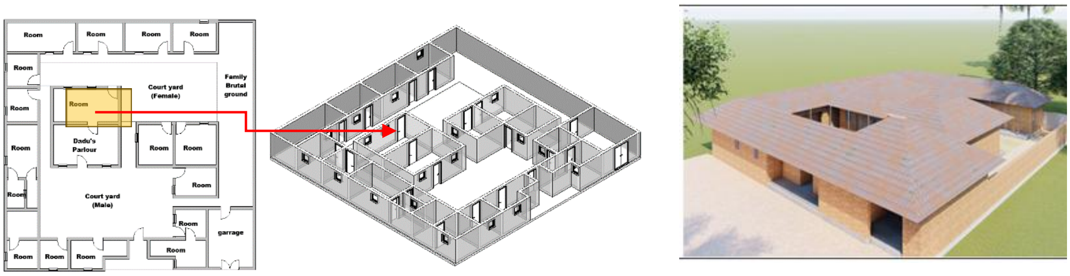
According to this "rule of thumb" (Average Daylight Factor), an average daylight factor of > 2% should be attained to meet the standards for the minimum average daylight factor necessary for a space to appear mainly illuminated. (CIBSE, 2015). Also, another general rule of thumb (Depth of Room), as shown in Equation (6-4,6-5,6-6,6-7), implies that the minimum area of glass as a percentage of a window area of space less than 8m should be 20% of the total window wall area and a space greater than 14m should be 35% of the total window wall area in other to experience good visual comfort.

6.3.2 In-situ Monitoring

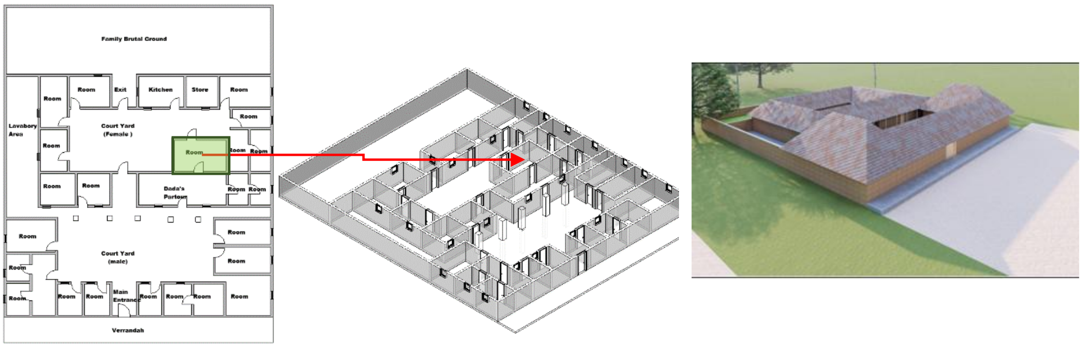
An objective evaluation of the case study buildings was carried out through an experimental monitoring process of quantifying the indoor thermal comfort of the buildings with the use of tiny tag data loggers. The traditional Ilorin adobe buildings with zinc roofs and tiny windows were chosen in order to address the problem of overheating. It should be noted that one of the noteworthy trends in traditions of Ilorin vernacular architecture from the past to the present is the type of roof from thatch to zinc. The monitored buildings, which are also the simulation models, represent passive design strategies, fundamental building construction materials used, such as 300mm thick adobe walls, and the performance of the building envelope for the studied climate in the present. However, they might not accurately depict Ilorin, adobe traditional buildings from earlier times due to slight building envelope modifications put in place by occupants. For instance, the roof changed from thatch to Zinc, and the walls changed from 300 mm thick adobe walls to 300 mm thick adobe walls plastered with 15mm cement on both sides.

Monitored buildings: The monitored buildings were detached bungalow buildings with several rooms facing a central courtyard, as illustrated in Figure 6-2. The building envelope for the four buildings was categorised into two sets, having two case study buildings per set, where set 1, also considered As built (these buildings have been modified according to occupant's strategies), was built with Mud walls plastered with cement, mud floors plastered with cement, timber framed hip roof covered with Zinc sheets, small timber windows and rooms facing two courtyards. Set 2 buildings were built with mud walls, mud floors, timber framed hip roofs covered with zinc roofing sheets, tiny timber framed windows, and rooms facing only one courtyard. The rooms monitored were bedrooms with plywood ceilings with a maximum of 6 occupants and a minimum of 2 people during off-peak day hours (9 am to 4 pm). The data loggers were suspended from the ceiling and placed carefully at the top corner of the room wall at about 1.3 to 2m above the floor. This height was chosen to prevent children/occupants from playing or tampering with the bright, yellow-coloured tiny tag data logger, which also had blinking-coloured lights. The loggers were placed in strategic locations away from direct solar radiation in naturally ventilated rooms. The room sizes ranged between 14.4m^2 (Case study C&D), 15.66m^2 (Case A), and 27.8m^2 (Case study B) approximately. The four main rooms were selected as they were the most frequently occupied rooms all day. Thus, they served as the main and most habitable places in each building.

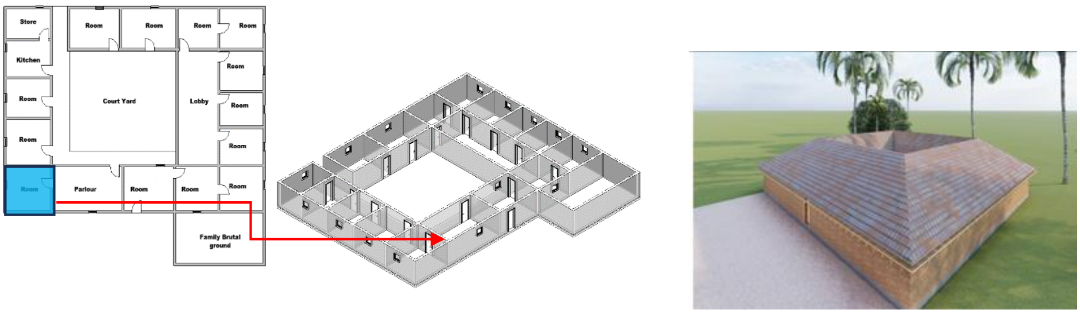
The process assisted with the calculations of new thermal comfort temperature set points to achieve minimum standards for the occupants to adopt. The recommended temperature and standard effective temperature (SET) for each case study building were achieved for the hottest and coldest months of the year. The comfort temperature for occupants in typical Ilorin traditional adobe buildings was determined to be within the range of 25.2 to 32.1 ˚C.



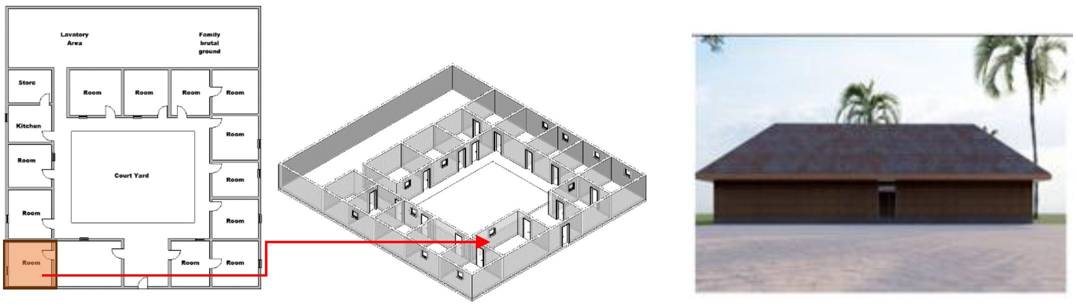
Case Study A



Case Study B



Case Study C



Case Study D

Figure 6-2: Photo showing images of the monitored case study buildings.

6.3.3 Ventilation

For this research, the researcher calculated the rate of airflow/ air exchange of Ilorin traditional buildings using the Optivent 2.1 version. Different scenarios have been tested, starting with the current situation: single-sided ventilation (the reference case) and cross-ventilation with modified stack height effects between the openings and parameters of the worst-case scenario. The goal was to determine the best design space in terms of airflow and thermal comfort temperatures for the living spaces and bedrooms of Ilorin Adobe building designs. Height of stack (m): The vertical distance between the centres of the inlet and the outlet is referred to as stack height. Figure 5-3

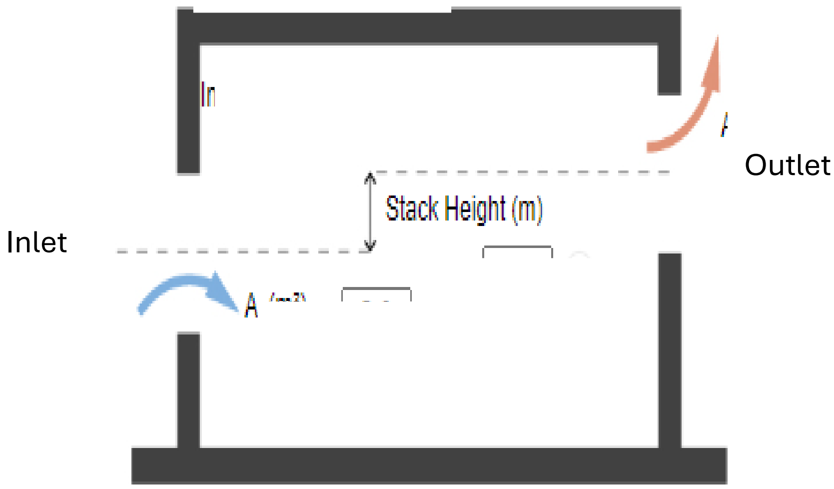


Figure 6-3: The stack height between the inlet and outlet.

Table 6-2: Scenarios tested.

▪ Single-side ventilation
o Typical window size – 600mm * 600mm /effective opening- 60% (likely worst-case scenario) o Increased effective opening by 50% in current windows. o Increased window size (1.2mm * 1.2mm to (or add more windows) o increase effective opening to 90%
▪ Cross-ventilation with modified stack height in accordance to building height (1.0 m to 1.3 m, 1.0 m to 0.8 and 1.0 m to 0.7 m)
o Typical window size/effective opening o Increased effective opening in current windows. o Increased window size (or add more windows) to increase effective opening

i. Optivent Design Calulation

Table 6-3: Fixed parameters used for Optivent 2.1

Location Data:		U-value of construction materials	W/(m²K)	Heat Gains	
Latitude and longitude (decimal degrees):	8.5ºN, 4.5 ºE	Roof (a) Zinc	7.142	Highest number of occupants per room	6
Month:	March	Roof (b) Thatch	0.334	Lowest number of occupants per room	2
Hour:	6am, 12noon & 8pm	Walls (external/internal) (a) 15mm cement plaster 300mm Adobe brick 15mm cement plaster	0.684	equipment W/m²	15
Prevailing mean outdoor:	29.6ºC	Walls (external / internal) (b) Adobe brick	0.544	lighting W/m²	10
Meteorological Wind Speed (m/s):	2.0 m/s	Floor (a) 10mm Cement 15mm Mud	4.059		
Terrain data:	Meteorological value	Floor (b) 25mm Mud	3.647		

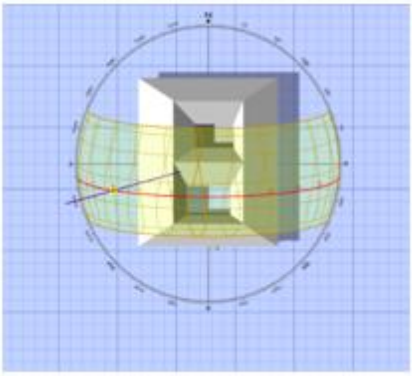
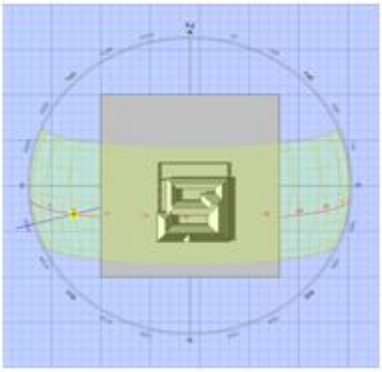
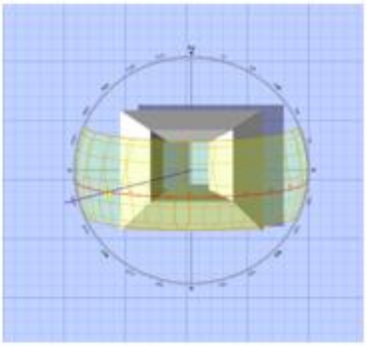
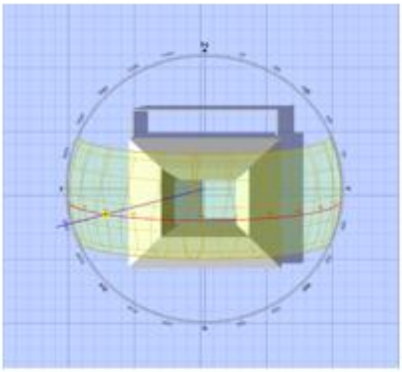
6.3.4 Solar Geometry

Tables 6-4, 6-5, 6-6, and 6-7 detail the impact of sun radiation on exposed building envelopes and the effects on the roof, walls, and windows for each building studied throughout the two seasons. The tables include data on the annual percentage shading and total sunlight hours/ time for different heights/levels, angles, and azimuth throughout the year.

i. Solar Radiation, Angles, and Daylighting Analysis

The sun path diagrams for the buildings in Tables 5-4, 5-5, 5-8, and 5-11 and 5-14 were simulated using the online application "www.AndrewMarsh.com." The simulation shows the sun's position during the equinox and solstices, the degree rise, azimuth angles, and daylighting time for sunrise and sunset during summer and winter (AndrewMarsh, 2022). The highest and lowest solar altitudes of 74.50° and 40.77° occur at 12:00 (noon) and 15:00 hrs in mid-summer (June 21st solstice), while the highest and lowest sun altitudes in mid-winter (December 22nd solstice) are 57.77° and 31.72°, respectively. Understanding solar angles is crucial for protecting building elements from excessive exposure on the year's hottest days and for planning adequate shading.

Table 6-4: Solar geometry of the hottest day in the year

Hottest day of the year: 08 March 2023	Average daily high $T_{outdoor}$: 36.5 °C
Time: 3:00pm	Azi / Alt: -104.93° / 41.53°
Rise / Set: 05:53 / 17:54	Daylight: 12:00 Hrs
Case study A	Case study B
	
Case study C	Case study D
	

The impact of solar radiation and its position at 3:00 PM on the building on the hottest day of the month (March 8th) is shown in Table 6-4. The sun's angle/altitude is 41.53, and the azimuth is -104.93. The sun rises at 5:53 AM and sets at 5:54 PM. This is the hottest day of the year in the warm-humid climate of Ilorin, Nigeria. At 9:00 AM, the sun hitting the building brings early morning warmth and natural daylight into the building. Between 10:00 AM and 2:00 PM, the sun lies directly overhead of the building, and most of its energy hits the roof's surface. However, between 2:00 PM and 5:00 PM, the sun's angle begins to lower towards sunset, causing the sun rays/solar radiation to hit directly on the west walls and windows of the building, which could lead to the heating of the building. The sun path analysis in Table 5-4 indicates that the western elevation wall is prone to solar heat and effects from sunlight from solar insolation when left unshaded. This shows that solar radiation affects the building structure and has prompted the assessment to propose quantifying solar radiation's impact on the buildings between 2:00 PM and 5:00 PM with 3:00 PM being the most affected hour and the provision of shading components to help block incident rays from solar radiation during the late morning, mid-day periods, and late afternoon. This will help to curtail the impacts of undesired solar radiation on the buildings. To make shading equipment effective in tropical areas, it is necessary to measure sun insolation (Kiamba, 2016).

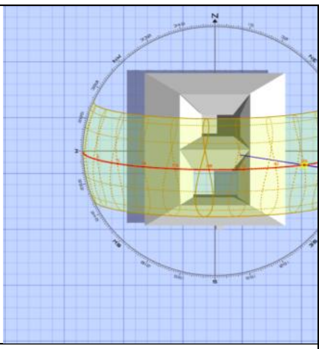
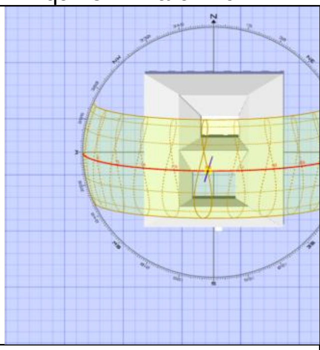
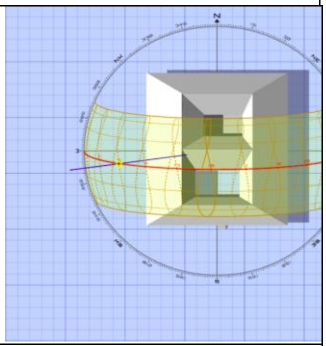
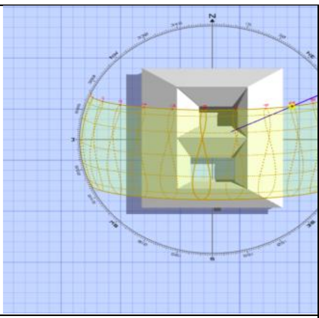
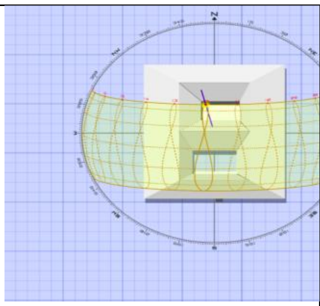
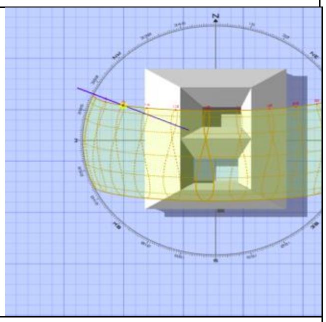
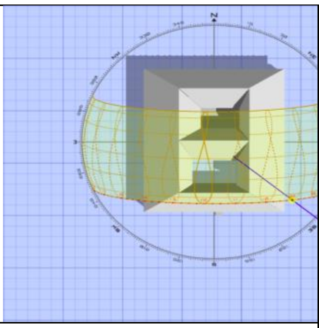
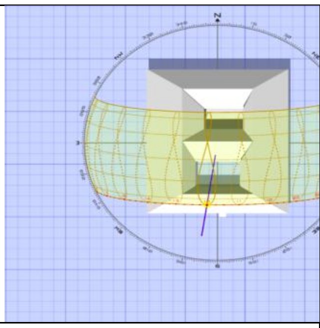
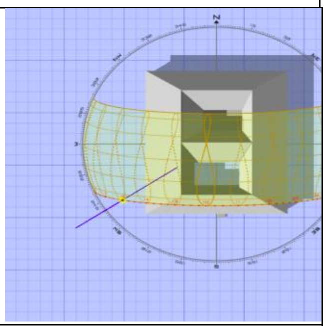
6.4 Characterisation through Rules-of-Thumb: Solar Geometry, Ventilation, and Daylighting

The results of solar geometry for the case studies are presented in Table 6-5 and Figure 6-4 respectively.

6.4.1 Case Study A

i. Solar Geometry

Table 6-6:Solar geometry of the hottest day in the year

	Case study A		
	Equinox- March 20th		
			
	9am Azi / Alt: 99.47° / 46.83°Rise / Set: 05:47 / 17:53Daylight: 12:06 Hr	12 noon Azi / Alt: 163.64° / 80.95°Rise / Set:05:47 / 17:53Daylight: 12:06 Hrs	3pmAzi / Alt: -97.98° / 41.86°Rise / Set: 05:47 / 17:53 Daylight: 12:06 Hrs
	Summer solstice – June 21st		
			
	9am Azi / Alt: 64.11° / 48.10 Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs	12 noon Azi / Alt: -14.15° / 74.50° Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs	3pm Azi / Alt: -66.24° / 40.77° Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs
	Winter solstice – Dec 22nd		
			
	Azi / Alt: 130.08° / 39.55° Rise / Set:05:51 / 17:29 Daylight: 11:38 Hrs	Azi / Alt: -171.43° / 57.77° Rise / Set:05:51 / 17:29 Daylight: 11:38 Hrs	Azi / Alt: -124.35° / 31.72° Rise / Set:05:51 / 17:29 Daylight: 11:38 Hrs

ii. Ventilation

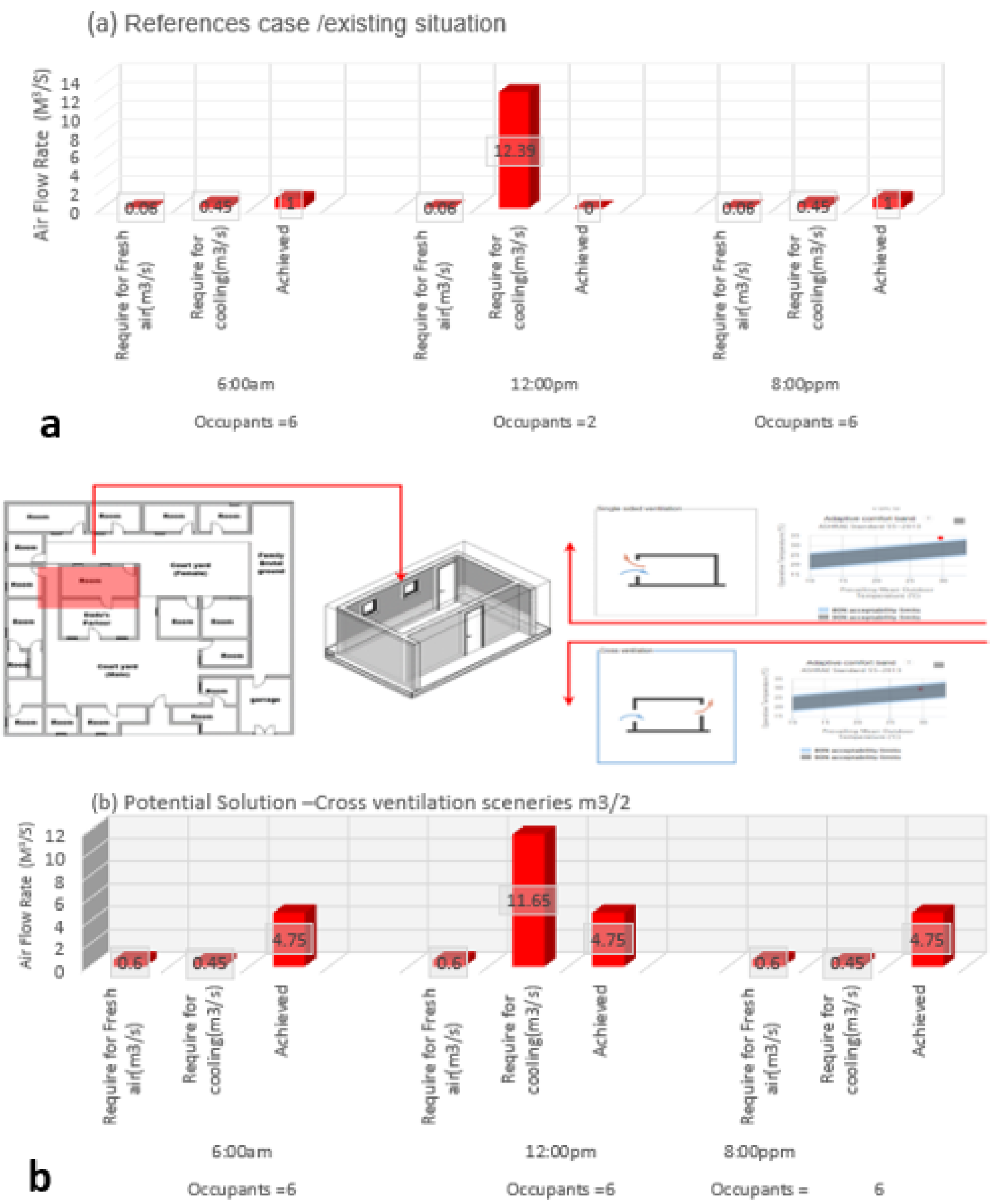


Figure 6-4: Ventilation results for room Case study A (a)Reference case (b) potential solution:

iii. Rules-of-Thumb and Daylighting

Table 6-7:Rule of Thumb 1; Average Daylight Factor (Manual calculation)

S/n	Building	Space type	Number Of Windows	Window size	W	A	T	Θ	R	D = average daylight factor
1a.	Case A	Room	2	0.6 *0.6	0.64	81.24	0.09	90	0.5	0.08

Table 6-8:Rule of Thumb 2: Depth of Room (Manual calculation)

S/n	Building	Space type	Wall area	Criteria (%)	Existing window area	Minimum Window area (%)	Depth of Room rule
1b.	Case A	Room	12.18	20	0.72	2.4	Not successful

$$Depth\ of\ room < 8m\ = 20\%\ Window\ area$$

Table 6-6 shows that the average daylight factor for the room simulated in case A is calculated to be 0.08%, which is lower than the required minimum of 1.5% for residential buildings. This was achieved using the Equation 6-3.

$$\bar{D} = \frac{W}{A} \cdot \frac{T\Theta}{(1-R^2)} \qquad (6\text{-}3)$$

Table 6-7 indicates that the window area for the depth of the existing room is 2.4%, which is unsatisfactory and significantly lower than the required minimum standard value of 20% for the window area. Figure 5-5 further illustrates the building plan, the room's location, and the dynamic daylighting simulation result from the AndrewMarsh App.

iv. Dynamic daylighting simulation

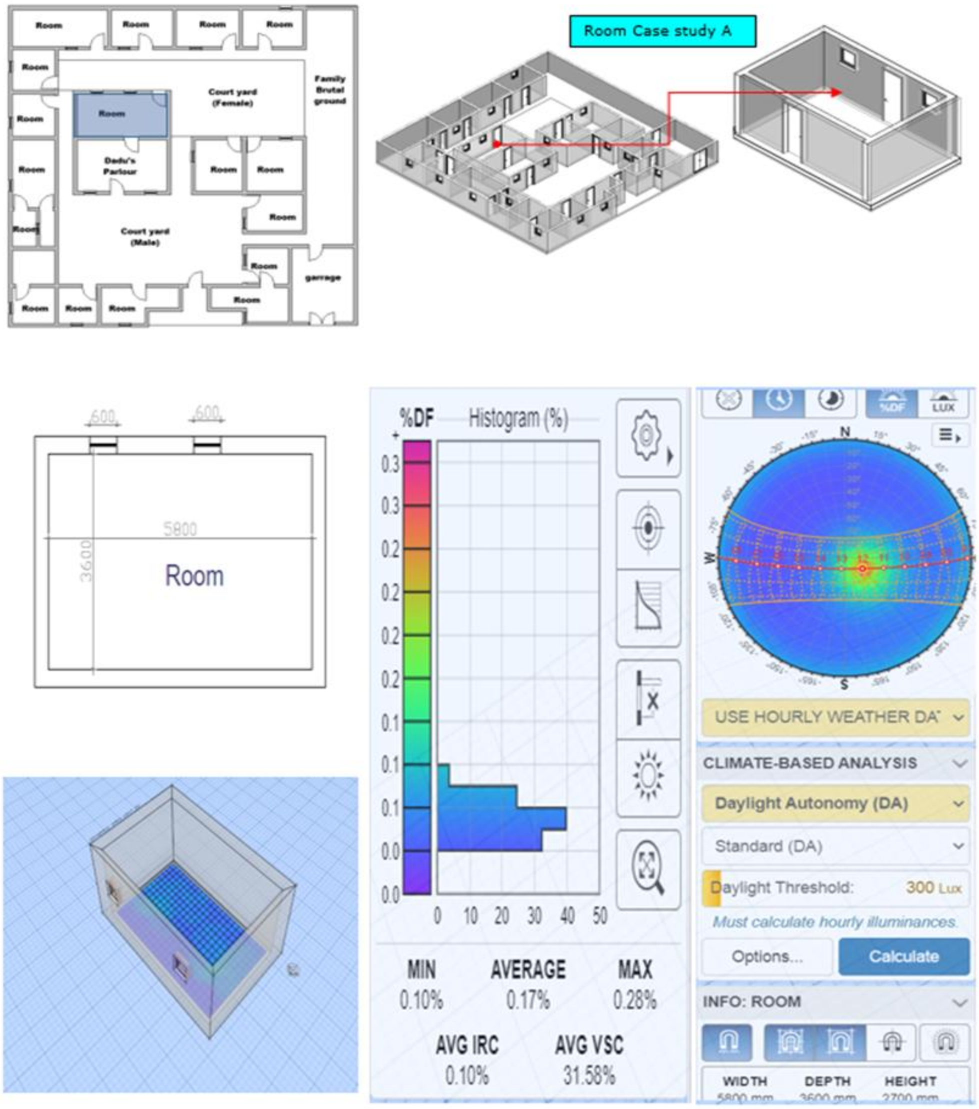
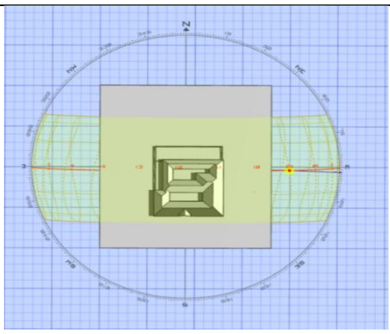
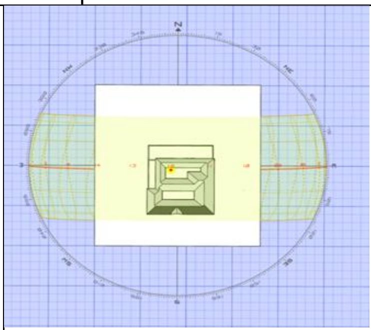
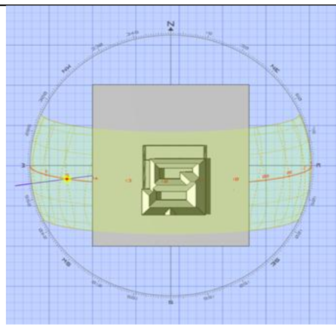
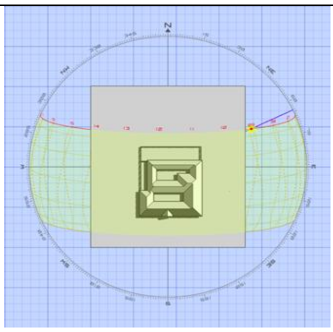
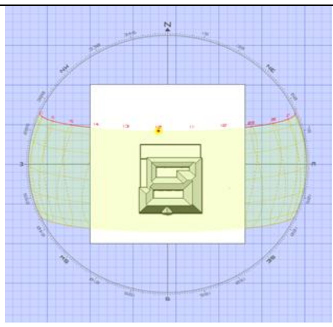
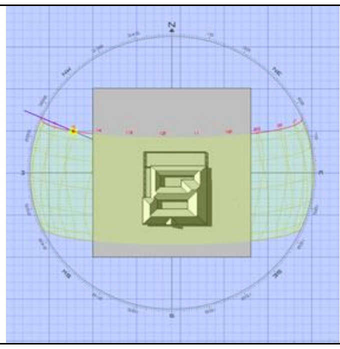
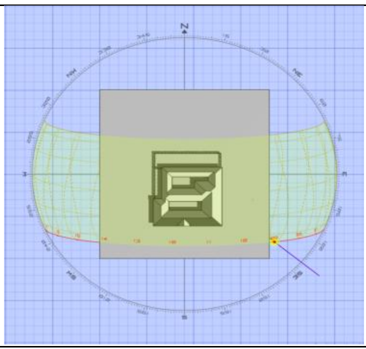
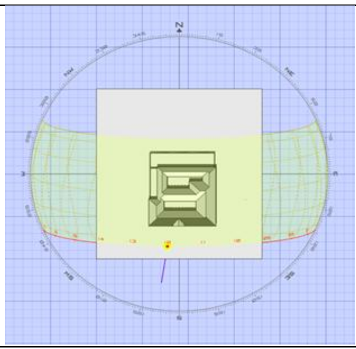
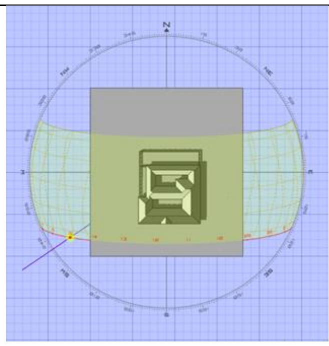


Figure 6-5: Simulation result showing daylight factor entering the typical case study room- Case A

6.4.2 Case Study B

Solar Geometry

Table 6-9:Sunpath geometry of case study B

Case study B		
Equinox- March 20th		
		
9am Azi / Alt: 99.47° / 46.83° Rise / Set: 05:47 / 17:53 Daylight: 12:06 Hr	12 noon Azi / Alt: -163.64° / 80.95° Rise / Set: 05:47 / 17:53 Daylight: 12:06 Hrs	3pm Azi / Alt: -97.98° / 41.86° Rise / Set: 05:47 / 17:53 Daylight: 12:06 Hrs
Summer solstice – June 21st		
		
9am Azi / Alt: 64.11° / 48.10 Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs	12 noon Azi / Alt:-14.15° / 74.50° Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs	3pm Azi / Alt:-66.24° / 40.77° Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs
Winter solstice – Dec 22nd		
		
Azi / Alt: 130.08° / 39.55° Rise / Set: 05:51 / 17:29 Daylight: 11:38 Hrs	Azi / Alt: -171.43° / 57.77° Rise / Set: 05:51 / 17:29 Daylight: 11:38 Hrs	Azi / Alt: -124.35° / 31.72° Rise / Set: 05:51 / 17:29 Daylight: 11:38 Hrs

i. Ventilation

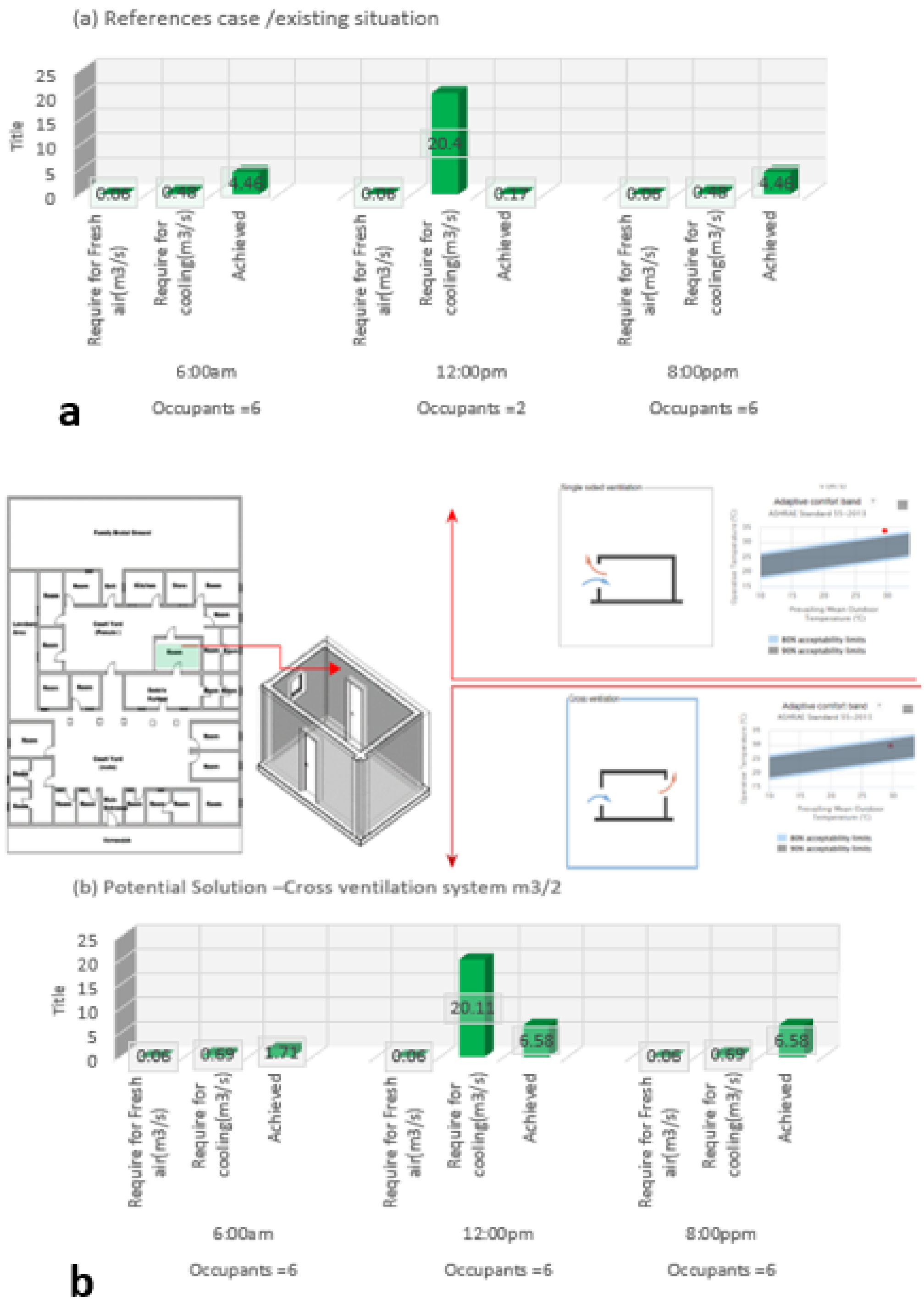


Figure 6-6: Ventilation results for room Case study B *(a)Reference case (b) potential solution:*

ii. Rules-of-Thumb and Daylighting

Table 6-10: Rule of Thumb 1; Average Daylight Factor (Manual calculation)

S/n	*Building*	*Space type*	*Number Of Windows*	*Window size*	*W*	*A*	*T*	*Θ*	*R*	*D = average daylight factor*
1a.	Case A	Room	1	0.6 *0.6	0.324	101.5	0.09	90	0.5	0.03

Table 6-11: Depth of room<8m =20% Window area

S/n	Building	Space type	Wall area	Criteria (%)	Existing window area	Minimum Window area (%)	Depth of Room rule
2b		Room	8.4	20	0.36	1.86	Not successful

The data suggests that the average daylight factor for the room in case B is only 0.03%, well below the required minimum of 1.5% for residential buildings as per *Equation 6-3.*

$$\bar{D} = \frac{W}{A} \cdot \frac{T\Theta}{(1-R^2)} \qquad (6\text{-}3)$$

Additionally, Table 5-8 indicates that the window area for the existing room is just 1.86%, significantly lower than the required minimum standard of 20% for window area. Furthermore, Figure 5-7 provides a visual representation of the building plan, the room's location, and the dynamic daylighting simulation result from the AndrewMarsh App.

iii. Dynamic daylighting Simulation

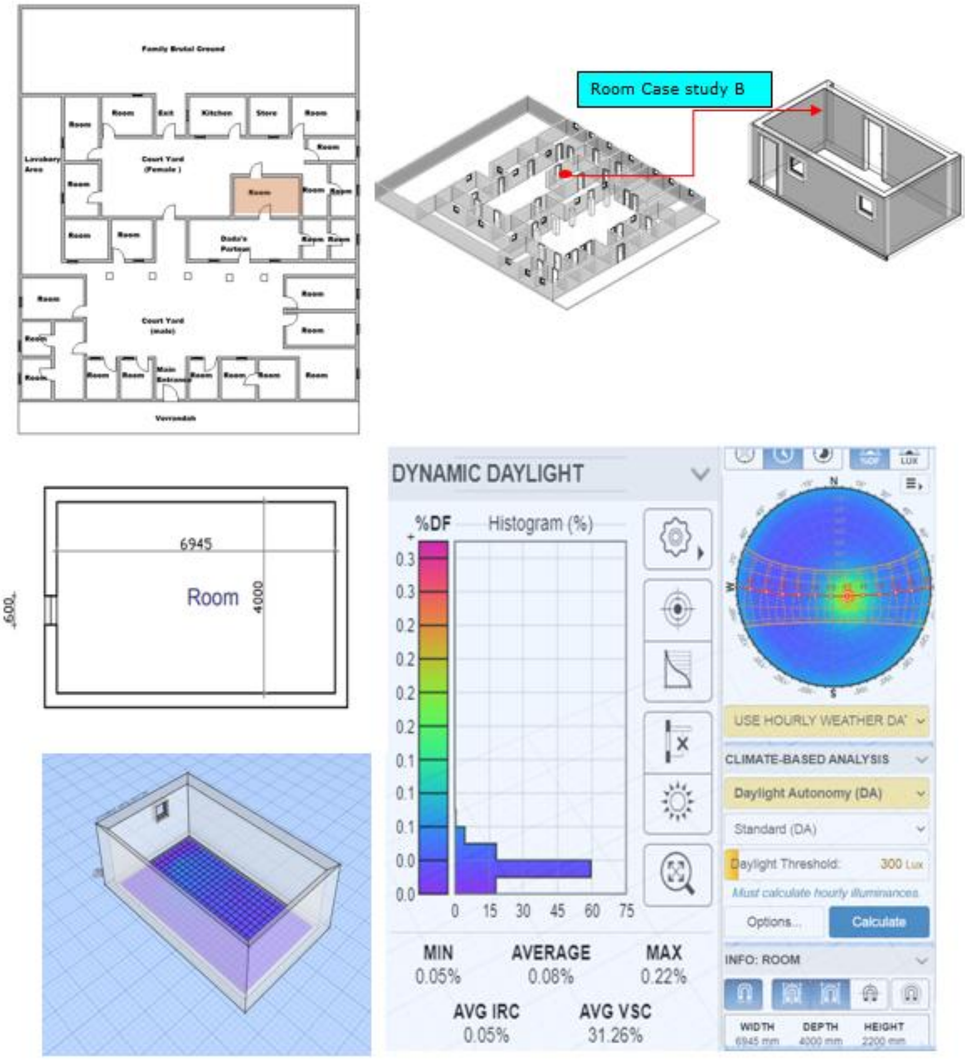
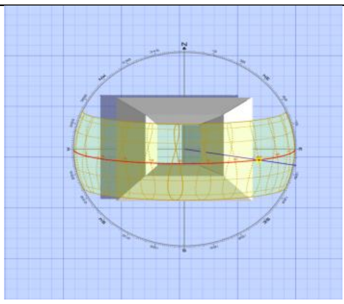
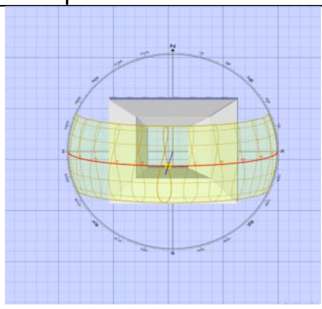
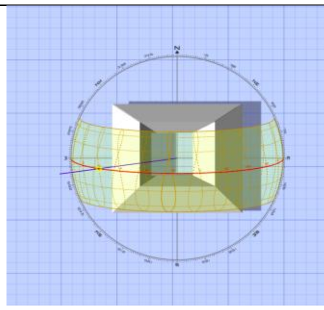
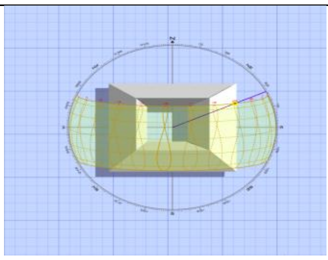
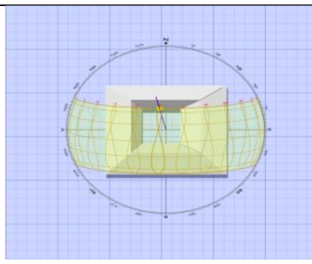
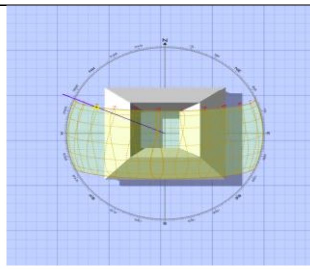
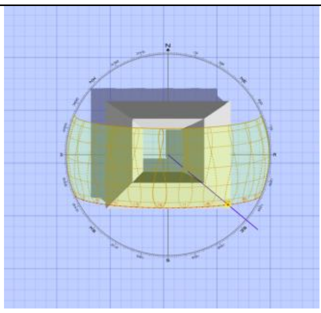
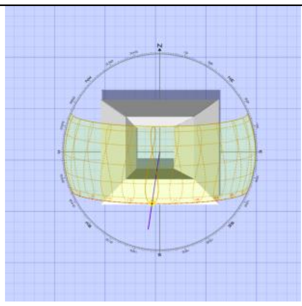
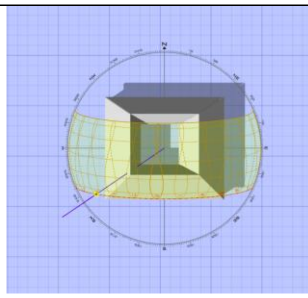


Figure 6-7: Simulation result showing daylight factor entering the typical case study room - Case B

6.4.3 Case Study C

i. Solar Geometry

Table 6-12: Showing solar geometry for case C

	Case study C		
		Equinox- March 20th	
			
	9am Azi / Alt: 99.48° / 46.83°Rise / Set: 05:47 / 17:53Daylight: 12:06 Hrs	12 noonAzi / Alt: -163.63° / 80.95°Rise / Set: 05:47 17:53Daylight: 12:06 Hrs	3pm Azi / Alt: -97.98° / 41.86°Rise / Set: 05:47 / 17:53 Daylight: 12:06 Hrs
Summer solstice – June 21st			
			
	9am Azi / Alt: 64.11° / 48.10 Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs	12 noon Azi / Alt: -14.15° / 74.50° Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs	3pm Azi / Alt: -66.24° / 40.77° Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs
Winter solstice – Dec 22nd			
			
	Azi / Alt: 130.08° / 39.55° Rise / Set: 05:51 / 17:29Daylight: 11:38 Hrs	Azi / Alt: -171.43° / 57.77°Rise / Set:05:51 / 17:29 Daylight:11:38 Hrs	Azi / Alt: -124.35° / 31.72°Rise / Set:05:51 / 17:29Daylight: 11:38 Hrs

ii. Ventilation

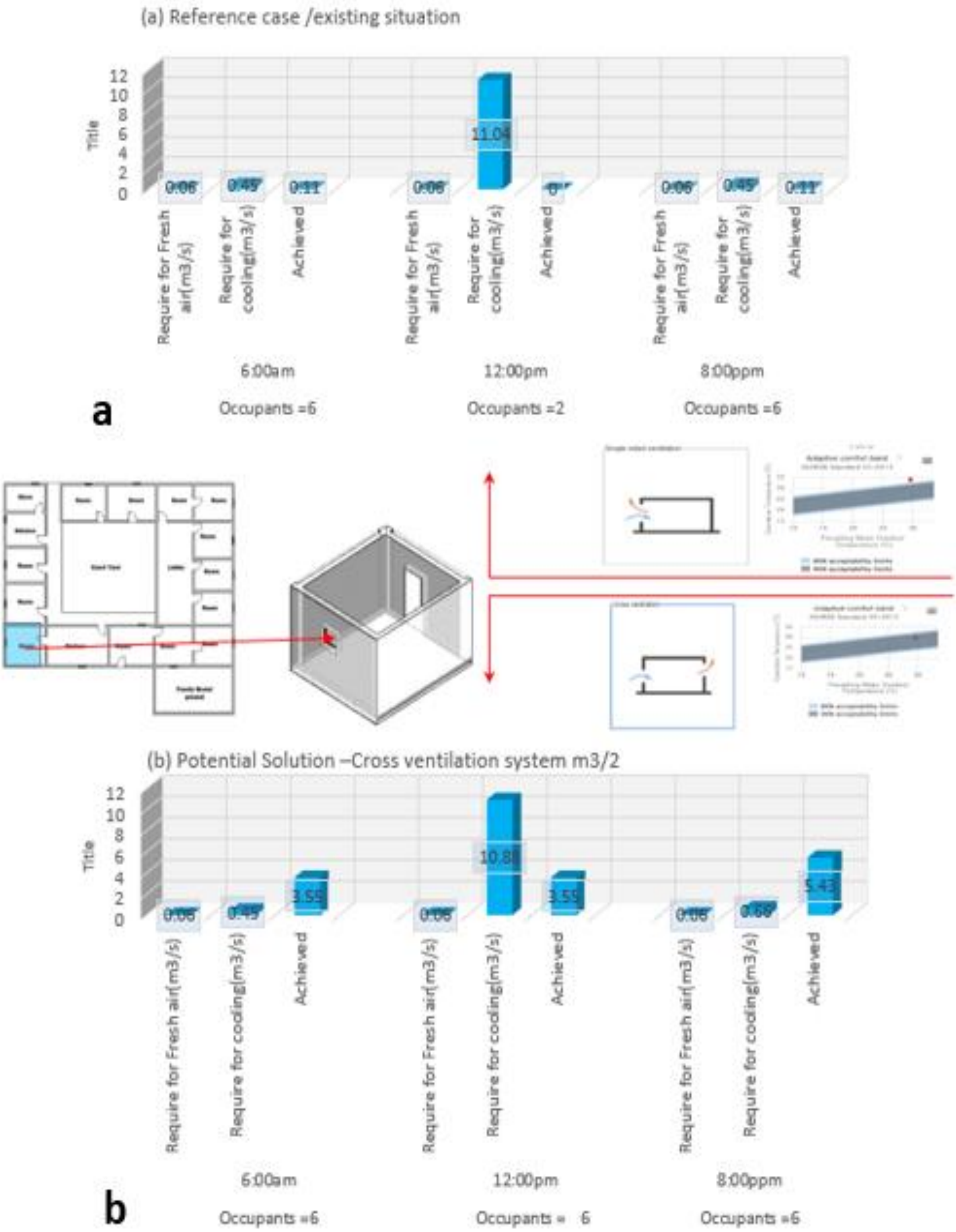


Figure 6-8: Ventilation results for room Case study C (a)Reference case (b) potential solution:

iii. Rule-of-Thumb and Daylighting

Table 6-13: Rule of Thumb 1; Average Daylight Factor (Manual calculation)

S/n	Building	Space type	Number Of Windows	Window size	W	A	T	Θ	R	D = average daylight factor
3a	Case C	Room	1	0.75*0.6	0.41	60.72	0.09	90	0.5	0.11

Table 6-14: Depth of room<8m =20% Window area

S/n	Building	Space type	Wall area	Criteria (%)	Existing window area	Minimum Window area (%)	Depth of Room rule
3b	Case C	Room	8.4	20	0.45	1.68	Not successful

The data clearly shows that the average daylight factor for room B is a mere 0.11%, falling far below the required minimum of 1.5% for residential buildings . Furthermore, Table 6-12 unquestionably indicates that the window area for the existing room is a meager 1.68%, starkly below the required minimum standard of 20% for window area. Additionally, Figure 6-9 confidently presents a visual representation of the building plan, the room's location, and the dynamic daylighting simulation result from the AndrewMarsh App.

iv. Dynamic daylighting Simulation

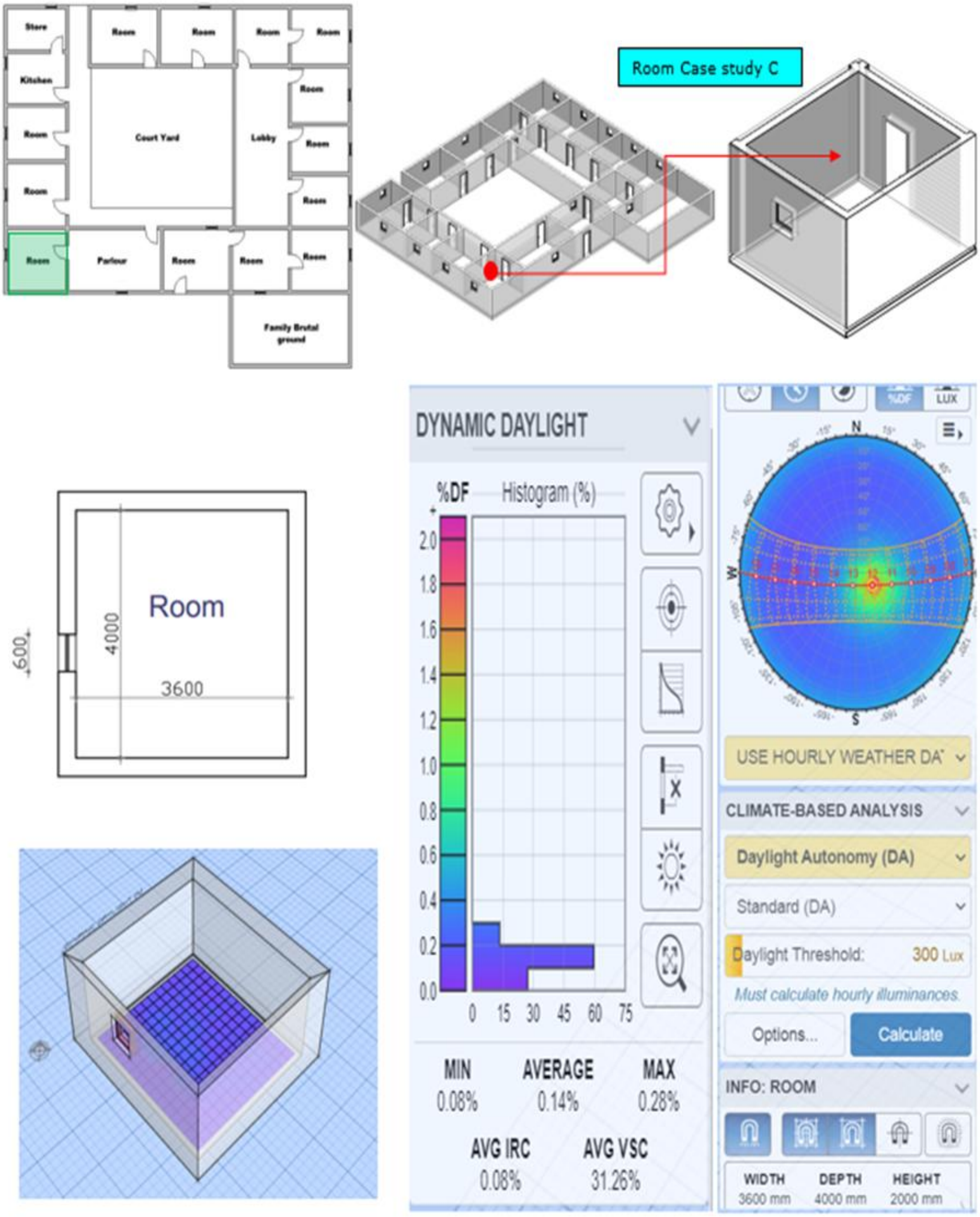
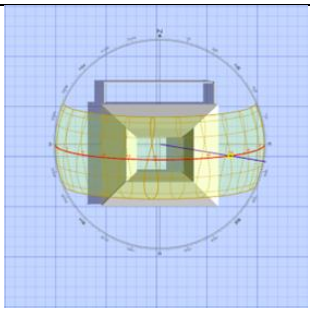
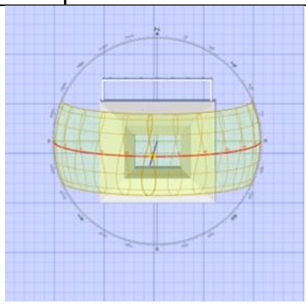
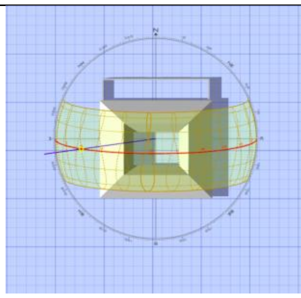
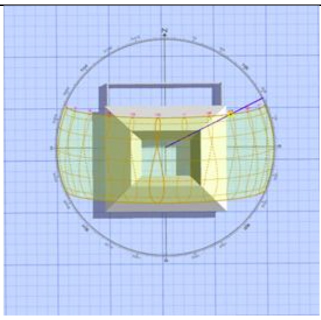
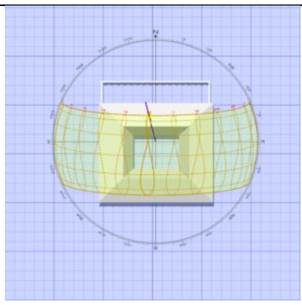
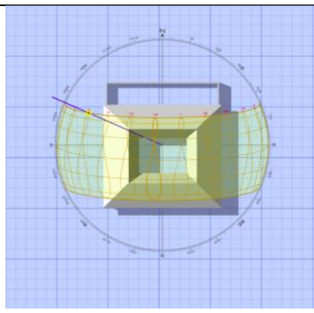
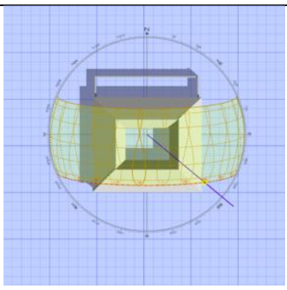
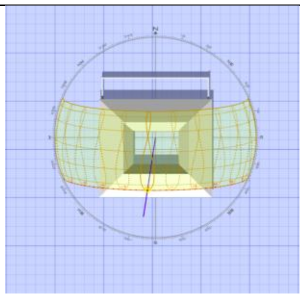
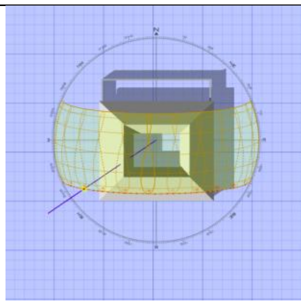


Figure 6-9: Simulation result showing daylight factor entering the typical case study room - Case C

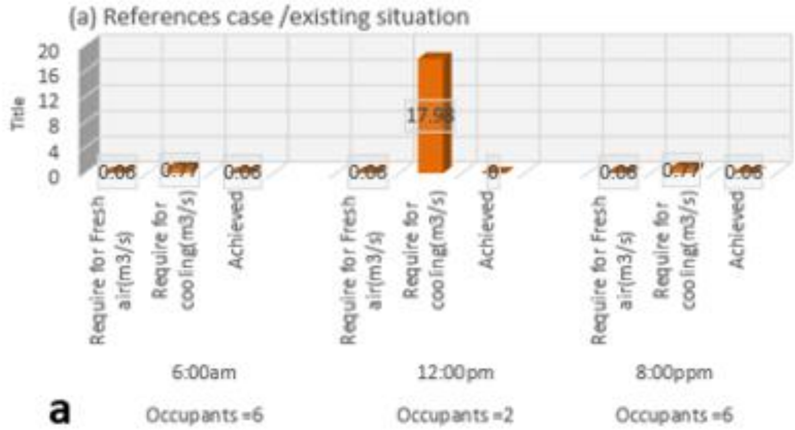
6.4.4 Case Study D

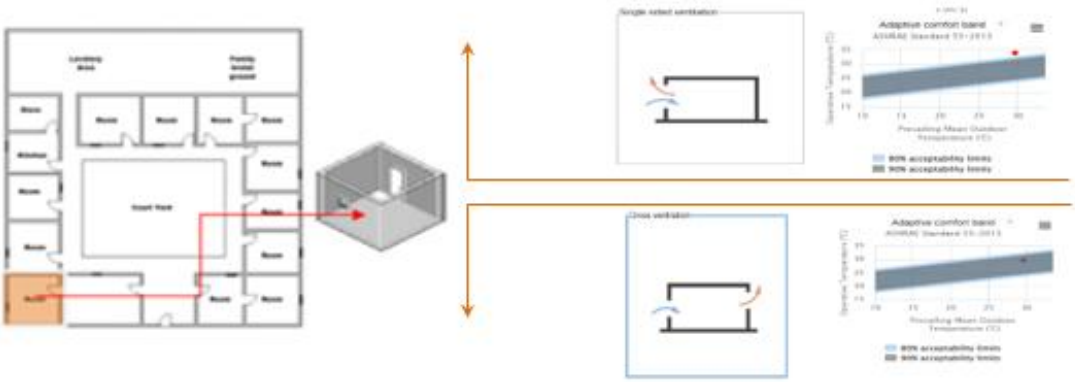
i. Solar Geometry

Table 6-15 Showing solar geometry for case D

	Case study D		
		Equinox- March 20th	
			
	9am Azi / Alt: 99.48° / 46.83° Rise / Set: 05:47 / 17:53 Daylight: 12:06 Hrs	12 noon Azi / Alt: 163.63° / 80.95° Rise / Set: 05:47 / 17:53 Daylight: 12:06 Hrs	3pm Azi / Alt: -97.98° / 41.86° Rise / Set: 05:47 / 17:53Daylight: 12:06 Hrs
		Summer solstice – June 21st	
			
	9am Azi / Alt: 64.11° / 48.10 Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs	12 noon Azi / Alt:-14.15° / 74.50° Rise / Set: 05:25 / 18:02 Daylight: 12:37 Hrs	3pm Azi / Alt:-66.24° / 40.77°Rise / Set: 05:25 / 18:02Daylight: 12:37 Hrs
		Winter solstice – Dec 22nd	
			
	Azi / Alt: 130.08° / 39.55° Rise / Set: 05:51 / 17:29 Daylight: 11:38 Hrs	Azi / Alt: -171.43° / 57.77° Rise / Set:05:51 / 17:29Daylight: 11:38 Hrs	Azi / Alt: -124.35° / 31.72°Rise / Set:05:51 / 17:29 Daylight: 11:38 Hrs

ii. Ventilation





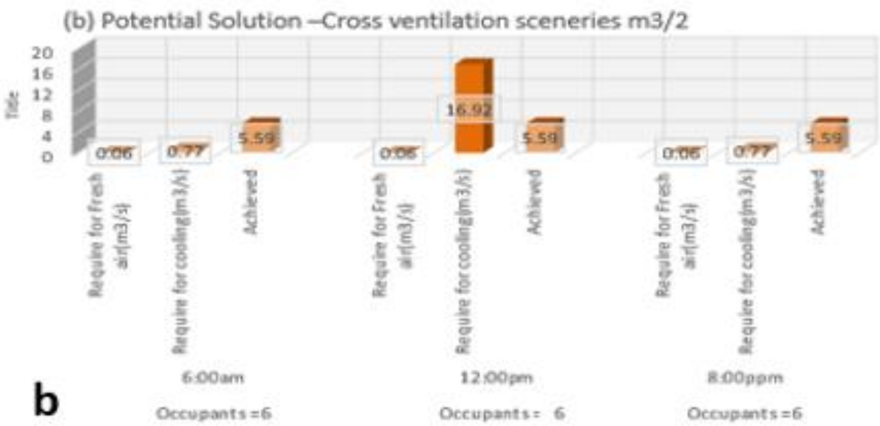


Figure 6-10: Ventilation results for room Case study D (a)Reference case (b) potential solution:

iii. Rules-of-Thumb and Daylighting

Table 6-16: Rule of Thumb 1; Average Daylight Factor (Manual calculation)

S/n	Building	Space type	Number Of Windows	Window size	W	A	T	Θ	R	D = average daylight factor
4a	Case D	Room	1	0.6 *0.6	0.324	60.72	0.09	90	0.5	0.06

Table 6-17:Depth of room<8m =20% Window area

S/n	Building	Space type	Wall area	Criteria (%)	Existing window area	Minimum Window area (%)	Depth of Room rule
4b	Case D	Room	8.4	20	0.36	1.68	Not successful

Room D has an average daylight factor of 0.06%, significantly lower than the 1.5% minimum for residential buildings. The current window area is only 1.68%, far below the required minimum of 20%. Figure 5-7 visually illustrates the building plan, room location, and the dynamic daylighting simulation result from the AndrewMarsh App.

iv. Dynamic Daylighting Simulation

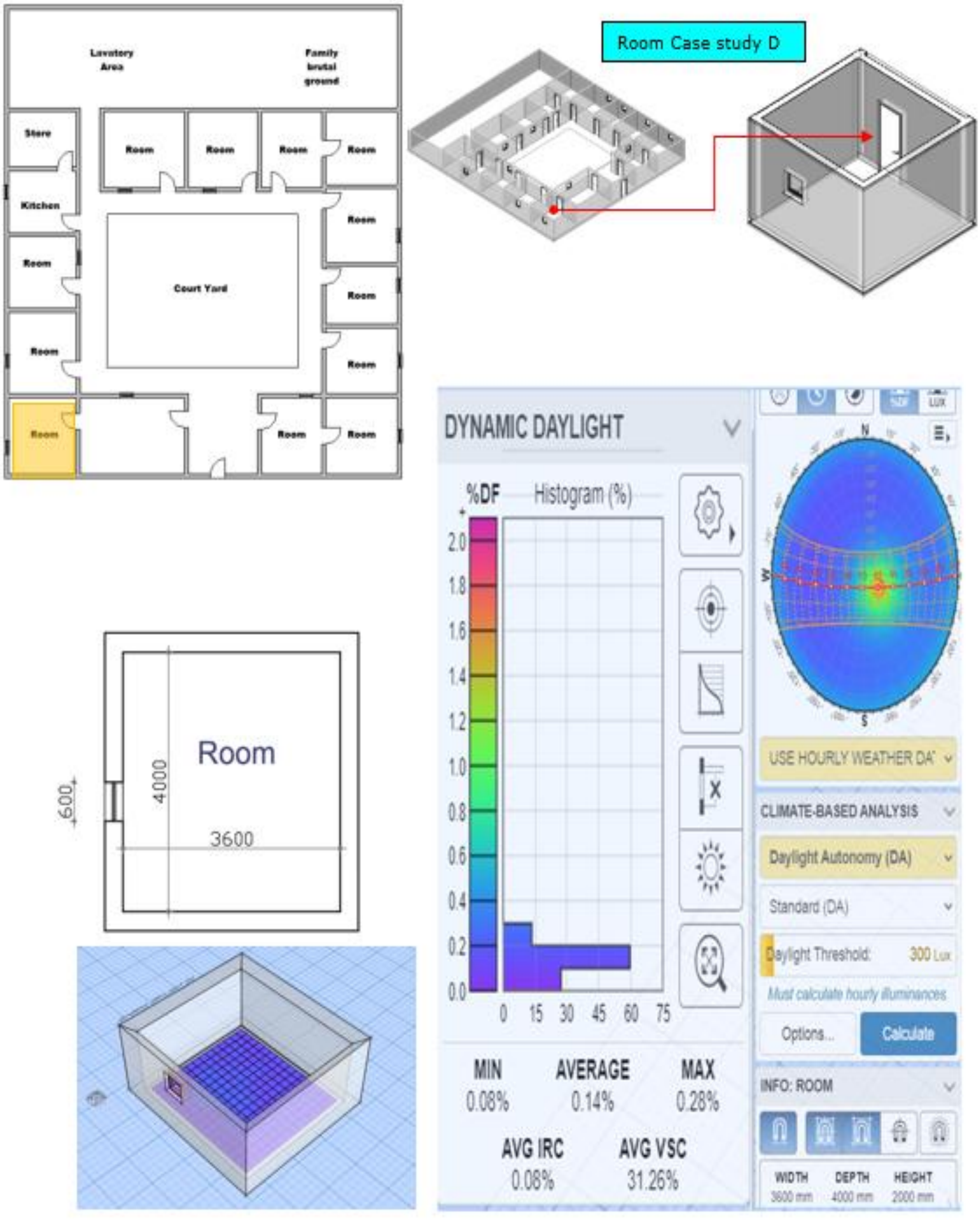


Figure 6-11: The simulation result shows the daylight factor entering the typical case study room- Case D.

6.5 Indoor Thermal Comfort Monitoring

The experimental measurements for all four case studies were conducted. For this study, the room for the head of household of each building studied was selected to represent a typical room because it was always occupied. The monitoring experiment was conducted for a typical calendar year of 365 days, covering both the hot and cold seasons. The hot season starts from January to April, with March being the hottest month, with an outdoor maximum temperature of 34°C. In addition, the cold season starts from June to October, with the coldest month being August, with a minimum outdoor temperature of 21°C (Figure 6-12).

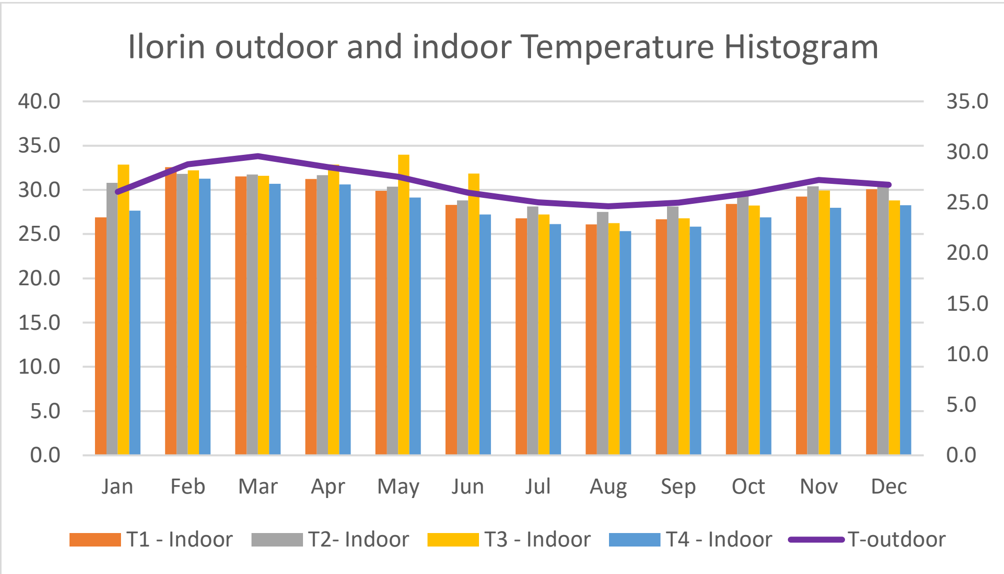


Figure 6-13: Histogram of indoor and outdoor temperature

Tiny tag data logger devices monitored the indoor climate, including indoor air temperature and relative humidity, and the room occupancy was considered. Throughout the study period, the hottest month of March was considered the reference month for investigating overheating in this study. This also provides a better understanding of how the house occupants impact indoor environmental conditions. The readings for indoor air temperature and relative humidity were taken at every 30 minutes for an entire year. This was required because the building is residential, and occupants/ people are always present 24/7. This is a temperature histogram showing the frequency of outdoor temperatures compared to indoor temperatures in selected monitoring locations in Ilorin. Following this monitoring, the thermal comfort limits for each location in Ilorin were extracted based on the findings of the section using equations 6-4 and Equation 6-5. The predicted comfort limits for the warm, humid city of Ilorin were calculated, and the results are presented in Tables and Figures 6-17 to 6-20.

6.5.1 Monitoring Process

From July 18, 2022, to July 31, 2023, Tinytag TGU-4500-Ultra-2 Gemini data recorders were used to constantly monitor the indoor air temperature and relative humidity (RH) at 30-minute intervals. Tinytag data loggers are durable, reliable and affordable monitoring devices for environmental conditions. According to Fang et al. (2014) and Zune et al. (2021), tiny tag data loggers provide a low-level indication, fast download rates, high resolution, high accuracy, high storage capacity, and other characteristics. Therefore, they are frequently employed to monitor the internal thermal environment and conduct energy-efficient chamber tests in several facilities used in pharmaceutical production, museums, heritage sites, etc. Several studies show that tiny tag loggers can precisely record temperatures between -25 and +85°C and relative humidity between 0% and 90% (Gemini Dataloggers, 2017). A calibration with a 32,000-reading capacity that can be kept in the tiny tag data logger memory, the integrated sensor’s high reading precision makes it appropriate for continuous tracking at 30-minute intervals for a year.

6.5.2 Data Analysis Method

The study of the psychometric chart presented in Chapter 2 revealed that the key environmental design aspects for Ilorin are primarily related to heat gain prevention (solar control and ventilation) design solutions. An extensive site monitoring exercise was carried out for a typical year (365 days) to gain more knowledge of how Ilorin adobe traditional building design techniques contribute to optimal indoor thermal performance and analyse indoor conditions regarding building envelope features and their impact on the comfort of occupants. The site monitoring data was analysed, and the findings were reported. The site measurements included indoor air temperature and relative humidity. The data logger's positions are shown in Figure 6-12.

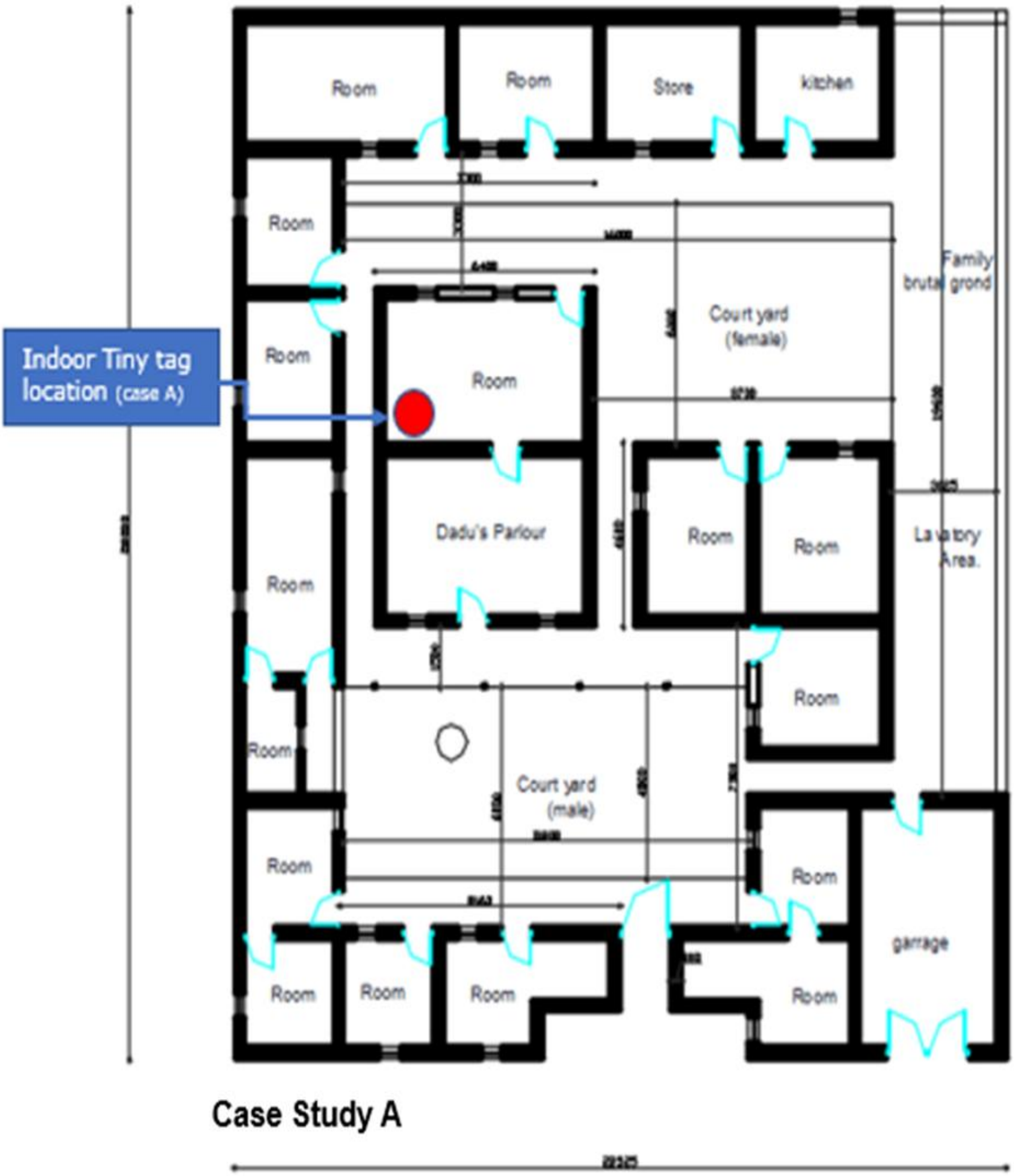


Figure 6-12: Floor plan showing datalogger positions in case study A

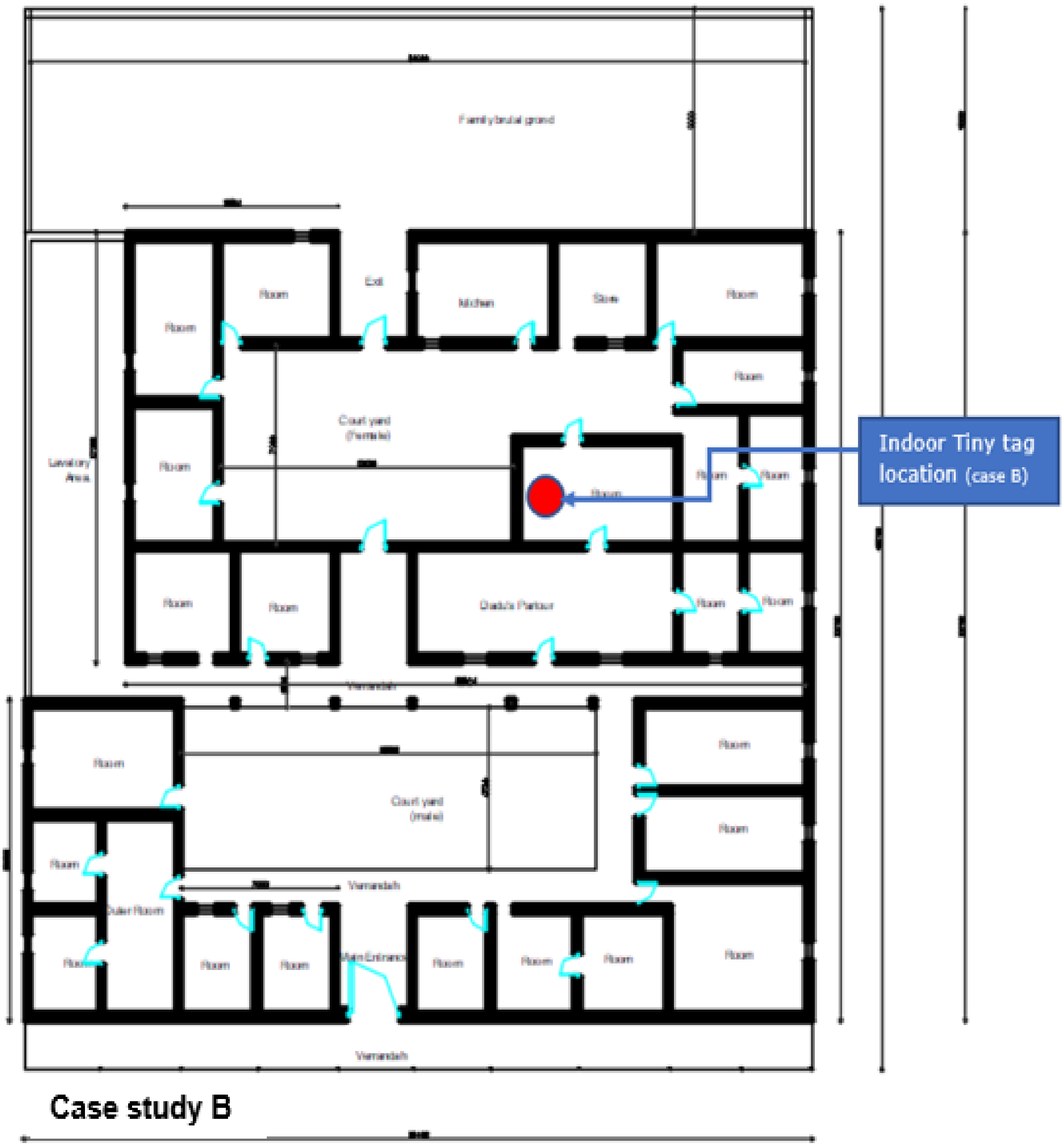


Figure 6-13:Floor plan showing datalogger positions in case study B

Figure 6-14: Floor plan showing datalogger positions in case study C

Figure 6-15: Floor plan showing dataloggers position in case study D

The monitoring action was performed by employing instruments for objective instrumentation of the indoor bedroom area to assess comparative heat indices, following standards outlined in several research. Studies by Onyenokporo et al. (2024), Adekeye et al. (2023) and Kiamba, (2016), demonstrate that when subjective occupant preferences were matched to measurement findings to achieve transitional thermal responses, a holistic picture that provided a solution to the problem was established.

6.5.2.1 Air Temperature

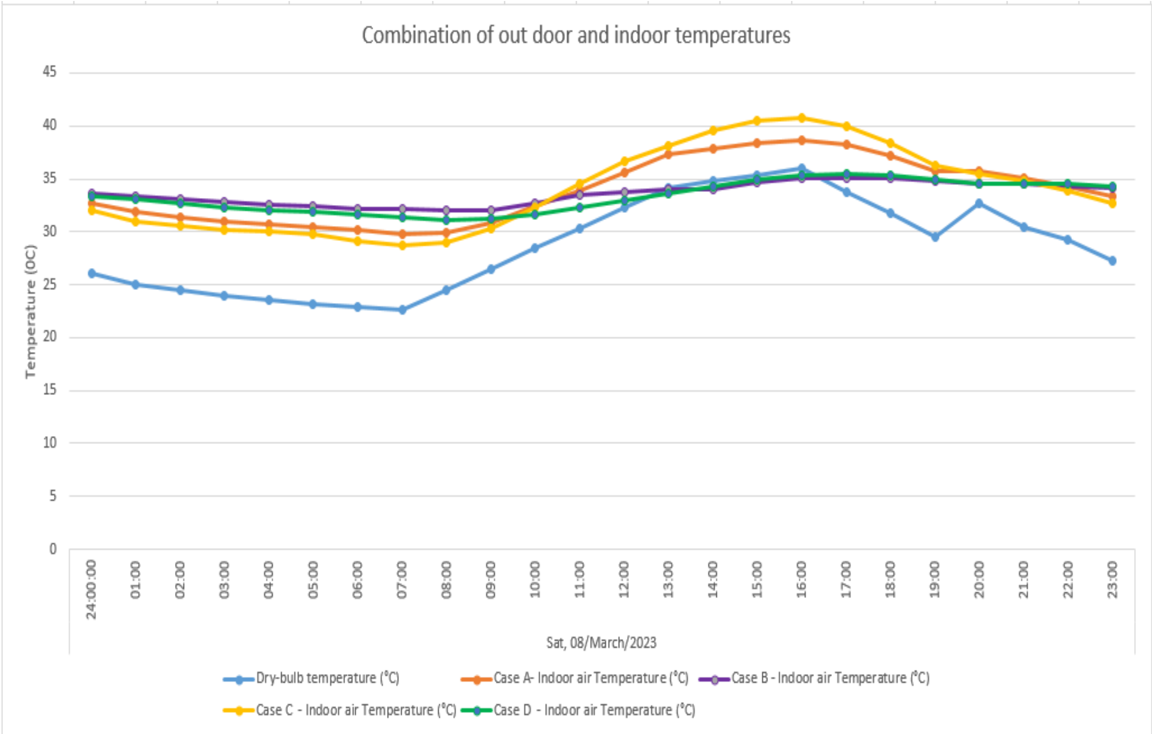


Figure 6-16: Combination of outdoor and indoor temperatures

The minimum and maximum indoor temperature values measured throughout the warm month of March 2023 is shown in Figure 6-19 The 8th of the month saw the highest recorded temperatures of 38.6°C, 35.1°C, 40.8°C and 35.5 °C, respectively. The lowest readings were reported on the 19th of the month, with temperatures ranging from 23.4°C to 27.3°C. Typically, indoor air temperature peaked in the afternoon (12:00 hrs – 17:00hrs) and lower temperature values were recorded to the early morning hours (from 02:00hrs – 08:00hrs). The outdoor temperature, which was not measured on site but was generated through NASA global systems for this study, varies by 13.4°C during the day (from 22.6 to 36°C). The daily temperature differential between indoor and outdoor locations ranged from 2 to 6.2°C, typical in warm and humid areas. This temperature change may have an impact on other comfort indicators. The data analysis presented data indicating that indoor temperature was higher than outdoor temperature all through; this impact can be attributed to the impact of the combination of lightweight roofing materials, which allows heat gain into the building through solar radiation and the presence of high thermal mass wall fabric with tiny window units which helps to absorb and retain heat inside the building from internal heat gain sources. For instance, the presence of lower outdoor temperatures compared to indoor temperatures suggests that with passive strategies, the building system will try to maintain a higher comfort level. When the outdoor temperature is above normal, the indoor temperature is maintained at a lower comfort level.

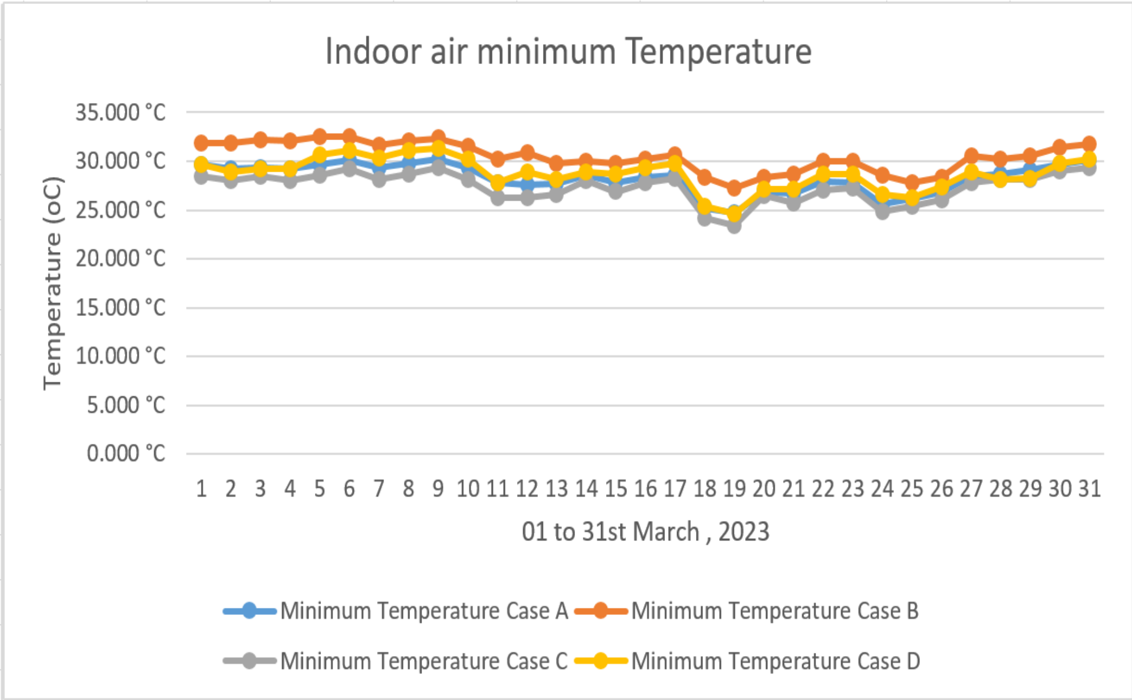


Figure 6-17: Measured minimum indoor temperature in the hottest month of the year

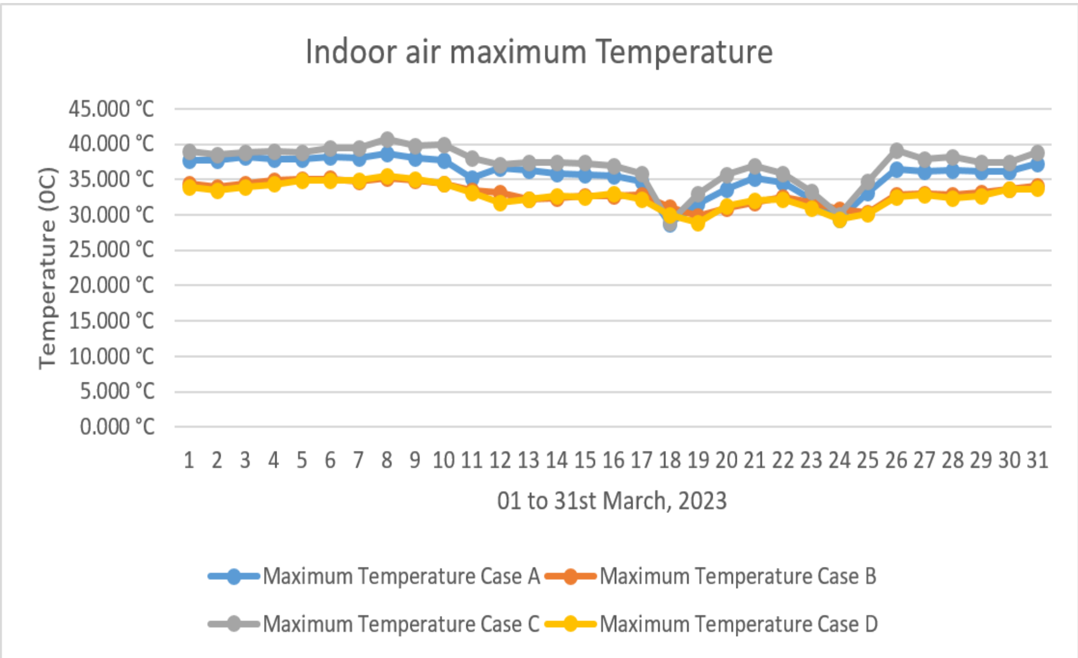


Figure 6-18: Measured maximum indoor temperature in the hottest month of the year

Based on the monitored results shown in Figure 6-20, Case Study C had the warmest temperature values, with more than half of its data above 32 °C. This can be attributed to the small size of the room space with internal heat gains from occupants (6 to 7 people) and equipment, effects of external heat gains, where the location of the data logger was 2m from the ground and only 0.2 meters from the door adjoining to the living room and the fact that this room had no form of ceiling to serve as an insulating material to curb heat gain from direct solar radiation. In addition, considering the warmest hours of the day, where hours between 14:00 and 17:00 fall under, the room at Case Study C, which has only one small window on the west facing façade can indicate the impact of solar heat gains from the west façade on the indoor air temperature. However, Case Study C was also identified to have the lowest temperature values, which suggests the influence of the outdoor temperatures on the indoor air temperature due to lightweight roofing cover material and the large thermal mass of the walling fabric.

6.5.3 Humidity

Figures 6-21 present the highest relative humidity values recorded during monitoring in all case study buildings.

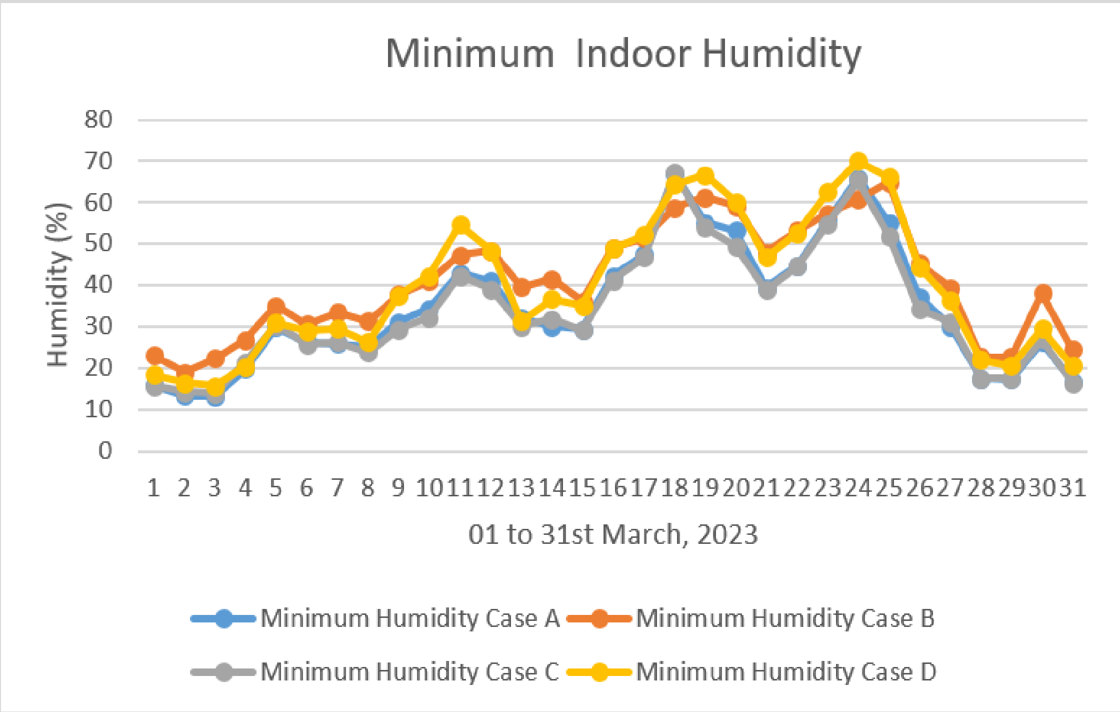


Figure 6-19:Minimum indoor relative humidity

The highest values were recorded in Case Study D Figure 6-22, between 5:00 and 8:00 hours on the 18th and 19th, with 88% and 92%, respectively, with corresponding temperatures of 29 and 30 °C. The lowest values were recorded in Case Study C, with values ranging from 13.9%, 14.3%, and 15.9% at 15:30 to 19:30 hours on the 1st, 2nd, and 3rd of March, with corresponding temperatures of 28°C.

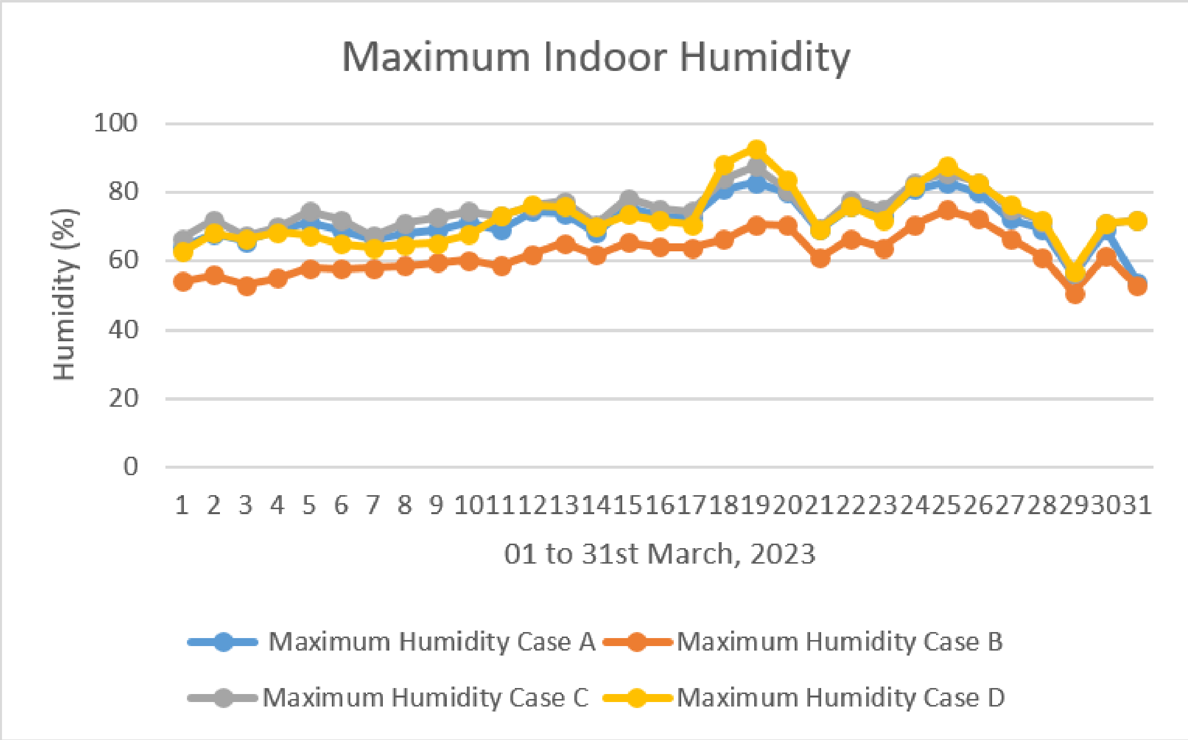


Figure 6-20: Maximum indoor humidity measurements

6.6 Determining Adaptive Thermal Comfort Limits

One method for assessing overheating in buildings is to use a set temperature criterion, specifically focusing on the standard effective temperature (SET) point with minimum and maximum limits and values for the temperature inside the building and calculating the number of exceedance hours. The adaptive thermal comfort technique detailed by Nicol and Brian, (2013) gives insights into how two adaptive comfort limit models in naturally ventilated buildings can be calculated and compared to support the decision on the method to adopt for research in warm, humid climates. These adaptive comfort models were well explained in Chapter 2 and the values calculated in this study were achieved using the Equation 6-8 and 6-9

$Tn = 17.6 + 0.31 \times To.av$ *(6-8)*

To determine Temperature neutral (Tn), this equation suggests that the comfort zone is comparable to the neutral temperature, as reported by Szokolay (2008).

$Tc = 13.5 + 0.54To$ *(6-9)*

Nicol and Humphreys (2002) present indoor temperature as relatively linked to outdoor temperatures. He further explains that the comfort temperature range is $\pm 2\ °C$ With the potential of increasing it further through the availability of adaptive possibilities.

To find the upper limits and lower limits of Equation 6-8 and Equation 6-9:

UTc: $UTn01 = (Tn + 2.5)°C, UTc02\ , (Tc + 2.0)°C$ *(6-10)*

LTc: $LTn01 = (Tn - 2.5)°C, LTc02, (Tc - 2.0)°C$ *(6-11)*

From the results obtained in Chapter 4, when considering that during the warm months when the indoor temperature appeared slightly higher than the outdoor temperature, about 80% of the respondents living in Ilorin adobe traditional buildings voted to be satisfied with the indoor temperature. Based on these findings, the equation stated by Nicol and Humphreys (2002) gives a more suitable range of internal temperatures that occupants find satisfactory. In addition, similar studies reviewed were found to utilise equation 6-5. After reviewing the results from all four cases, the Tc comfort limits of 25.2 - 32.1. °C were established for this investigation (Figure 6-23 to 6.26).

Case Study A

The adaptive comfort limit of the Case study A building is presented in Figure 6-21

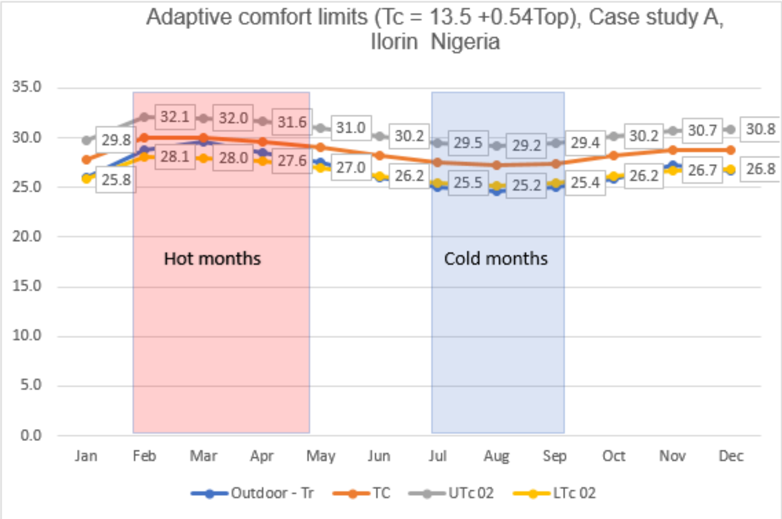


Figure 6-22: Case study A comfort limit

Case Study B

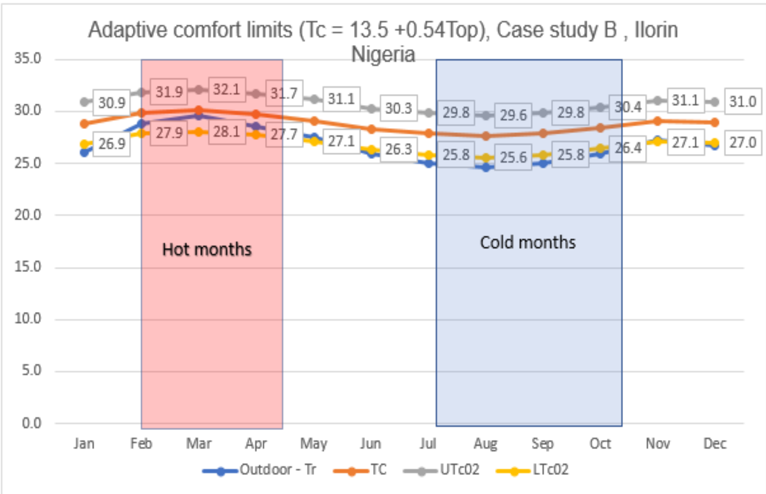


Figure 6-24: Case study B comfort limit

Case Study C

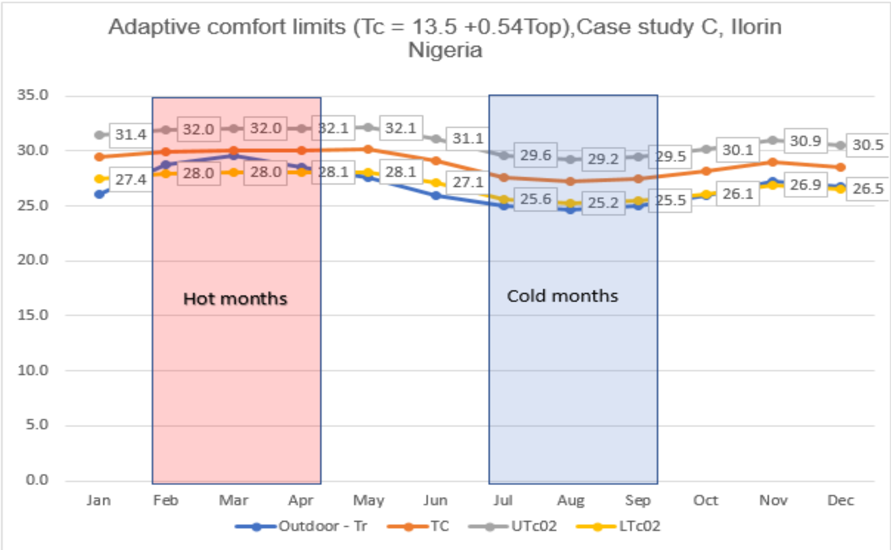


Figure 6-23: Case study C comfort limit

Case study D

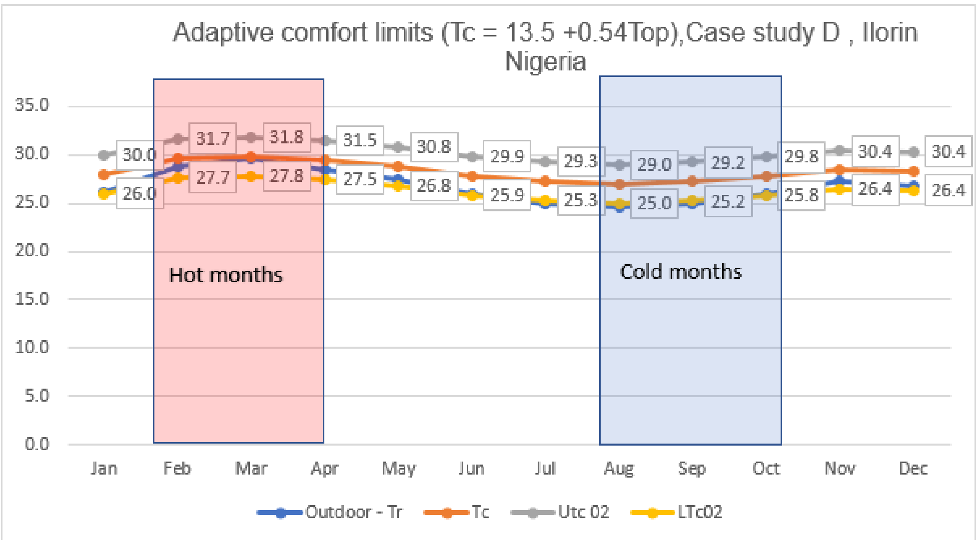


Figure 6-24: Case study D comfort limit

6.7 Discussion

6.7.1 Simulation of Natural Daylighting

The findings indicate that the Ilorin traditional adobe buildings being studied do not have average natural daylight factor values that meet or exceed the threshold of > 1.5%, indicating that the lighting condition is inadequate. This supports the reports of a high number of occupants who are dissatisfied and experiencing visual discomfort. According to this general rule (Depth of Room), the window area given on existing Adobe Ilorin traditional buildings is less than 20% of the total window wall area. Thus, the criteria is not satisfied. This is most likely why the respondents reported visual discomfort. Based on these results, a typical Ilorin Adobe traditional building will need more extensive and probably additional windows. See simulation results in section 5.5.3

6.7.2 Simulation of Ventilation

Table 6-18: Ventilation (Temperature across all building cases

Building	Window Area(m^2)/ Aperture (%)	Outdoor temperature (°C)	Indoor temperature (°C)	Outdoor and indoor (∆T)
Case A	0.72 /90	29.6	31.5	1.9
Case B	0.36 / 90	"	31.7	2.1
Case C	0.45 / 90	"	31.6	2
Case D	0.36 / 90	"	30.7	1.1

Table 6-18 shows the results of the tested scenarios in summer conditions with a mean outdoor temperature of 29.6°C and a mean indoor temperature of 31.5°C, 31.7°C, 31.6°C and 30.7°C, indicating a slight difference between the indoor and outdoor of ΔT (1.9°C, 2.1°C, 2.0°C and 1.1°C) respectively. For the baseline case study, A, B, C, and D- rooms with a window area of 0.72 m^2, 0.36 m^2, 0.45 $m^{2,}$ and 0.36 m^2 and side hung effective aperture of 90% fitted in the windows as follows: 90% of each window area (0.65, 0.32, 0.41 and 0.32). The fresh air required is 0.06 m3/s, and the cooling required at noon for each case is (case A - 12.39 m^3/s, case B- 12.59 m^3/s, case C and D – 13.58 m^3/s). However, only 1.0 m^3/s ,0.06m^3/s and 0.1m^3/s was achieved across the cases, with the current window size indicating that the average operative temperatures are outside the temperature comfort band for all four cases. The current window area size (Table 6-18) and simulation results (Figures 6-5a,6-7a,6-9a and 6-11a). A change in the ventilation system from single-sided to cross ventilation and an increase in window sizes from 0.72m^2 to 6.4m^2, 0.36m2 to 6.0m^2,0.45 to 8.6m^2 with a modified stack height of (case A – 1.0 to 1.3, case B -1.0 to 0.8, Case C & D – 1.0 to 0.7) resulted into an airflow of 4.75 m^3/s, 4.46 m3/s and 5.53 m^3/s respectively This means that the observed air flow rate of 3.55 to 6.58 was achieved across the simulated rooms, exceeding the requirement for a fresh air flow rate (0.06 m^3/s). This demonstrates an excellent synchronization between external climatic conditions and indoor thermal comfort requirements. However, in the worst-case scenario, all four cases required additional cooling for 7.89m3/s. The simulation shows that the modified ventilation design for all cases meets the required adaptive comfort band, as shown in Figure 6-28.

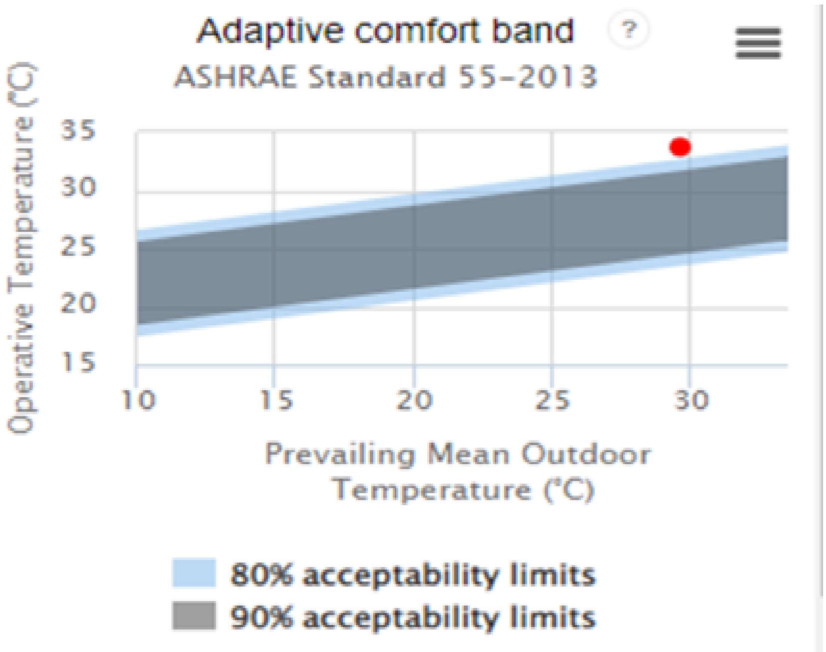


Figure 6-25:Poor ventilation outside the comfort limit

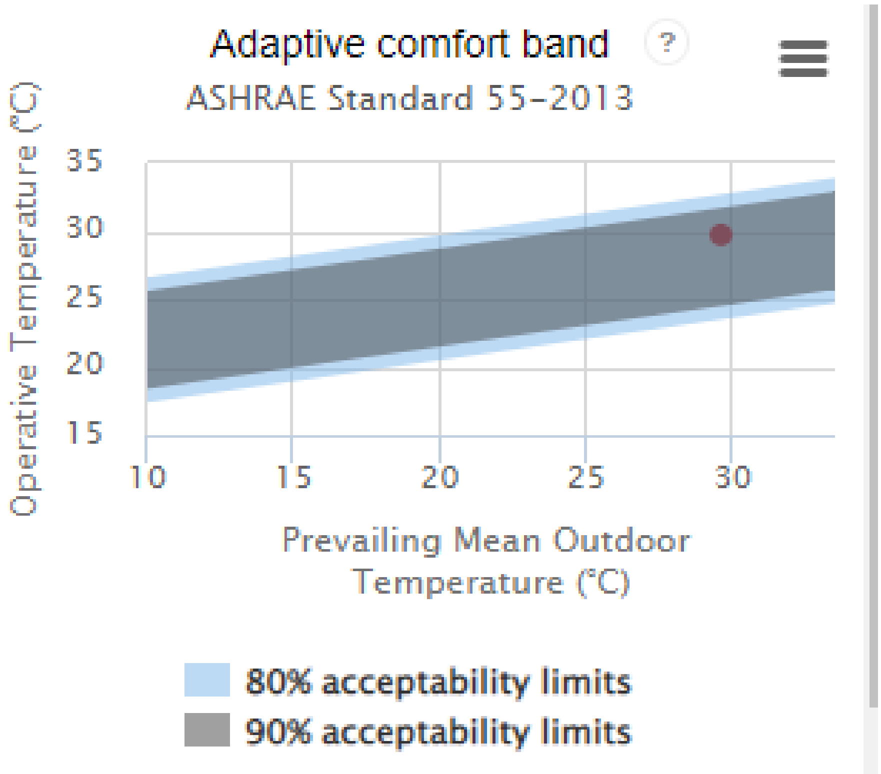


Figure 6-26:Ventilation within the comfort limit band.

Small windows are standard features of Ilorin traditional adobe buildings. This window size makes it challenging to maximize natural ventilation due to restricting fresh air flow and removing heat and humidity. In the past, these smaller openings were designed to provide privacy and better protection against harsh elements and to maintain a more stable interior environment. However, with the introduction of advanced building techniques and the accessibility of passive cooling technologies, the requirement for improved natural ventilation has become evident. Innovative design solutions that combine traditional knowledge with modern understanding are required to address the occupant's dissatisfaction with comfort levels. This could entail maximising natural ventilation by adding larger windows in strategic locations, changing the ventilation system from one-sided to cross ventilation, and implementing passive cooling strategies like planting trees, wind catchers, etc.

Table Overall Optivent simulation

Table 6-19:Optivent simulation

	Case A	Case B	Case C	Case D
Current window sizes Effective aperture of 90%	0.72 m^2 0.65	0.36 m^2 0.32	0.45 m^2 0.41	0.36 m^2 0.32
Stack height	1.0	1.0	1.0	1.0
Fresh air required	0.06 m^3/s	0.06 m3/s	0.06 m^3/s	0.06 m^3/s
Cooling required	12.39 m^3/s	12.59 m^3/s	13.58 m^3/s	13.58 m^3/s
Achieved	1.0 m3/s ,0.06m3/s and 0.1m3/s	1.0 m3/s ,0.06m3/s and 0.1m3/s	1.0 m3/s ,0.06m3/s and 0.1m3/s	1.0 m3/s ,0.06m3/s and 0.1m3/s
Potential solution cross ventilation and an increase in window sizes	0.72m^2 to 6.4m^2	0.36m^2 to 6.0m^2	0.45m^2 to 8.6m^2	0.36m^2 to 6.0m^2
Modified stack height of	1.3	0.8	0.7	0.7
Achieved	4.75 m^3/s, 4.46 m^3/s and 5.53 m^3/s	4.75 m^3/s, 4.46 m^3/s and 5.53 m^3/s	4.75 m^3/s, 4.46 m^3/s and 5.53 m^3/s	4.75 m^3/s, 4.46 m^3/s and 5.53 m^3/s

6.7.3 IESVE Simulation

The IESVE simulation results of existing case study buildings show that the average daylight factor within all four buildings was less than 1% in almost all rooms. This indicates insufficient daylight entering the house's interior and supports the result of the dissatisfied respondents earlier discussed. Due to this, the results for the as-built case study buildings are shown in Figure 6-26. This suggests that artificial lighting was mostly turned on when the building was occupied and used for purposes other than sleeping. However, the result of different window sizes, positions, and numbers of windows suggested based on optivent ventilation simulation revealed that a significant retrofit design is necessary to enhance visual performance. This can be achieved by increasing the window size. Additionally, solar shading would minimise solar heat gains and glare, enabling effective passive cooling via natural ventilation (cross ventilation or mixed method). This would also enhance natural daylighting to levels above 1.5, promoting optimal visual and thermal comfort without compromising privacy and cultural values.

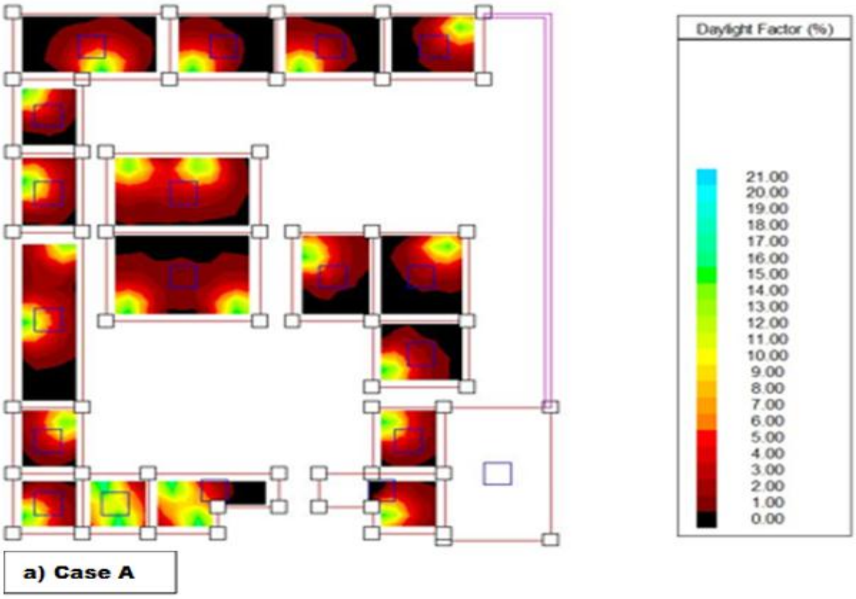


Figure 6-27:floor plan simulation showing Daylight factor of existing case study plan A (IES-ve)

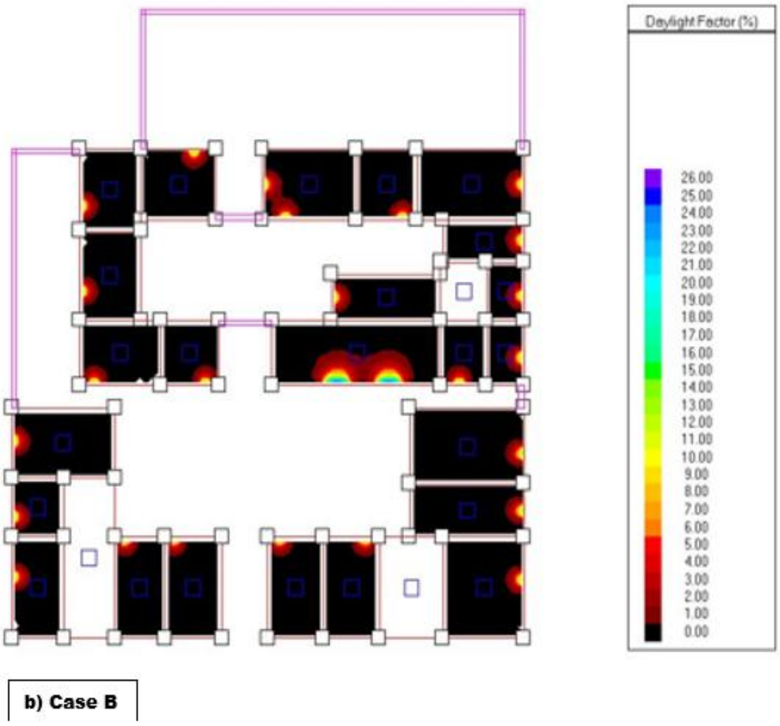


Figure 6-28 :Flow plan simulation showing daylight factor of existing case study plan B (IES-Ve).

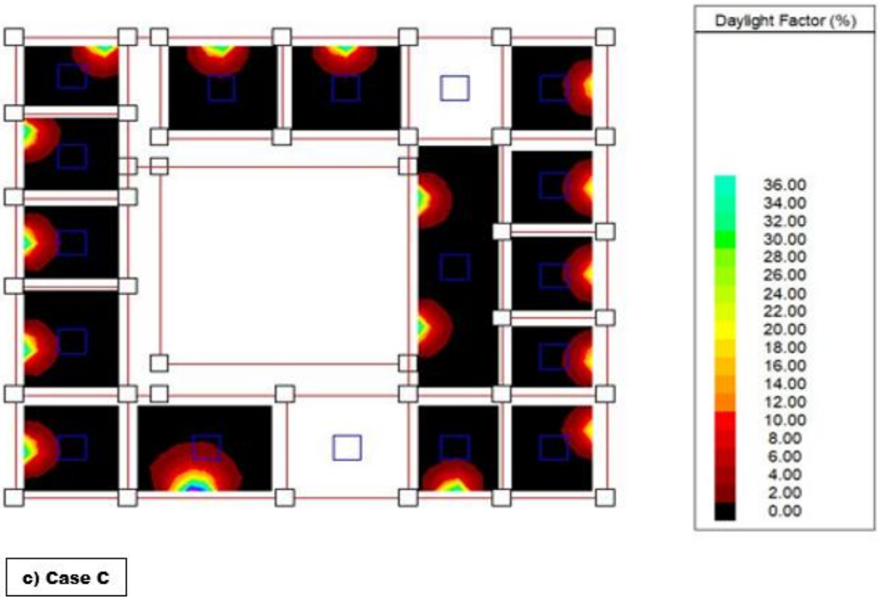


Figure 6-29: Floor plan simulation showing daylight factor of existing case study plan C

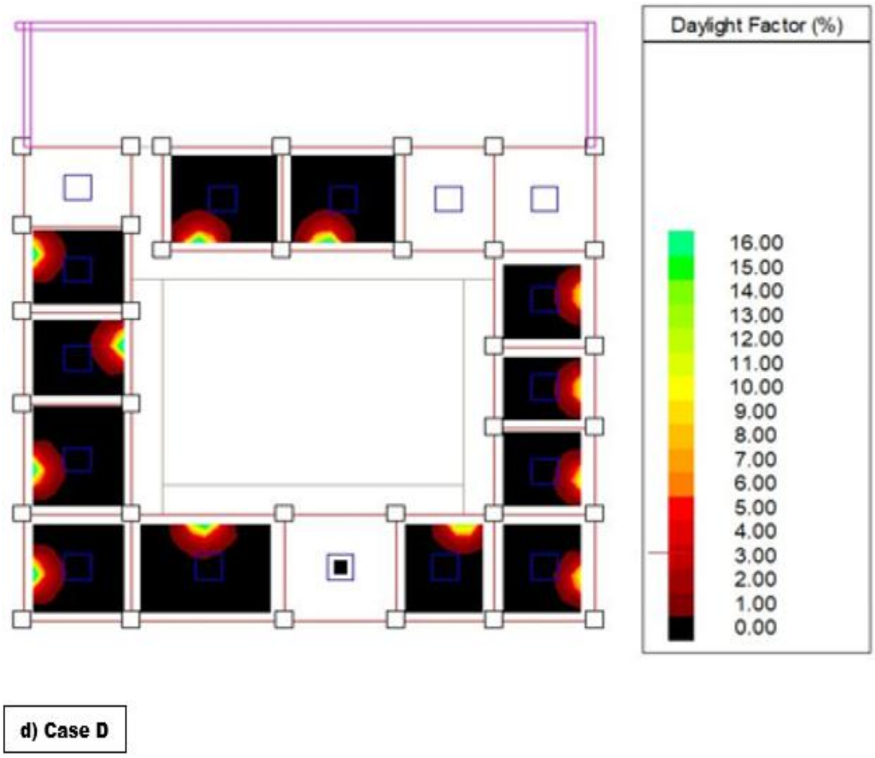


Figure 6-30:Floor plan simulation showing daylight factor of existing case study plan D

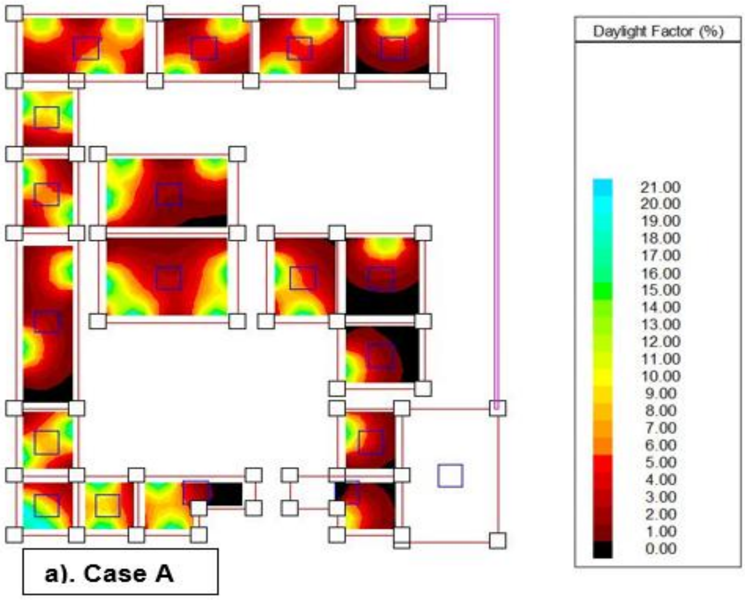


Figure 6-31: floor plan showing improved daylighting and effective ventilation of existing case study plan A (IES-Ve)

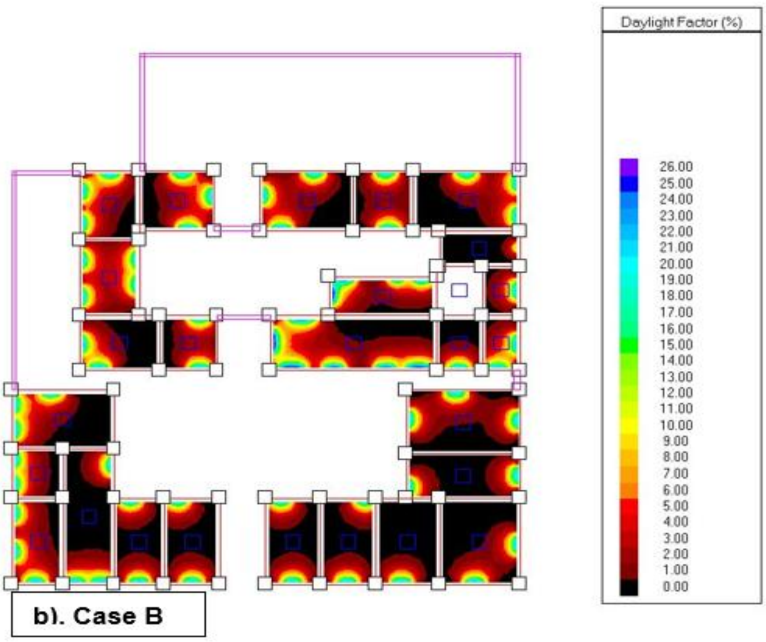


Figure 6-32: : Floor plan showing improved daylighting and effective ventilation of existing case study plan B (IES-ve)

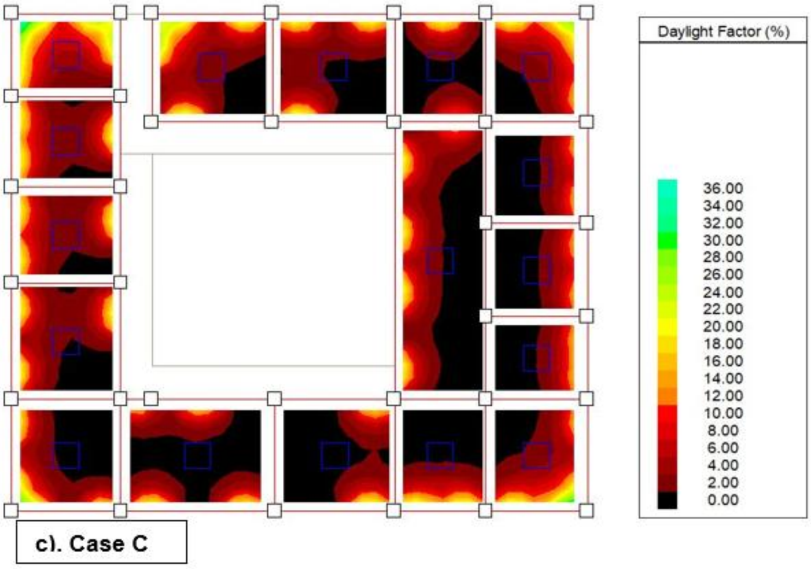


Figure 6-33: Floor plan Simulation result showing improved daylighting and effective ventilation of existing case study plan C (IES-VE).

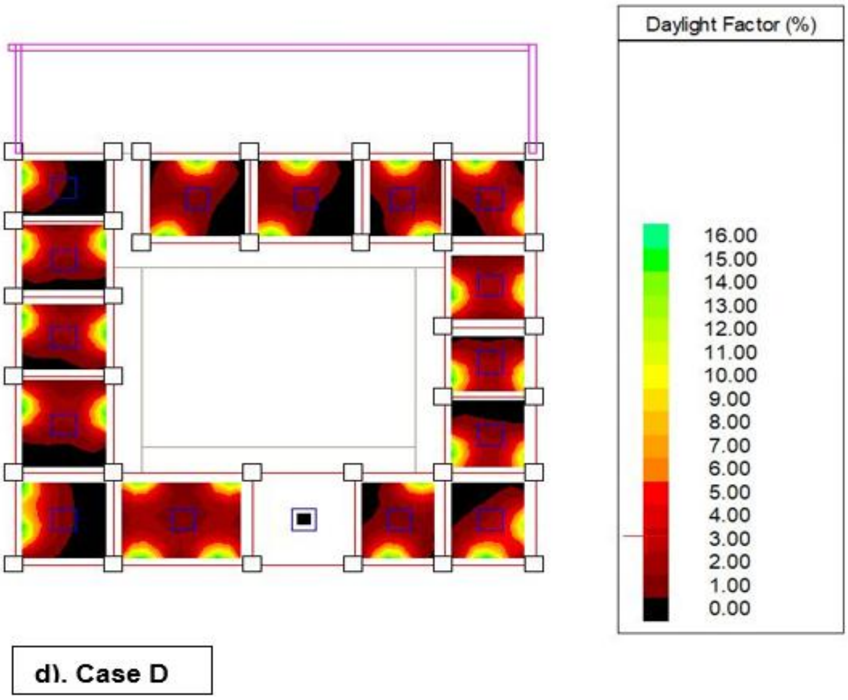


Figure 6-34:The floor plan shows improved daylighting and effective ventilation of the existing case study plan D (IES-VE).

6.8 Conclusions

This section has investigated the root cause of visual discomfort experienced by dissatisfied respondents during the fieldwork. Simulation results provide in-depth knowledge on why typical Ilorin traditional adobe buildings appear poorly lit by sunlight throughout the day. The significant findings are linked to the existing small window sizes and below-standard daylight factor reaching the interior of the buildings. Further examination revealed that with additional openings and larger window sizes from 0.6m to 1.3m, the rooms will be well-lit, and occupants will save energy by turning off artificial lighting during the day. The ventilation results for the bedroom, measured during the climactic peak of March, the warmest month, show that to preserve ideal indoor environmental conditions, the airflow into the tested spaces is low. This indicates that the buildings need cooling to avoid overheating and thermal discomfort for the occupants, especially at noon. Furthermore, the analysis from the IES simulation proved that the window-wall ratio can improve occupants' visual comfort during the day. The effective daylight factor serves as a key parameter for evaluating natural illumination. The simulation results are evaluated according to the BREEAM criteria explained in Chapter 2, which stipulates a minimum uniformity ratio to ensure a continuous daylight factor of at least 2% in 80% of the total area (CIBSE, 2015). Lastly, from Section 5.4: The primary reason for the monitoring procedure was to acquire oversight visibility of the indoor conditions of Ilorin adobe buildings. The data loggers provided input parameters for calculating and improving building thermal comfort conditions. Results revealed that the thermal comfort limit of traditional Ilorin adobe buildings was determined to be a thermal comfort limit of 25.2ºC and an upper limit of 32.1 ºC. This set the stage for simulation/parametric study in the next chapter. Also, the standard effective temperature (SET) in Ilorin's warm, humid climates was established as 28.6 ºC.

Chapter 7: Thermal Performance Simulations

This chapter presents the parametric study stage based on the field study results discussed in chapters 4,5 and 6. It also covers the application of an array of selected thermal simulations to provide an insight into the simulation assessment procedure and results of a parametric evaluation and improvement of a naturally ventilated single-detached typical Ilorin adobe traditional building. The model was selected based on the building envelope characteristics of typical Ilorin adobe traditional buildings built circa 1800 as domestic residential buildings owned by prominent district heads in the warm-humid region of Ilorin, Kwara state, Nigeria, with the aid of a computer-based dynamic simulation known as the Integrated Environmental Solution tool (IES-ve), which served as the subset methodology used by ASHRAE and CIBSE guidelines to assess and compare buildings' energy and environmental performance. The impact of Building orientations, fabrics, ventilation and shading on the thermal performance of typical Ilorin adobe traditional buildings with the related effects on the thermal comfort of the occupants was examined.

7.1 Approach and Scope

This chapter addressed the parametric study in typical adobe traditional buildings in Ilorin, by simulating simplified building models that required few inputs and provided a better connection between the direct inputs and the outcomes. It was straightforward to achieve the assessment of four major characteristics: (i) Building orientation (ii) Building fabrics, (iii) shading and (iv) ventilation. The parametric study investigated the impact of each attribute on the thermal comfort experienced in the case study building. Furthermore, the best results obtained from the simulations were combined to create an optimised building design strategy. The study informed the next chapter, where the optimised building design strategies are combined and implemented to establish the framework of a proposed optimised building envelope for Ilorin adobe traditional buildings and lessons learned from the entire study were discussed in detail.

7.1.1 Basis for Parametric Study

The parametric study covered the process of evaluation and improvement of a naturally ventilated single-detached Ilorin adobe traditional building, the process and results were based on results presented in previous chapters (4 and 5), it was found that thermal comfort in typical Ilorin adobe traditional buildings was not achieved for up to 80% of the time all year round, and also results showed there was a significant need to enhance the overall quality of the dilapidating building envelope conditions due to lack of proper guidelines on adobe traditional building maintenance and thermal discomfort caused by the strategies occupants have adopted in a bid to persevere their homes. The process involved providing a frame work for sustainable alternative fabric for building components (roofs , walls and floors) in order to promote thermal performance and preservation of typical Ilorin Adobe traditional buildings, testing and establishing standards for vernacular buildings which can be implemented in to the Nigerian building codes as mentioned previously , improving internal conditions for the occupants' comfort and providing climate responsive design strategies to ignite occupants satisfaction with their homes as they mostly rely on passive design strategies.

To the best of the researcher's knowledge, little or none has been done to quantify the thermal comfort of occupants and the thermal performance of traditional adobe buildings in Ilorin. A series of simulations were run to derive the number of thermal comfort hours experienced in a typical Ilorin adobe traditional building in Ilorin, Nigeria, for a typical year of 365 days. One specific case study building was selected for in-depth analysis, drawn from the four previously mentioned case study buildings in Chapter 4. The choice was made by categorizing the buildings based on similar architectural features such as building materials, shape, window orientation/positions, and overall form. Additionally, considerations were given to the building layout, including the number of courtyards, as well as the strategies implemented by occupants to enhance their traditional adobe buildings. The findings from the simulations were thoroughly reviewed and analysed to mitigate the knowledge gap identified by the researcher in the introductory chapter, where the researcher emphasised the lack of proper documentation of vernacular building guidelines in the existing housing regulatory policies developed by the Nigerian Energy support program (NESP) and The National building code (NBC) in Nigeria. However, the existing developing documents recommend passive strategies and techniques to improve performance and efficiency in Nigeria buildings. One of the objectives of this study is to provide a documentation on vernacular architectural building guidelines for Ilorin, which can be used for other vernacular buildings all over Nigeria by implementing this framework into the housing policies of both the Nigerian national building code and the Building Energy Efficiency guidelines for Nigeria (BEE). Due to the abovementioned gap, ASHRAE and CIBSE criteria were employed in this study.

Likewise, the researcher also gave insight into the gradual disappearance of Ilorin's traditional adobe buildings in (Chapter 1) stating that the structures, characterized by unique designs and cultural significance, play a crucial role in defining the identity and sense of place for the Ilorin people. However, their diminishing presence significantly threatens the value of historical buildings in Ilorin and Nigeria. Considering this, there is an urgent need to preserve these buildings and create a detailed framework for traditional / Vernacular architectural design strategies for Ilorin and the nation; furthermore, due to the region being populated with low-income earners who are continually faced with epileptic energy resources (Chapter 2) with little or no access to mechanical appliances that can aid cooling in their homes, it is essential to provide affordable houses that deliver good thermal performance and provide comfort for all. Also, considering the climatic condition result of the region provided by the climate consultant 6.0 psychometric chart as discussed in (chapter 2), which indicated that the adaptive comfort hours of 44.26% annually was experienced in naturally ventilated buildings and it could be improved by exploring potential alternatives such as climate-responsive design that are appropriate for the region, this study focused only on suggestions made regarding the building envelope with natural ventilation and passive design strategies. Several researchers have found that effective passive design strategies and natural cooling systems in traditional buildings provide a good percentage increase in thermal comfort hours to occupants all through the year (Subramanian.et al., 2017). From these explanations, it was proposed that the incorporation of passive design strategies could show potentials for improving thermal comfort hours in naturally ventilated vernacular structures in Ilorin. To validate this Ilorin inspired techniques, there is a need to highlight the importance and advantages of preserving these adobe traditional buildings as durable and sustainable, particularly with regards to the thermal comfort of occupants in naturally ventilated buildings both currently existing and future constructions within the warm-humid climate of Nigeria.

Thus, this research sought to offer an integrated approach for enhancing thermal comfort in Adobe traditional buildings situated in the warm-humid climate zone of Nigeria. The primary objective is to explore the impact of architectural designs of Ilorin's traditional adobe buildings that can effectively maintain thermal performance without relying on mechanical cooling systems. Additionally, the study sought to identify passive methods for optimizing the building envelope. This involved conducting a sensitivity analysis through computer-aided simulations with a focus on key parameters like building materials, orientation, and shading devices. During the thermal simulations, modifications made to building envelope components were planned in compliance with accepted practices, such as regional and national requirements. The materials chosen and the design changes made account of what is locally available. The ultimate objective is to provide insights that support the long-term sustainable preservation of the historic traditional adobe buildings of Ilorin and enhance the thermal performance of such structures in the warm-humid climate of

Nigeria. The improvements focused on enhancing the buildings' general functionality as well as their physical structure (envelope). These enhancements were intended to solve problems with preservation difficulties, privacy issues, and cultural values. The inability of occupants to effectively employ dynamic adaptive controls because of barriers arising from functional concerns, cultural values, privacy concerns, structural instability, and poor construction and preservation issues were the fundamental issues found. As a result, indoor thermal comfort was negatively impacted slightly by the inefficient operation of environmental controls. To address these problems in a comprehensive manner, the solutions put in place considered factors like cultural values, privacy concerns, and preservation obstacles in addition to improving the building's envelope. The goal of this all-encompassing strategy was to design a more versatile and useful living environment.

7.2 Method

The simulation scenarios employed five research phases to examine the thermal performance of typical Ilorin adobe traditional buildings under different specified conditions, as seen in Table 7-1

The effects of orientations and the window-to-wall ratio on the indoor air temperature for a typical model were examined in the first phase of the investigation. From Figure 7-1the impacts of heat gains on the indoor air temperature by comparing two models were investigated in the second phase of this study. In the third phase of the study, the effects of different combinations of construction elements on indoor air temperature were examined through comparisons of a total of 15 models, as illustrated in Table 7-3 and Figure 7-1. The impact of solar shading devices on exposed building surfaces on indoor air temperature was investigated in the fourth phase. The effect of window sizes and window openings on the indoor air of the model were investigated in the fifth phase, and lastly, the combination of the parameters with the best thermal comfort percentage hour results from all phases mentioned were simulated to test the optimal thermal performance of the typical model

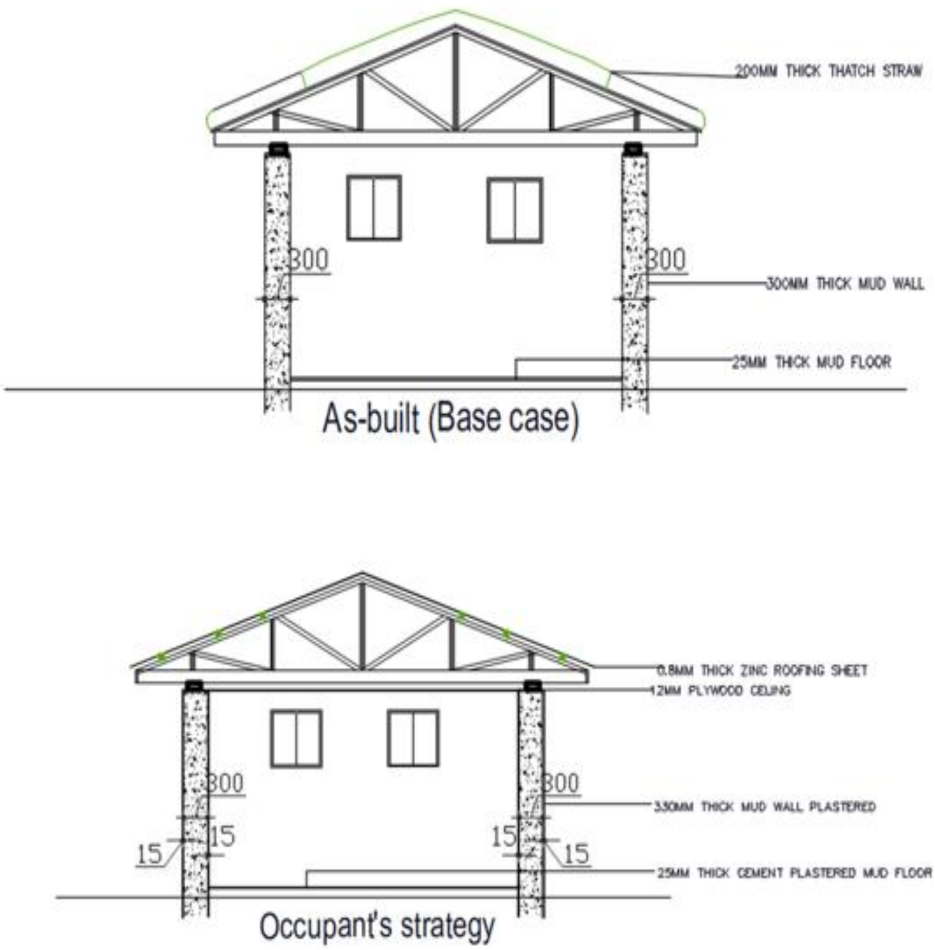


Figure 7-1: a and b Sections of a typical Ilorin traditional adobe room model as As-built (base case) and Occupant's strategy.

Table 7-1: A variety of thermal simulations based on different building fabrics

Sets	Parameter
Set 1 Orientation of the access	North (as built)
	West
	East
	South
	Window to wall ratio
Set 2 Gains	(As-built, Occupant's strategy)
	External and internal heat gains
Set 3 Building fabrics (possible building component combination)	As built
	Occupant's strategies (Most common long-term strategies adopted)
	Roof coverings
	Ceilings
	Walls
	floors
Set 4 Ventilation	Optimised ventilation
	Completely closed window
	Completely opened window
	Original sized side hung window
	Larger sized side hung window
	Number of original window size
	Additional original window
	Size and number of windows as informed by Optivent
Set 5 Shading	Shaded roof
	Canopy on North façade
	Vertical shade
	Proposed planting on all façades
	Canopy and vertical shade
	Canopy and proposed planting
	Canopy, vertical, shading and plants
	Proposed canopy and planting
	Plant shade on West façade
	Plant shade on North façade
	Plant shade on East façade
	Plant shade on South façade
	Roof shade, canopy, vertical shading and plants.
Set 6 Combinations	Window shading and original ventilation New shading design for orientation variations
Optimised case	Best strategies combined

The drawings and necessary details were provided by physical measurements of the buildings and observations made by the researcher during the field work.

The Ilorin Adobe traditional case study buildings are simple traditional adobe structures with rooms surrounding one or two courtyards as seen in Figure 7-2.

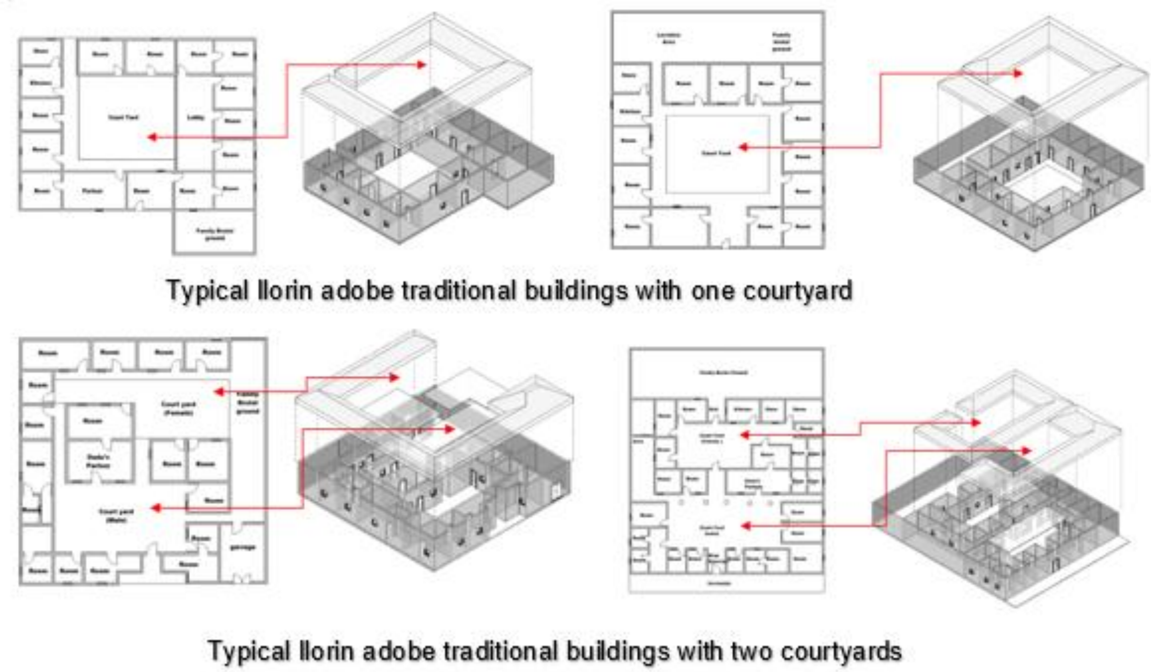


Figure 7-2: Typical Ilorin adobe traditional building plans showing positions of courtyards.

The building models are examples of prototype Ilorin adobe traditional buildings at four different locations that serve as residential buildings of prominent district heads in Ilorin, Kwara, Nigeria. The climatic data of Ilorin identifies March as the hottest month, with an average maximum temperature of 34° and minimum temperature of 23°C, while the coldest month, August, has an average minimum temperature of 21°C and maximum of 28°C. The two main wind directions in Ilorin are the Southeast and Northeast. The temperatures in Ilorin usually vary from 18 to 35°C. (Climate Consultant 6.0).

The methodology employed in this study involved utilizing parametric simulations conducted through the Integrated Environmental Solutions (IES) Virtual Environment 2023 software. This software facilitated the creation of a typical room model for one selected case study by defining the geometry and incorporating fixed parameters of the building. For this study, a typical room space was analysed for one case study with features that can be replicated and applied to all other buildings. This made it possible to explore various adaptation patterns and evaluate the resulting indoor conditions within the structure.

In this research, a series of dynamic simulations were run to determine the effects of solar heat gain by establishing how solar insolation impacts different sides of the building envelope and other variables, particularly, indoor temperature, dry bulb temperature and relative humidity, which function as markers of comfort. Other fabric elements such as roof, ceiling, walls and floors were evaluated and improved. In addition to accessing the fabrics, structural shading devices were designed on existing windows and walls, which were simulated to enhance thermal comfort, retrofit, and preservation purposes. Ventilation and shading against solar radiation are key passive strategies for building retrofit and comfort in warm, humid climates. The international thermal metric ASHRAE-55 served as a benchmark for assessing comfort levels. This criterion was employed to determine whether the independent parametric modifications were successful in providing comfort within the typical climatological conditions, as referenced in Climate. OneBuilding. Org (2021) and considering on-site occupancy patterns. The results of each modified parameter were subsequently compared against a reference base case model constructed and referred to as As-built. The results showed the impact of each parameter on the air temperature in the adobe buildings, indicating the expected level of indoor thermal comfort. Additionally, the results showed which parameters had the most effective impact on the indoor thermal comfort of Ilorin adobe traditional buildings, as well as how a combination of these parameters could maximise the indoor thermal comfort.

The findings emphasised the significance of ventilation and showed that Ilorin adobe traditional buildings can be optimised to get the best thermal control to facilitate the reduction of overheating all year long by incorporating an optimised window schedule along with a combination of shading devices. The second-best strategy was the use of roof shading devices. Thirdly, it was discovered that building fabrics with low U-values and high thermal mass improved indoor conditions with the introduction of an appropriate ceiling-insulating material.

7.3 Base Case (As built)

To develop the model on IES, the following assumptions were considered: The first step was using the "Model IT" and "Building Template Manager" characteristics to model the geometry of one main room model, with the first simulated with properties of the As built case study (original) building envelope specifications as it was in the past (The selected Ilorin adobe traditional buildings as built and geographical location selected was Ilorin Kwara state Nigeria) and the second with properties as it is currently built (The selected Ilorin adobe traditional building with occupants strategies), this process was done to compare the difference in thermal comfort percentage hours experienced in the internal spaces of both considering their different building envelope fabrics and also to analyse the effects of the most common building modification types adopted by occupants as depicted in the occupants strategy building, this included the change of roofing material from thatch to Zinc , walls made from thick adobe bricks to walls made from thick adobe bricks plastered with cement and floors- from mud to cement plastered mud floor. To evaluate occupants' thermal comfort, a thermal template was assigned to the model in which infiltration airflow rates, number of occupants, and indoor heat gains were specified. Following that, decisions about which passive strategies to include during optimization were made using this data. For every option, the incremental improvements in thermal performance were examined.

To estimate accurate shadow cast in the solar analysis and wind directions for the investigation of natural ventilation. The site data are shown in Table 6.2. The dynamic simulation's climate was established by using an up-to-date climate data file to simulate. The climate file replicated a typical year in the city based on conditions documented throughout a 14-year research period (2007-2021) developed by using the typical Meteorological year 651010_TMYx.2007-2021 (Climate.OneBuilding.Org,2021).

Table 7-2: Location Data for Ilorin, Nigeria

Latitude	8.5^0N
Longitude	4.5^0E
Elevation	343m
Altitude	320m

To reduce heat transfer into the building by conduction, convection, and radiation, during the field study, observations considering a mix of the existing building components relating to passive cooling strategies which included the use of courtyards, type of building fabrics and its properties, type of ventilation system and solar shading methods present with the potentials of aiding heat removal and heat gain prevention strategies in warm, humid climates were investigated. Important envelope parameters were grouped into four primary sets: (I) Orientation, (II) Building fabrics, (III) Natural ventilation and (IV) shading. Following the discovery of the optimised characteristics for each set, a combination set was developed to comprehend the interactions of different parameters. Lastly, an integrated model was established to maximise thermal comfort. See Table 7.1; for each set of envelope parameters, profiles were simulated considering the following: (I) As built in the past, (II) the most common long-term building envelope modifications made by the occupants, (III) potential building optimisation strategies based on literature, including national and international guidelines for thermal comfort and, (IV) suggested strategies for achieving an in-depth understanding of the thermal results. The simulation was conducted by progressively adding each modification to the original typical As-built case. As illustrated in Table 7-2.

Table 7-3: Arrays of potential arrangement of structural elements in Ilorin traditional buildings

S/N	Case code	Roof	Ceiling	Wall	Floor
1.	R1 - AS BUILT (Base case)	Thatch	No	Mud	Mud
2.	R2	Zinc	No	Mud	Mud
3.	R3	Clay tiles	No	Mud	Mud
4.	C1	Thatch	Plywood	Mud	Mud
5.	C2	Thatch	Asbestos	Mud	Mud
6.	C3	Thatch	PVC	Mud	Mud
7.	C4	Thatch	Fibreboard	Mud	Mud
8.	W2	Thatch	No	Cement plastered mud	Mud
9.	W3	Thatch	No	Compressed earth bricks with 5% Cement	Mud
10.	W4	Thatch	No	Compressed earth bricks with 5% cement and 8% shea meal	Mud
11.	F2	Thatch	No	Mud	Cement plastered mud
12.	F3	Thatch	No	Mud	Wooden floor
13.	F4	Thatch	No	Mud	Clay tiles
14.	OCCUPANTS STRATEGY - 1	Zinc	No	Cement plastered mud wall	Cement plastered floor
15.	OCCUPANTS STRATEGY - 2	Zinc	Plywood	Cement plastered mud wall	Cement plastered floor

The alterations were made in the sequence indicated in Table 7.3 to ensure that each parameter was fully examined and the impact on occupant comfort and fabric benefits were established. For example, natural ventilation enabled cool air to enter the building once the windows were opened. Similarly, to determine the impact of each profile individually, the first sets of (Sets:1- 3) simulation parameters included (I) The orientation of the building to produce the best orientation and to analyze the impact of external gains on the building envelope through solar radiation, (II) the internal gains from appliances and lastly, (III) completely opened windows, 100% operable area which was adopted by all other simulations thereby setting the stage for the base case to which each profile results were then compared.

Table 7-4 :Table of thermal simulations and simulation rationale

Sets	Parameter description	Simulation rationale.
▪ **Set (0)**	As-built with infiltration, no gains, and ventilation.	-For a baseline comparison
▪ **Set (1) – Orientation of the access.**	▪ North, ▪ South, ▪ East ▪ and West	-To investigate surfaces that are exposed to direct solar radiation to find the most convenient orientation of the selected typical room model. - To examine the effect of the window-to-wall ratio on indoor air temperature. - To determine effective shading design to prevent overheating. External shading devices were examined to control the amount of radiation getting into the interior of the room. It was discovered that the projection in front of the walls is the west façade from 3 pm to 6 pm. The horizontal and vertical shading devices were calculated using the solar altitude angles detailed in Chapter 5. Results show that the projection of horizontal shading needed is 0.75m to 1.2m, and vertical shading of 2.4 to 9.2 will suffice. For this study, plants are also used as shading devices since the room modeled is within a bungalow. Due to the low solar angles calculated, a canopy of 0.75m and a vertical device of 0.4m was adopted. ▪
Set (2) Building gains	As-built shell with gains and without ventilation	-To test the impact of gains (Base case and As-built)
Set (3) Optimised base case model	As-built shell with gains and completely opened windows	-To form an optimized baseline comparison

Set (4a) Building fabrics. **(Roof change)**	Optimized As-built model with Zinc roof.	To investigate the impact of roof change commonly adopted by occupants
Sets	**Parameter description**	**Simulation rationale.**
▪	Optimized As-built model with a clay roof.	To investigate the impact of roof change as a proposed alternative.
Set (4b) Building fabrics. ▪ **(ceiling strategy)**	Optimized As-built model with Plywood ceiling	To determine the ceiling that provides the best insulation. The practical approach of insulating roofs proved to be successful; it was discovered that "the higher the u-value, the better" might supersede "the lower the u-value, the better" in cases in some cases when the roof had high thermal emissivity and low solar absorptivity.
Set (4c) Building fabrics. **(ceiling strategy)**	Optimized As-built model with Asbestos ceiling	
	Optimized As-built model with PVC ceiling	
	Optimized As-built model with Fibreboard ceiling.	
Set (4d) Building fabrics. **(Wall fabric change)**	Optimized As-built model with Plastered mud wall.	To test the impact of wall fabric, change commonly adopted by occupants on thermal comfort as explained in section 6.2. The most commonly adopted wall modification is the introduction of cement plaster on thick mud walls. This is a major feature analyzed in the As-built model.

Sets	Parameter description	Simulation rationale.
	Optimized As-built model with Compressed earth brick with 5% cement.	To test the impact of durable and sustainable walling material (proposed alternative) for preservation and optimal thermal comfort.
	Optimised As-built model with Compressed earth brick with 5% cement and 8% shea meal.	
Set (4e) Building fabrics. **(Floor fabric change)**	Optimized As-built model with Plastered mud floor.	To test the impact of flooring material (commonly adopted occupants' strategy) on the thermal comfort of the building
	Optimized As-built model with Wooden floor.	To test the impact of flooring material (Proposed alternative) on the thermal comfort of the building
	Optimised As-built model with Clay tiles floor.	To test the impact of flooring material (Proposed alternative) on the thermal comfort of the building
Set (5) Building Shading **(Shading design strategy)**	Optimized As-built model with Shaded roof,	To establish the best shading strategy that protects the building from overheating

Sets	▪ ▪ Parameter description	▪ Simulation rationale.
	Optimized As-built model with Canopy	To test the impact of horizontal shading devices by protecting the building from high sun angles.
	Optimized As-built model with vertical shade	
	Optimized As-built model with Plants.	To test the impact of the vertical shading device by protecting the building from the sun on the sides of the elevations
	Optimised As-built model with combined shading devices.	
Set (6a) Ventilation. **(Operable window schedule)**	As-built with gains and an optimized window schedule.	To examine the impact of optimized ventilation on the thermal comfort of the building.
	As built with gains and 100% opened window	To examine the impact of natural ventilation on the thermal comfort of the building.
Set (6b) Ventilation. **(Window size change)**	Optimized As-built model with as-built window size (600mm * 600mm) at original window position	To determine the best strategy to optimize natural ventilation to achieve a cooling effect in the building.
	Optimized As-built model with large window size (1300mm * 1200mm) at the original position	To determine the best strategy to optimize natural ventilation to achieve a cooling effect in the building.
Number of windows	Original number of windows versus additional window	To examine the effect of window numbers on indoor air temperature as informed by optivent tool

Case study building A

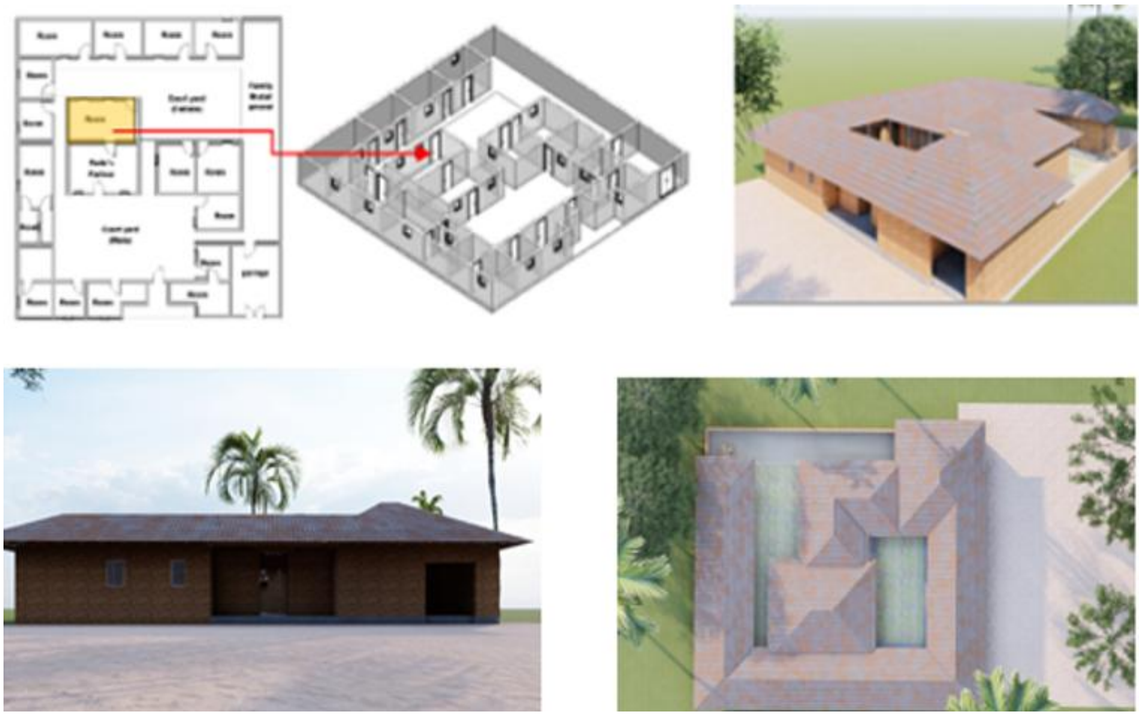


Figure 7-3: The photos of the selected case study (A) building where the main room was simulated in this study.

Based on the occupancy results obtained from Chapter 4, Ilorin adobe traditional buildings were anticipated to be occupied all through the day, having at least 2 people only from 08:00 am to 14:00 pm and full occupancy from 18:00 pm to 08:00 am carrying out different activities other than sleeping. Hence artificial light (Fluorescent light) was considered switched on from 18:00 pm to 22:00pm on daily. Figure 6-3 shows the reference building model views created using Revit, and the fabric specifications in Table 6-3 of the building were set based on the u-values of construction elements provided in the case study information detailed in Chapter 3, and the associated compositions of construction materials were assigned into ApachePro template.

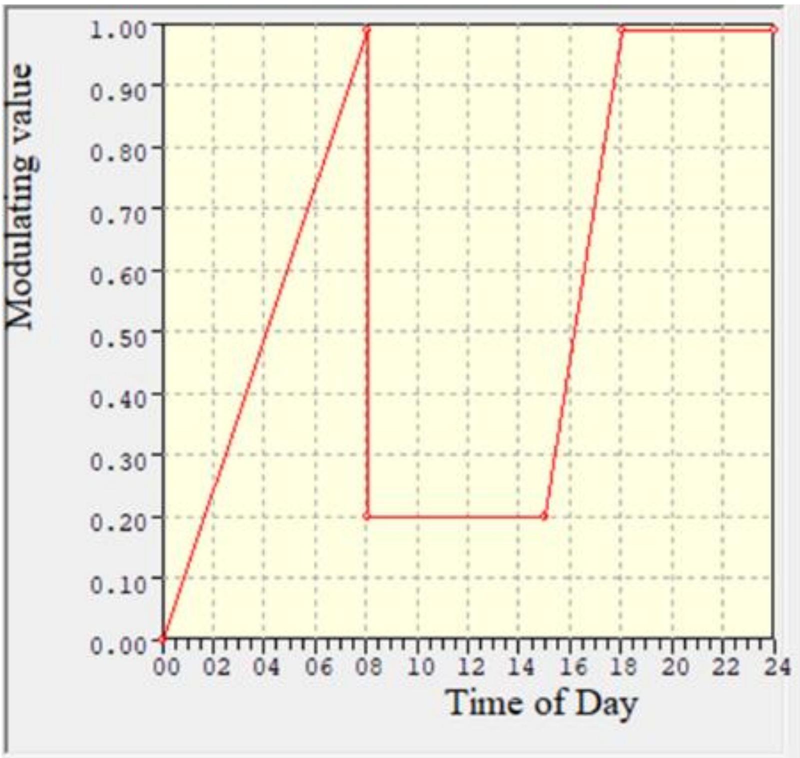


Figure 7-4: Weekday occupancy profile

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7.3.1 Building Fabric

The case study building fabrics were simulated based on how the building was originally built as indicated (As-built) in Figure 6-1a and Table 6-3. The process of increasing fabric insulation on building elements should be carried out strategically, one after the other individually to test the impact of each type of insulation or fabric on the building component on the thermal performance to derive the most suitable result for the purpose of study. For instance, materials with high thermal mass on a building envelope limit heat transfer efficiently. This section tests the impact of different u-values from different building construction materials on the internal and external conduction gains of a typical Ilorin adobe building. A thorough analysis was carried out to give comprehensive results on the best fabrics to be applied to Ilorin traditional buildings to deliver optimal thermal performance. Considering this, the impact of different combinations of construction elements on indoor air temperature was examined through comparisons of a total of 15 room models in this section. As illustrated in Figure 7-5

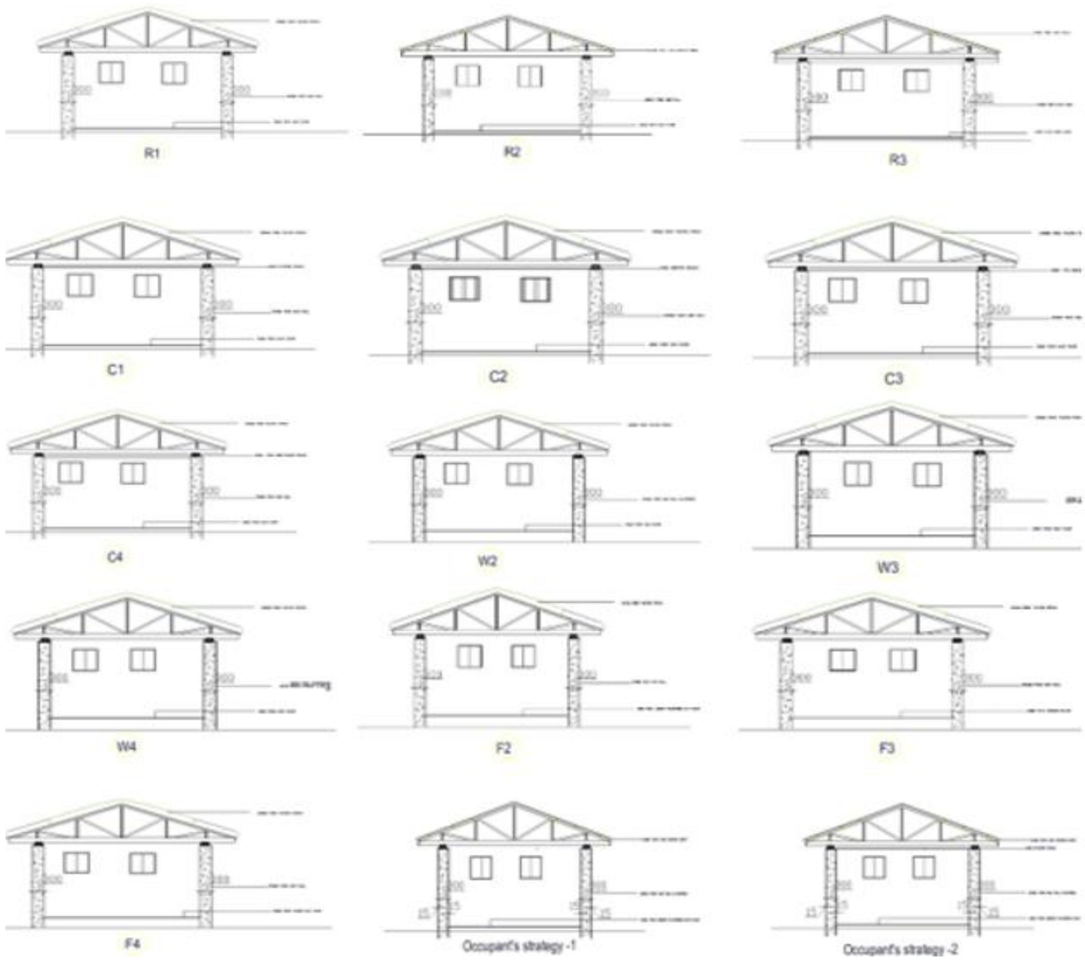


Figure 7-5: Potential arrangement of structural elements of Ilorin traditional adobe buildings

Table 7-5 Construction materials

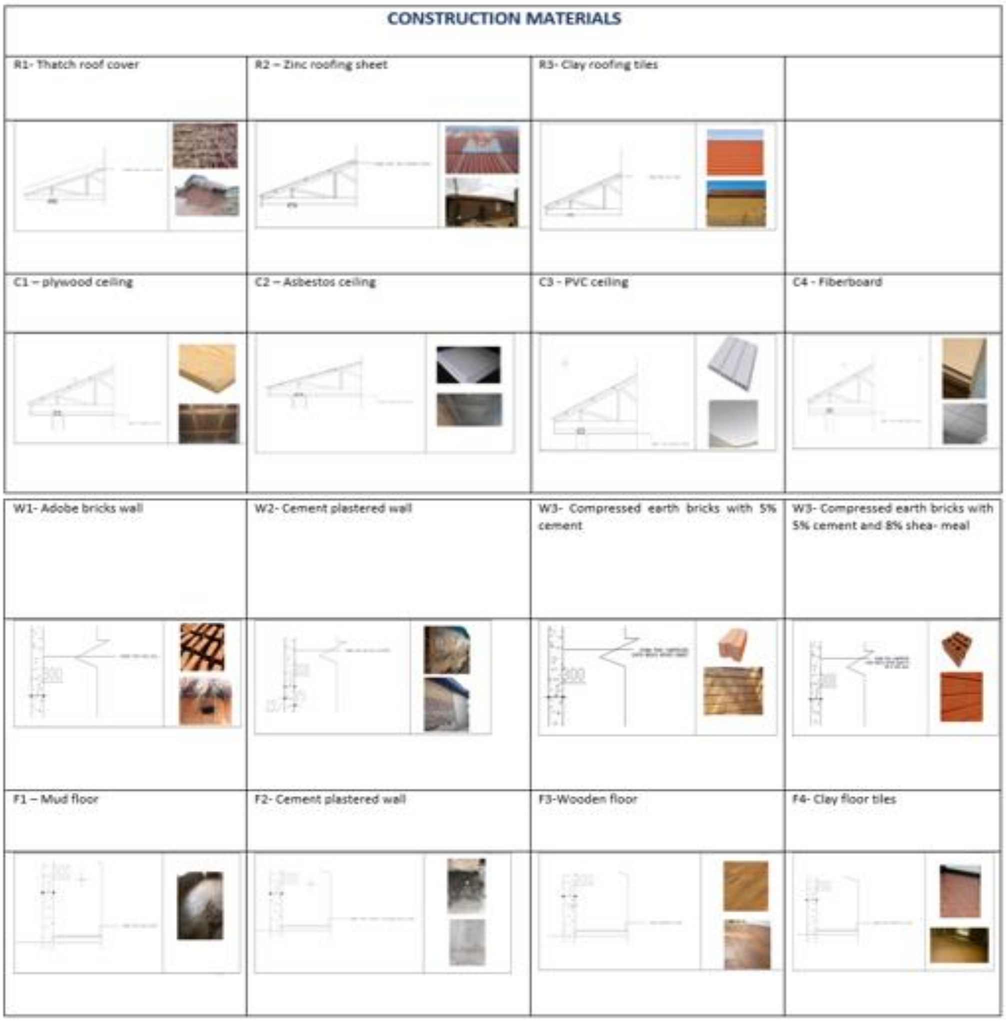


Table 7-6: As-built Building Fabrics composition and U-value based on IES-VE (2023)

Building element	Material (mm)	U-value ($W/m^{2}.K$)	R- value (m^2k/w)
Roof	200mm Thatch straw	0.33	2.86
External walls	300mm adobe wall with straw	0.54	1.67
Floor	25mm thick mud	3.18	0.17
Windows	50 mm thick timber	2.11	0.30

7.3.2 Internal heat gains

For all simulations, as part of the thermal template for room setting in the Model IT tool under the template manager, the cooling and heating set points were turned off as the purpose of this study is to investigate passive cooling strategies. This was assigned prior to the addition of internal gain sources to the simulation matrix. For the as-built model (0), the building envelope with 0.6 ACH infiltration only was considered and internal gains and ventilation were not considered in the first set of simulations. As built model (1) the building envelope with 0.6 ACH infiltration, internal heat gains and ventilation were considered with the following schedules of typical internal heat gains included into the As-built model (0), which was created: (i) occupancy, (ii) fluorescent lighting, appliances (Television) and (iii) infiltrations (0.6 air changes per hour). Occupancy fluctuations informed these schedules according to the results of previous chapters. The results obtained in the study presented in chapter four revealed that the average number of occupants per house was 22 and approximately 6 people per room. This was found to be consistent across the respondents, where about 47% were recorded to have between 5 to 10 persons per family and most houses comprised of at least three or more families each due to the practice of communal living and religious attributes that encourage polygamy (having multiple wives with children as discussed in Chapter 3).

Heat gains from appliances were included based on results documented during the occupancy survey evaluation study, where the basic artificial lighting was (I) fluorescent tubes, and the most common appliances were (II) televisions and (III) transistor radios, which mostly used batteries. Due to this, only the first two mentioned (Lighting - Fluorescent tube and televisions) were considered to deliver heat gains according to their consumption rate in the simulations. Table 6-7 shows this. Furthermore, different independent schedule analyses were performed on the appliances to establish their uses. The schedule was set based on the following conditions: the television was considered switched on when the following conditions were attained: (I) when the activities carried out in the room were different from sleeping, and (II). When the occupancy was greater than 0. Lastly, the fluorescent light was switched on when it was sunset and when the subsequently mentioned conditions were met.

Table 7-7: consumption rates of typical appliances in Ilorin traditional adobe buildings (IES-VE, 2023).

Appliances	**Consumption rate (Watts)**
Fluorescent tube	40
Television	60

7.3.3 Thermal analysis

For the As-built case, the building was thermally analyzed considering only the shell and 0.6 ach air infiltration coefficients as the worst-case scenario where the infiltration level is considered to be poor (Below standard windows, unsealed cracks, and no vapour barrier) as indicated by Henderson and Harley (2022) and ASHRAE (2009), disregarding ventilation provided by window openings in order to observe the impact of the parameters in a more evident way and leaving the impact of the ventilation for later analysis. Air infiltration rates ranging from 0.2 ACH, 0.4 ACH, 0.5 ACH, and 0.6 ACH were tested according to residential infiltration standards ASHRAE-Fundamentals chapters (16.15 and 16.29), which recommends infiltration values for residential building range to be between 01-2.0 ACH. The results revealed that the results were similar but with negligible impact. For this reason, the value 0.6 ACH was employed for this study after cross-referencing with the Passivhaus standard (2017) and standards from (Henderson and Harley, 2022). For all the thermal simulations, a pre-calculation of 365 days was considered to get the most accurate starting point conditions and getting accurate results.

Results from the simulations of the whole building focused only on the head of the family's room, known as (Daudu's space) see Figure 7- 6, which is the habitable area where occupants were expected to spend most of their time. The main room chosen is highlighted in red, which was also selected as a typical room because it is the only room space that has the highest wall-to-window ratio, which was used to analyse the impact of the building orientation effectively and the only type of room that is adjoining to the living room, making it the most spacious room in the case study building. In addition, during the post-occupancy evaluation of the buildings, results showed that the main rooms in typical Ilorin Adobe traditional buildings were the most occupied all day. Overall, all these attributes made the room choice for this study ideal to represent a typical Ilorin adobe traditional room for a thermal performance test where the results can be applicable to other rooms as well as other buildings.

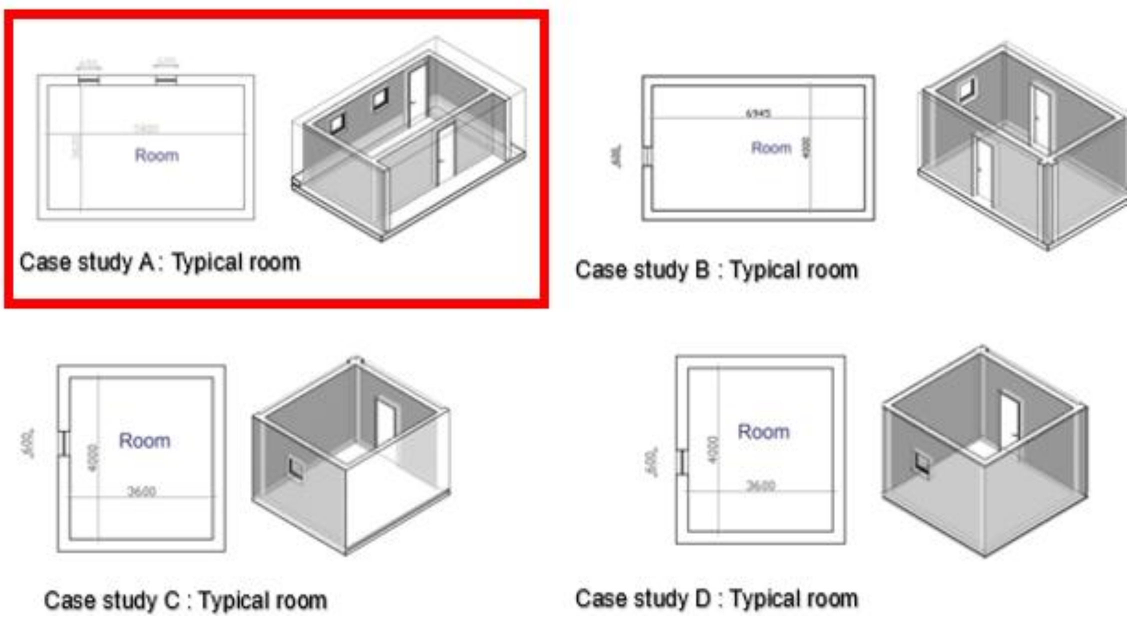


Figure 7-6: Typical Ilorin adobe traditional room plans and models

After results were obtained through the software IES VE (2023), they were exported to Microsoft Excel for further analysis and cross-comparison with other sets and parameters. The simulation results were evaluated and compared under an annual analysis and presented by months to understand the contrasting results during colder and warmer months. The percentages were compared individually to the optimised As-built case model to understand the independent influence of each factor. Afterwards, they were compared against different categories in each set to inform a later building optimisation presented in the next few sections.

7.3.4 Criteria for Comfort

The thermal data were examined with five comfort bands in consideration, as Chapter 4 indicated a slight variance in the way residents perceive heat. The definition of the comfort bands was done in accordance with ASHRAE (2017), which states that since higher wind speeds are projected for ventilation, naturally ventilated buildings with occupant control over the environment are likely to have wider comfort acceptability. The thresholds that defined the five bands were determined as follows: the upper comfort band is the temperature range where 90% of the occupants were expected to feel comfortable. The extended bands are the temperature range where only 80% of the occupants would agree to feel comfortable, according to ASHRAE (2017), as presented in Chapter 5. For this study, the comfort criteria were adjusted and grouped into three main categories (bands) annually for a deeper understanding. For this reason, the extended upper comfort, the narrow thermal comfort, and the extended lower comfort were within the thermal comfort limit. The thermal comfort limit was determined in the previous chapter as 25.2 - 32.1˚C See section 5.6 for details. Every simulation set analysed one parameter and resulted in a graph revealing the percentage of time conditions under (I) Below thermal comfort, (II) Within thermal comfort and (III) above thermal comfort.

In Table 7-8, the optimised As-built case model scenario was created to form the base case throughout the simulations. These included assumptions consisting of the building envelope with properties described in Table 7-2, with 0.6 ACH infiltration, all gains (internal and external heat gains) and completely opened windows.

Table 7-8: Table of thermal simulations for optimised base case model

Assumptions considered to form optimised Base case model	
1.	Building envelope as built originally
2	0.6 infiltration rate
3.	External and Internal gains
4.	Continuously opened ventilation with 90% openable area

Table 7-1 presents the simulation sets, and the parameters studied for each case. Only the studied parameter was altered, while the remaining parameters were held consistent with the As-built case throughout the sets. Variations to the properties of the construction type of As built were made to generate the model.

7.3.5 Thermal Simulations according to Building Envelope Parameters

After simulations were carried out, the results from each set were subsequently cross compared with the best strategies from other sets with the aim of establishing the best parameters to optimise the building. The detailed explanation of each set are presented as follows:

Set (0) Base case (As-built model)

To establish the base case for analysis of the results obtained from the sets simulated, the first simulation examined the original Ilorin adobe traditional buildings. An air infiltration rate of 0.6 ACH in accordance with (ASHRAE (2009); Passivhaus (2017); Henderson and Harley (2022)) was the only air exchange factor taken into consideration at this point. Ventilation and gains were not considered at all.

Set (1) – Orientation

In this set, the incident solar radiation that reaches the surfaces of a building envelope was investigated with the aim to establish the surface of the building with the most amount of direct solar radiation and to inform shading. The window -to-wall ratio of the room façades was used to test the impact of orientation on the indoor air temperature.

Set (2) – Gains

The next set was the simulation of the base case with the addition of 6.0 ACH infiltration and gains only to study the direct impact of gains on the building envelope. Ventilation was not considered at this stage.

Set (3) – Optimised base case model

To determine the optimised base case for analysis of the results obtained from the sets simulated, the simulation examined the original Ilorin adobe traditional buildings with an air infiltration rate of 0.6 ACH, gains and ventilation taken into consideration at this point.

Set (4) - Variants of building fabrics

Heat transfer into a building through conduction is dependent on the U-value of the building materials. As defined by Oral and Yilmaz (2002), U value is the transmissivity ability of a material or a combination of materials; this value is determined based on the rate at which heat flows through an insulating material of a structure. In this regard, it is noteworthy to understand that the envelope of a building is an important component to research on to prevent or stop conduction heat transfer–related overheating in buildings. The Passivhaus standard sets the baseline for the most proficiently used U-value (Institute,2007).

The building fabrics were examined in this set (All other building elements (envelope parameters) were considered unchanged). The variables listed under the four primary building modifications, as indicated in Table 6-6 were simulated and results were compared to the original state of the building fabric (As-built model). The building fabrics were separated and changed to investigate the direct effect of the U-values on the envelope's thermal gains. Simulations for the building fabrics was grouped based on (I) Building component (II) Most popularly adopted occupants' strategy and, (III) Proposed alternative strategy.

Firstly, Using the Modell IT tool and Apache tool in the IES -VE software, the building envelope was modelled according to the true North and measurements obtained during the fieldwork; construction templates were selected and assigned to the building components, gains were also assigned through the thermal template and profile schedules were created for ventilation and gains templates. Thereafter, the roofing materials were selected based on results derived in Chapters 3 and 4. Secondly, the insulation materials used as the ceiling were selected and simulated individually with the aid of the Apache sim tool in the IES-VE tool, followed by the walls and floors. As explained previously, the variables were changed one after the other for simulations to reveal the impact of each material change on the internal thermal conditions of the building. Lastly, each result was analysed and retrieved through the VistaPro tool in the IES-VE software. To observe the full impact of the building fabrics, see details in Table 7-9. Sources of ventilation were not considered initially as they were considered switched off continuously throughout these simulations. After results were analysed for the 15 fabric variables, it was revealed that all simulations resulted in thermal discomfort, indicating 100% above the set thermal comfort threshold (25.2 -32.1˚C) throughout the year. Hence, testing for the impact of fabric on thermal comfort was not achieved. For that reason, simulations were repeatedly tested considering minimum ventilation to investigate the possibility of getting any fabric impact. Ventilation was delivered through 30% and 45% effective operable area of the existing (600mm * 600mm) side-hung windows in the building. The operable area was chosen and considered as the minimum effective area to avoid overshadowing the impacts of the fabrics. As a result, negligible differences of less than 0.5% were discovered. Thus, the simulations did not deliver substantial data to give full insight into the impact of the building fabric on the indoor temperature. On this note, the simulations were run considering the optimised base case (as-built) model with completely opened windows.

Table 7-9 : Array of building fabric simulations

Building component	Variable	Thickness (mm)	U-value	Strategy
Roof covering	R1= Thatch	200	0.3337	Base case (As-built)
	R2 = Zinc	0.8	7.1411	(Occupant's strategy) The most popularly adopted occupants' strategy
	R3 = Clay tiles	15	6.3348	Proposed alternative
Ceiling	C1 = Plywood	12	3.3333	(Occupant's strategy) The most popularly adopted occupants' strategy
	C2 = Asbestos	12	4.5313	(Occupant's strategy) The most popularly adopted occupants' strategy
	C3 = PVC	12	4.6512	Proposed alternative
	C4 = Fibreboard	60	0.8101	Proposed alternative

Building component	Variable	Thickness	U-value	Strategy
Wall	W1= Mud mixed with straw.	300	0.5445	Base case (As-built)
	W2 = Plaster mud wall.	330	0.6842	(Occupants strategy) Most popularly adopted occupants' strategy
	W3 = Compressed earth bricks with 5% cement.	300	1.7045	Proposed alternative
	W4 = Compressed earth bricks with 5% cement and 8% Shea meal.	300	1.5834	Proposed alternative

Building component	Variable	Thickness	U-value	Strategy
Floor	F1= Mud	25	3.1830	Base case (As-built)
	F2 = Plastered mud floor	25	3.4198	(Occupant's strategy) Most popularly adopted occupants' strategy
	F3 = Wooden floor	21	2.5480	Proposed alternative
	F4 = Clay tiles	32	3.9056	Proposed alternative

Set (5) Shading Strategies

In Ilorin, as shown in Chapter 5, the Solar altitude angles are high for most of the year, varying from 57.77^0 during the winter solstice, 80.95^0 during the equinox, and 74.50^0 during the summer. With the presence of the sun at high solar angles, the roof is anticipated to have higher heat gain from solar radiation, which means that solar heat gain should be considered as an important factor that impacts on the indoor air temperature. In this case, the solar gains were calculated using Sun cast and Apache tools in the IES -VE 2023 software. The base case study (As-built) included the overall building geometry, building fabrics and openings maintained in their original state and both the direct solar radiation and shadow cast were analysed to provide an in-depth understanding of the impact of the external geometrical characteristics on the internal thermal conditions of Ilorin traditional adobe buildings through an entire year. Furthermore, based on physical building observations carried out during the fieldwork, it was established that Ilorin adobe traditional houses did not usually incorporate shading devices to prevent the building from overheating. However, some of the buildings depended on the little shade provided by roof overhangs as local solar shading. It was also discovered that the orientation of the typical Ilorin adobe room affected the amount of exposure of solar radiation that hit the building openings and facades. For this simulation, the following parameters were examined: (I) Roof shading (II) Horizontal shading device (Canopy) (III) Vertical shading device (IV)Plants (V) combination of Canopy and vertical shading device (VI) Combination of Planting Canopy and vertical shading device (VII) Combination of Planting, canopy, vertical shading and roof shading (VIII) Plant shade on West façade (IX) Plant shade on North Façade (X) Plant shade on East façade (XI) Plant shade on South façade, see Figure 7-7.

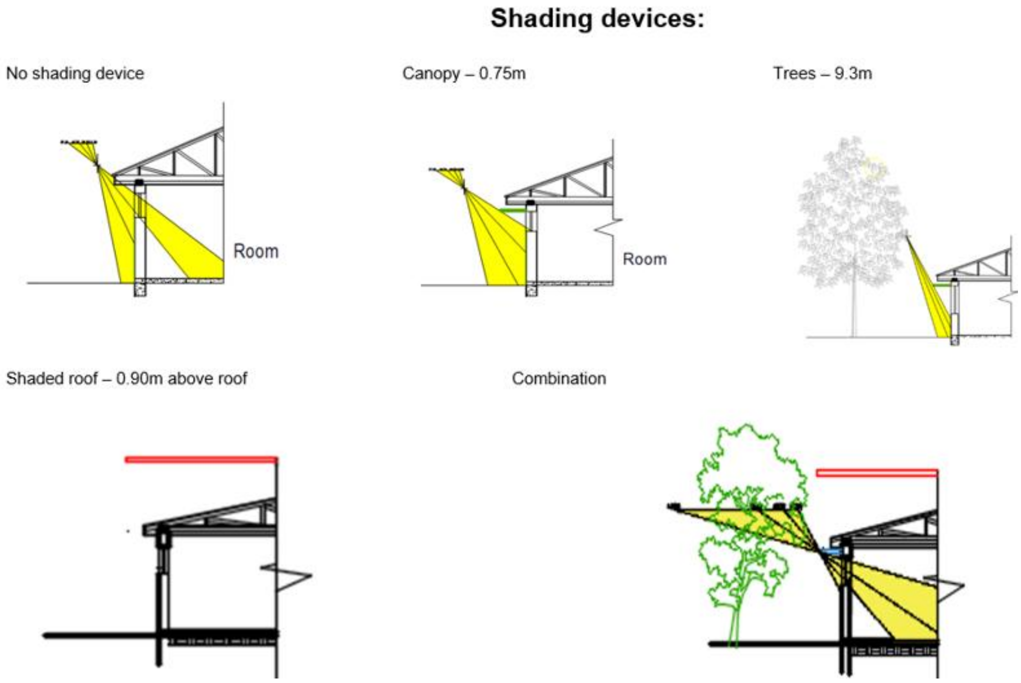


Figure 7-7: Types of shading methods employed in this study.

Set (6) Ventilation

This section was created to determine the most effective methods of maximizing natural ventilation to provide the building with a cooling effect. Natural ventilation offers three primary purposes in tropical buildings: (I) Providing fresh air, (II) facilitating connective cooling and (III) delivering physiological cooling (Koeigsberger,1973). Air movement meets the last and ventilation delivers the first two mentions.

In Chapter 2, ventilation was discussed in detail. Furthermore, the ventilation requirements for this study were analysed in Chapter (5) and the results informed this section to achieve the strategies employed for simulation. Moreover, in Chapter 1, according to ASHRAE Standard 55 and Current Handbook of Fundamental Model (climate consultant 6.0) which was employed to carry out the analysis of the passive design guideline recommendations for Ilorin city by ASHRAE-55 adaptive comfort via the psychrometric chart revealed the importance of harnessing good natural ventilation to give the building a cooling effect to improve thermal comfort and suggested a few strategies for achieving this. Liedl et al. (2012) describe the warm humid climate as a problem area for building designs. The prominent problem of this climate is heat and thus the solution professionals provide should be on cooling strategies. He points out that designers can only concentrate on ensuring that building designs do not allow heat to move into buildings and states that passive design methods, such as the placement of larger windows on the North and south walls and avoiding the placements of fenestrations on the east and west walls can be used to achieve passive cooling. Similarly, several researchers have suggested that notable risk factors for overheating in the built environment include trends towards hotter-than-average summer temperatures and an increase in the frequency of extreme weather events (Anderson and Bows 2008). Thus, securing thermal comfort in buildings within the indoor environment of buildings that depend on passive systems is one of these challenges currently experienced globally which has prompted researchers to produce innovative construction ideas to boost the efficiency of buildings so that they can rely on sustainable and natural energy supply. This section examined the impact of natural ventilation on the thermal comfort of the building and identified the best strategies to optimise natural ventilation to achieve cooling effects in typical Ilorin adobe buildings. To illustrate these effects of natural ventilation on the whole building, the windows of the buildings were set into opening angle 90^0 in MacroFlo tool IES-VE.

Operable Schedules for Windows

The first set of simulations to test the ventilation effect on the buildings were grouped into two variations (I) Optimised window schedule and (II) Completely opened windows (100% opened). The windows maintained the same size and opening area. Firstly, the optimised schedule template was set in daily profiles which are built into weekly profiles of the Apache profile database manager. By scheduling the window openings and closures based on the difference in temperature between the indoor temperature and outdoor temperature, the ventilation was optimised. Particularly, ventilation was only permitted by this optimisation when the outdoor temperature was more conducive to the indoor temperature. The windows were only regarded as open in the following scenarios explained in the equation below.

$$gt\ (T_{room} > 25\ .2)\ \&\ (\ T_{out}\ <\ T_{room})\ \&\ T_{out} < 32.1°\text{C}) \qquad \textit{(7-1)}$$

“T_{room} = Room air temperature

“T_o” is Outside air temperature.

“gt” is Greater than.

When a room is occupied, openings should (I) start to open when the indoor temperature exceeds 25.2°C, (II) Be fully opened when the indoor temperature exceeds 32.1°C, (III) Start to close when the indoor temperature falls below 32.1°C, and (IV) Be fully closed when the internal temperature falls below 25.2°C. The windows are considered closed if the Outdoor temperature is> 32.1°C in accordance with (CIBSE TM59,2017). Afterwards, simulations, including the base case with gains, were run using both the optimised weekly window schedule and completely opened windows where, the windows were on continuously. Results obtained were independently compared with the base case without ventilation to gain a good understanding of the impact of ventilation on the thermal comfort hours throughout the year.

Window Size Assessment

The next set of simulations considered the base case (As-built) model and two different window sizes. The variations consisted of (I) the as-built size of windows and (II). Larger windows which were considered based on results revealed in Chapter 5, where the Optivent simulation result indicated that the existing window size did not provide effective ventilation to cool the indoor environment of the building. Firstly, in the first set of simulations, the window type and size remained the same as built on the existing base model to maintain 90% opening area. Secondly, windows were enlarged by about 116% more than the size of the existing windows to comply with the result recommendations in Chapter 6 and in accordance with the local requirement for habitable spaces in Nigeria. (NBC,2006). This simulation aimed to assess the impact of window ratio on the indoor thermal comfort of the building. However, for this study, considering the room sizes are small and the enlargement of the window sizes will not be practicable on the existing buildings, it is recommended that other measures can be tested for future works and wooden shutters can be introduced while for newer buildings the enlarge windows can be implemented.

Number of Windows Assessments

In this section, a set of simulations considered the base case (As-built) model and two different window-to-wall ratios, with a focus on the number of windows on the building facades. The variations consisted of (I) the as-built model with the original number of windows which was a total of two windows with a dimension of 600mm by 600mm each and (II). An as-built model with an additional number of windows increasing it to three windows of the same size (600mm by 600mm each) which were considered based on results revealed in Chapter 5, where the Optivent simulation result indicated that additional window opening for cross ventilation could provide effective ventilation to cool the indoor environment of the building. (III) As-built model with three large windows as informed by the optivent result in Chapter 5, to test the impact of the result on the indoor air temperature of the model.

7.3.6 Orientation and Solar Radiation

The building envelope can be significantly impacted by the amount of solar radiation that hits the building envelope. The most effective way to reduce indoor overheating is to shade the roof, windows, and openings. The orientation of a building can be used to determine the impact of localised sun path and wind flow to inform climate-responsive design strategies and to inform the type and positioning of shading devices on buildings. According to Koenigsberger et al., (1973), climate-responsive design strategies for buildings located in warm–humid regions should be oriented with longer facades facing the North and South, and shorter facades facing East and West to reduce the impact of direct solar radiation into the building. However, this is not usually the case in Ilorin as the buildings have irregular forms due to the presence of several rooms arranged around courtyards to create the building envelope. Incident solar radiation is the quantity of solar energy that hits the building envelope and is measured in Wm^2 (Watts per meter squared). This energy can potentially overheat buildings if no cooling is allowed. As seen in Figure 6.8, the months with the highest solar gains are correlated with the dry resultant monthly mean temperature. For this reason, solar radiation penetration should be prevented to reduce overheating in the building. Hence, in this section, exposed and unexposed surfaces were determined with the aim of finding which surfaces received the highest amount of direct solar radiation to find the most convenient orientation of the building and inform later shading design devices accordingly to effectively protect the building from overheating.

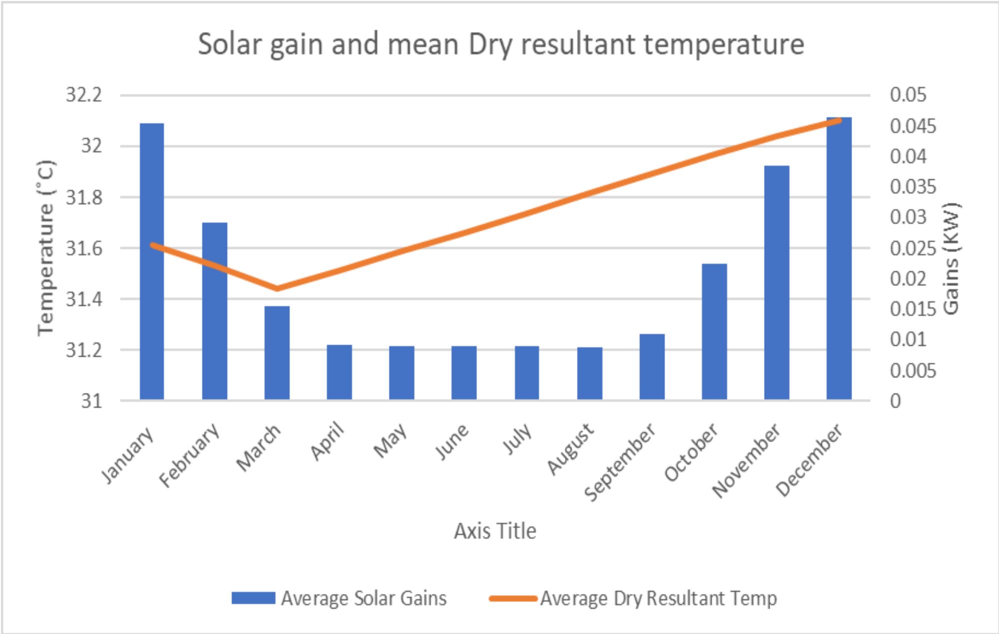


Figure 7-8: Monthly solar gains according to simulation in software IES-VE (2023).

***Orientation of Base Case* Study Building**

For the base case analysis for this study, the original building envelope parameters were considered. An annual analysis of solar gain was conducted to determine the building's most advantageous orientation in order to reduce the likelihood of overheating. The exposed skin of the building's basic geometry is the primary influencing factor in creating varying thermal conditions for the building's habitable space, for this reason, the resulting levels of energy received by the building throughout the year was established using a scale produced by Sun cast tool in (IES-Ve software, 2023). The scale remained constant throughout the solar radiation study since it was fixed as absolute to allow an easy comparison across cases. It could be seen in all cases that the roof defined the maximum solar radiation in the colour scale as the most exposed surface. In the analysis presented by each case, shadows were removed to deliver only the colour corresponding to the energy amount received on each façade and the exposure hours of each surface. Also, the impact of window-to-wall ratio on the indoor air temperature was informed by this analysis.

7.4 Result: Case study one

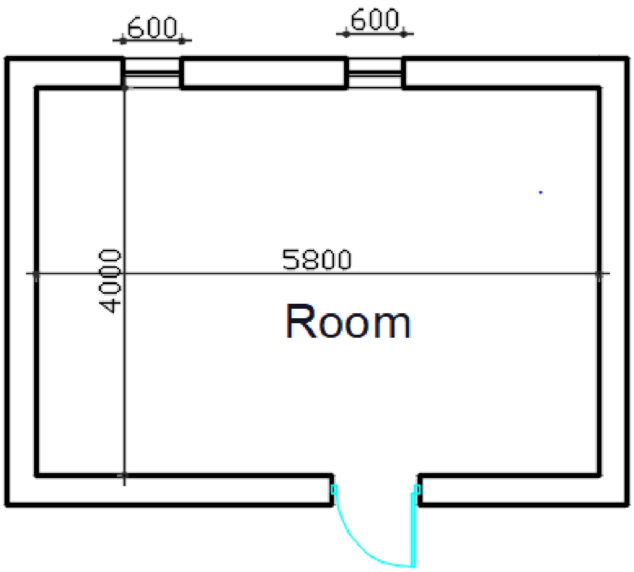
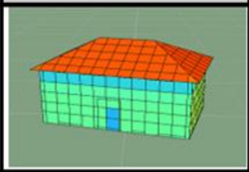
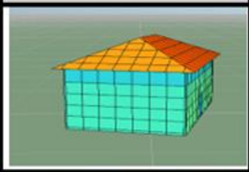
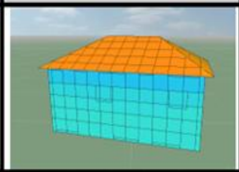
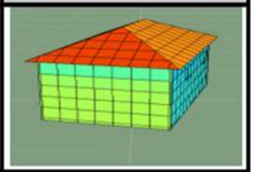
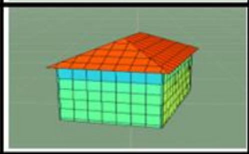
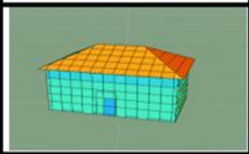
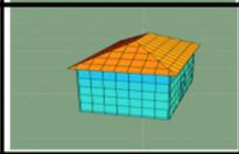
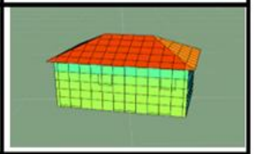
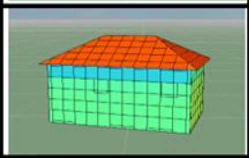
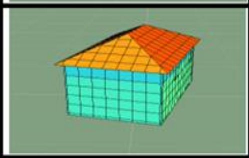
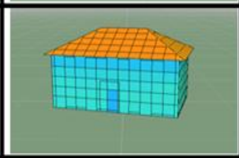
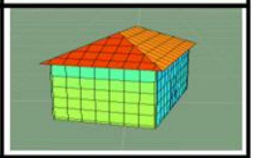
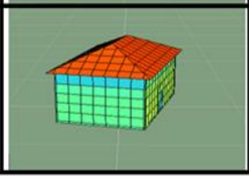
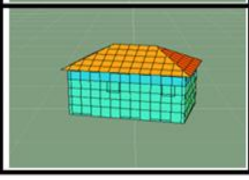
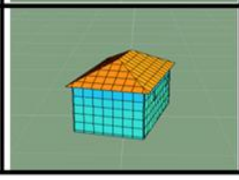
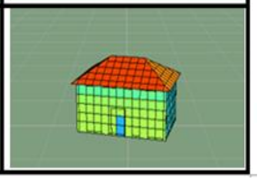


Figure 7-9: Typical room plan – Case study A

In the first phase of this study, the model of a typical Ilorin adobe room with hip roof made from thatch, mud walls, mud floors and timber windows and doors as presented in Figure 6-9 as R1 was considered. The model was characterized with 5.8m by 4.0m rectangular shaped plan, 2.7m height and 2.3m roof height. In this section, all simulations carried out employed this model.

7.4.1 Orientation and Solar Radiation

Table 7-10 : Annual Solar Radiation on External Surfaces of Base Case Study one

Building orientation	South	West	North	East
Access facing South. At 15⁰N				
Access facing West. At 105⁰N				
Access facing North. At 195⁰N				
Access facing East. At 285⁰N				

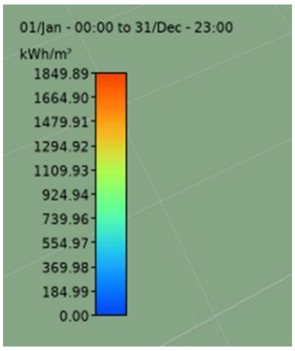


Figure 7-10: Scale for absolute solar radiation results.

The resulting levels of energy received by the building throughout the year, as shown in Figure 7-10, reveal that the roof defined the maximum solar radiation in the colour scale as the most exposed surface. The set location for this case study is 15 North, and the access to the building is southwest, having no windows on the West, South and East façade and having the less exposed façade (North Façade) to be one of the largest. The wall-to-window ratio (WWR) of the As-built case (just shell) was approximately 5% on the North façade, and 0% on all other facades of the model was employed to test the impact of WWR on the indoor air temperature of the room. The same model with the same 5%WWR was used to test four orientations (15^{0}N, 105^{0}N, 195^{0}N and 285^{0}N) with all the windows considered opened continuously. Results showed that the difference in percentage comfort hours annually using the comfort limit (25.2$^{\circ C}$ – 32.1°C) established in section 5.4 was negligible at 4.09% after employing the same model to test the impact of the window-to-wall ratio (WWR) on the indoor air temperature with varied window areas of 5%, 20% and 36% of WWR. See details in Figure 7 -11

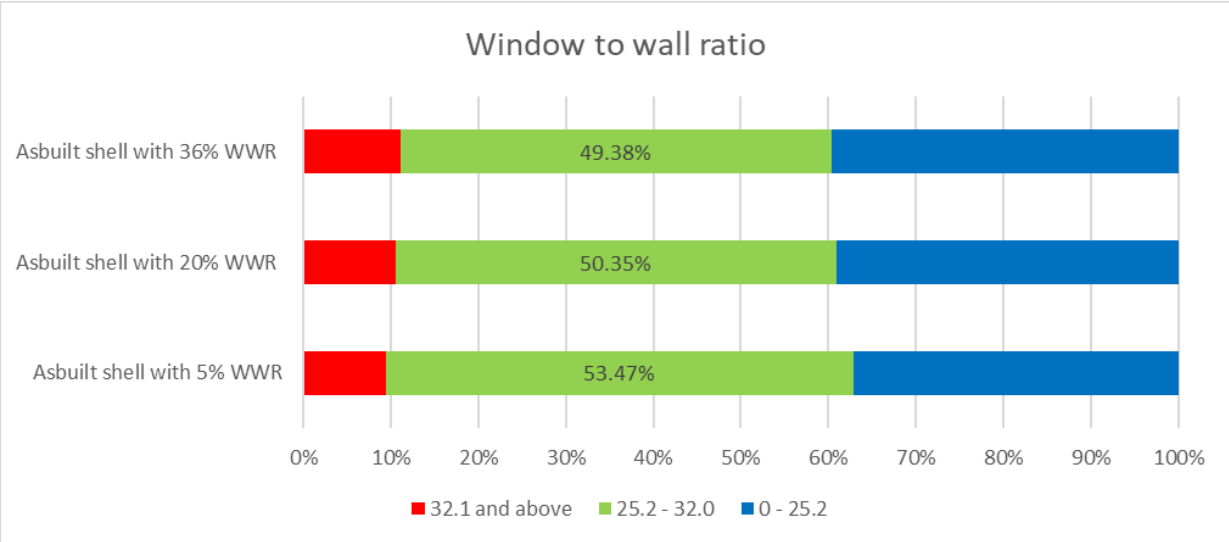


Figure 7-11: Impact of orientation on indoor air percentage comfort hours annually.

Furthermore, the result also suggested that the higher the WWR % on the facades of the case study model, the lower the comfort percentage hours of the year within comfort limits. This is due to the increase in the amount of direct solar radiation entering the room. The results indicated that the East and West orientations produced the best comfort percentage hours of 57.27% and 56.89%, respectively. However, considering that the building assessed was an existing building, the insignificant difference in the impact of the orientations on the indoor air temperature and the reason that little or nothing can be done to change the orientation of the existing building, the result of the simulations established that the original orientation of the case study (South- facing façade) was the best option and the 15^{0}N orientation was adopted for the entire parametric study of this case study despite performing worst with 53.44% comfort hours. See Figure 7-12.

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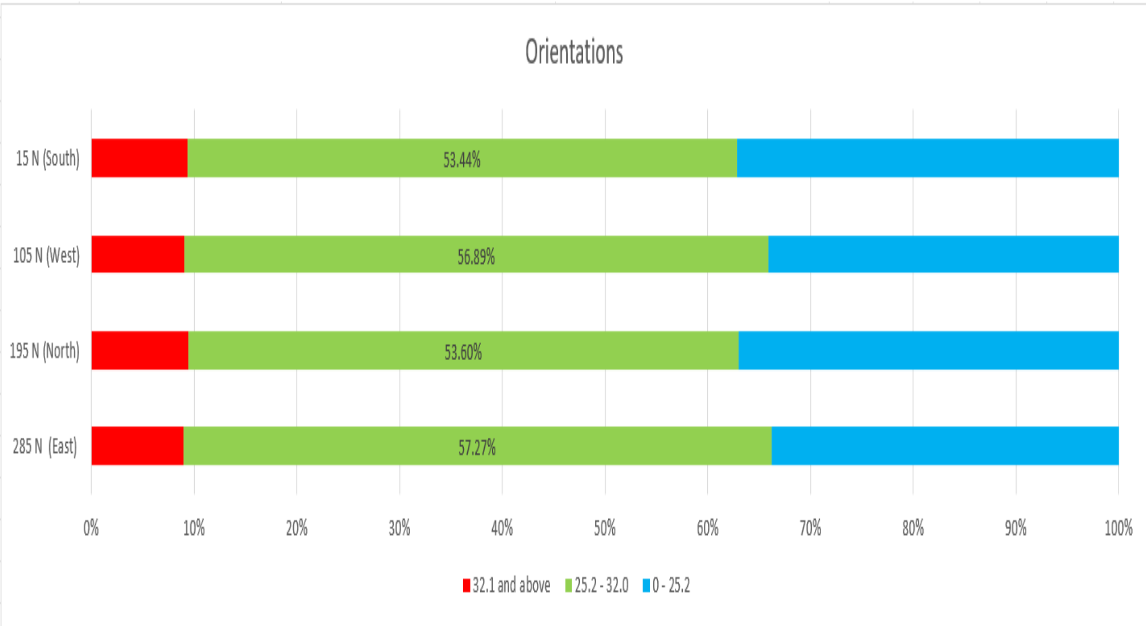

Figure 7-12: Impact of orientation on indoor air percentage comfort hours annually.

As seen in Table 7-10, the roof is the surface that gets most of the solar radiation, with a total of 1849.98 kWh/m² annually. On the other hand, the North and West façades receive the lowest solar radiation with only 554.97 kWh/m² and 739.96 kWh/m² respectively; the South, which is the access is 924.94 kWh/m² and the East façade receives around 1109.93 kWh/m². This information is useful in defining the best location to cast shadows and prevent overheating in the building. Thus, solar shading designs were examined to protect the building from direct solar radiation, considering the chosen orientation and the necessity of addressing overheating in the building for thermal comfort.

Further analysis of the building orientation also revealed that the longer building surfaces face the North and the South axis while the shorter surfaces face the East and West. Similarly, there are no existing openings placed on the East and West façade making the building orientation Ideal to respond to passive design strategies for warm humid climate zones as suggested by climate consultant 6.0. According to the orientation, the building access is located on the south façade with two window openings located on the North façade. In addition, the analysis of the solar exposure hours on the building façade showed that the West and North façades received low exposure hours of about 14.2% and 18.9% respectively all through the year according to the colour scale. Hence, the simulations included a thermal analysis in determining the orientation that delivered the best thermal conditions to the building throughout the year.

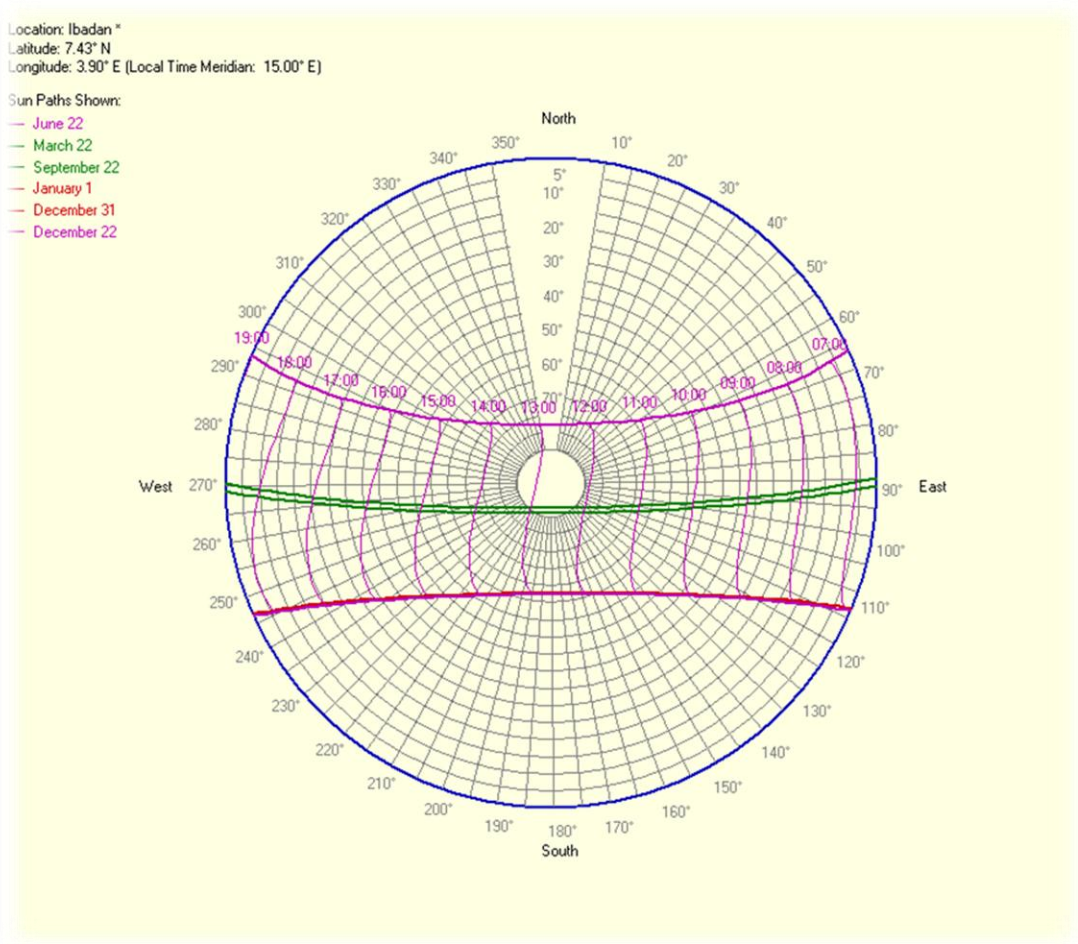

Figure 7-13: Annual sun path diagram for Ibadan, Nigeria from IES VE 2023.

The annual sun path diagram (Figure 7-13) is a tool for determining which months, hours, and façades require shading devices to stop solar radiation penetration. The lines on the diagram represent the autumn and spring equinoxes as well as the summer and winter solstices.

7.4.2 Building fabrics

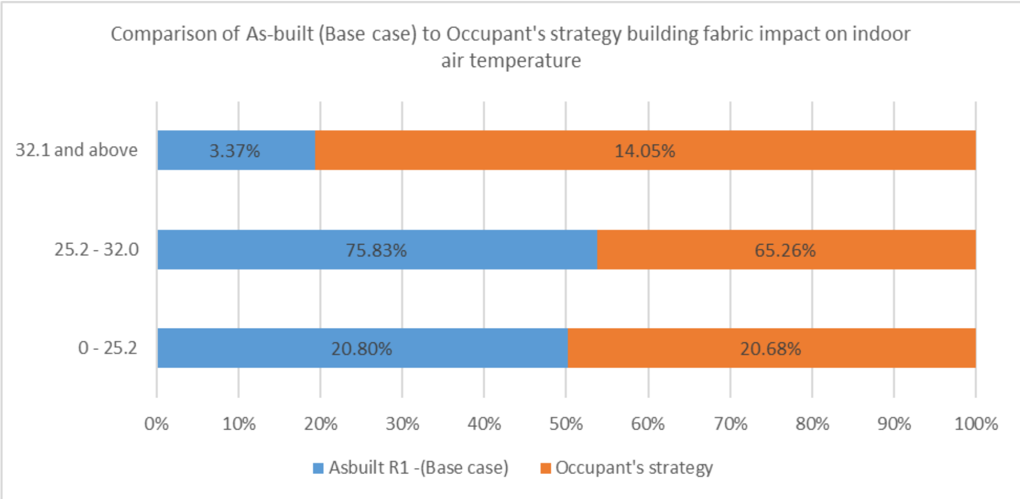

Figure 7-14: Annual percentage comfort hours within the comfort threshold (25.2 – 32.1°C) in the As-built and occupants strategy models

Impact of fabric change from original (base case/ As built) to Occupant's strategy on the indoor air of a typical Ilorin adobe traditional room. Figure 6-14 presents the comparison between the base case study, which depicts the As-built conditions and the occupant's strategy (the current state of the building); this analysis was done to show the impact of the most common strategy adopted by occupants on the indoor air annually. Results revealed that the Base case study, which was built originally with a thatch roof, mud walls, and mud floors without any alterations, performed better with a difference of 10.57% hours within the comfort threshold of 25.2 – 32.1˚C than the occupant's strategy form. Due to this reason, all other simulations for this study adopted the Base case model.

This subsection presents the resulting variations of thermal conditions inside the building across months throughout a typical year. Based on results collected during the in-situ monitoring via tiny tags, which was discussed in detail, as seen in Chapter 5, the warm months have been established to run from January to April, with March being the hottest month in Ilorin throughout the entire year. Similarly, from the orientations simulated in the previous section, it was discovered that in the month of March, the indoor air temperature of a building in Ilorin is prone to overheating due to the amount of solar radiation that hits the surface of the buildings. For this reason, to determine the thermal performance of typical Ilorin adobe traditional building fabrics, a couple of simulations were run, and the comfort hours achieved during the warm months, particularly in the month of March, were analysed.

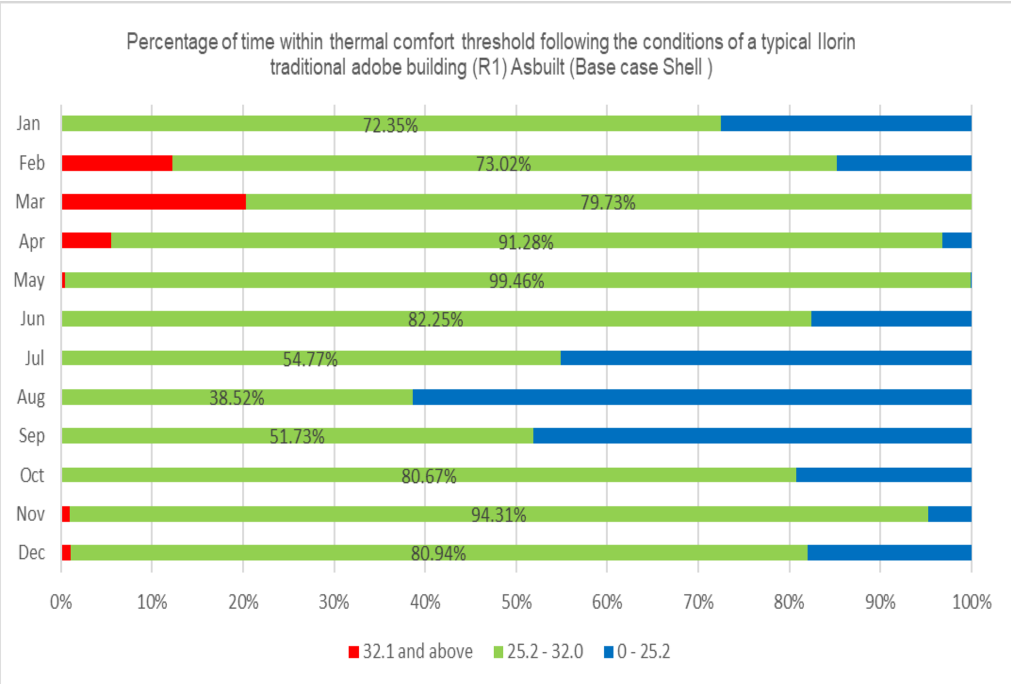

Figure 7-15: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building (As-built) case study.

Figure 7-15 shows the resulting percentage of hours achieved within comfort limits when the shell of a typical Ilorin traditional adobe building is in its original state without gains, and ventilation was simulated. This building comprises of a thatch roof, walls made from adobe mixed with straw, floors made from mud and slightly layered cow dung, wooden doors and windows. The result revealed that throughout a typical year, a typical Ilorin adobe traditional building shell steadily provided substantial comfort during the warm months, with March having about 80% comfort.

Comparing the percentage of hours within thermal comfort limits achieved in the case study building under the As-built shell conditions (Figure 7-15) and the occupant's strategy conditions (Figure 7-16), the results indicated a significant percentage difference of 17% comfort hours in the hottest month of the year (March). Due to this reason, the strategies adopted by occupants provide a counterproductive outcome at this stage.

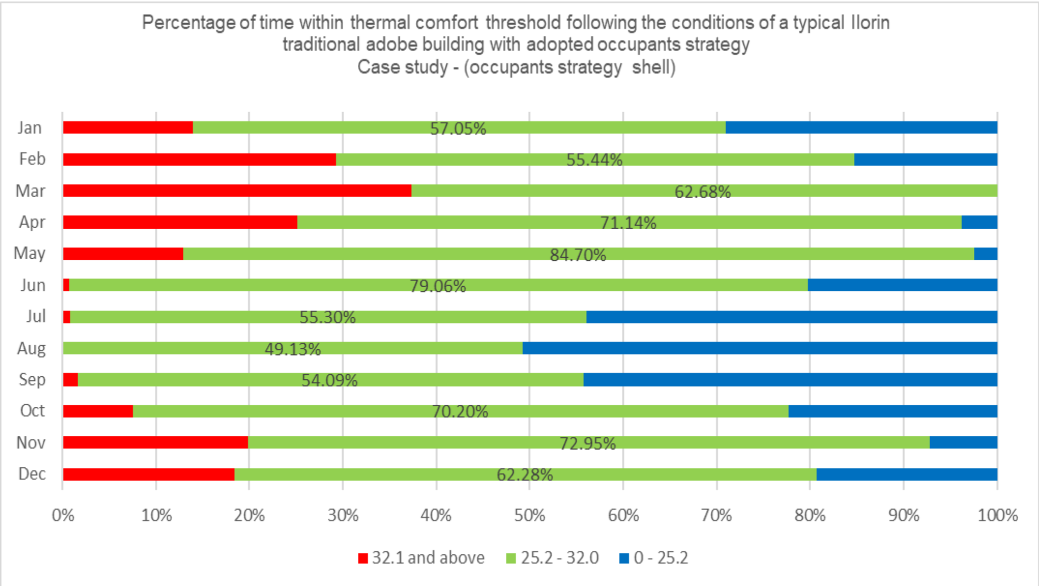

Figure 7-16: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building (Occupant's strategy) case study.

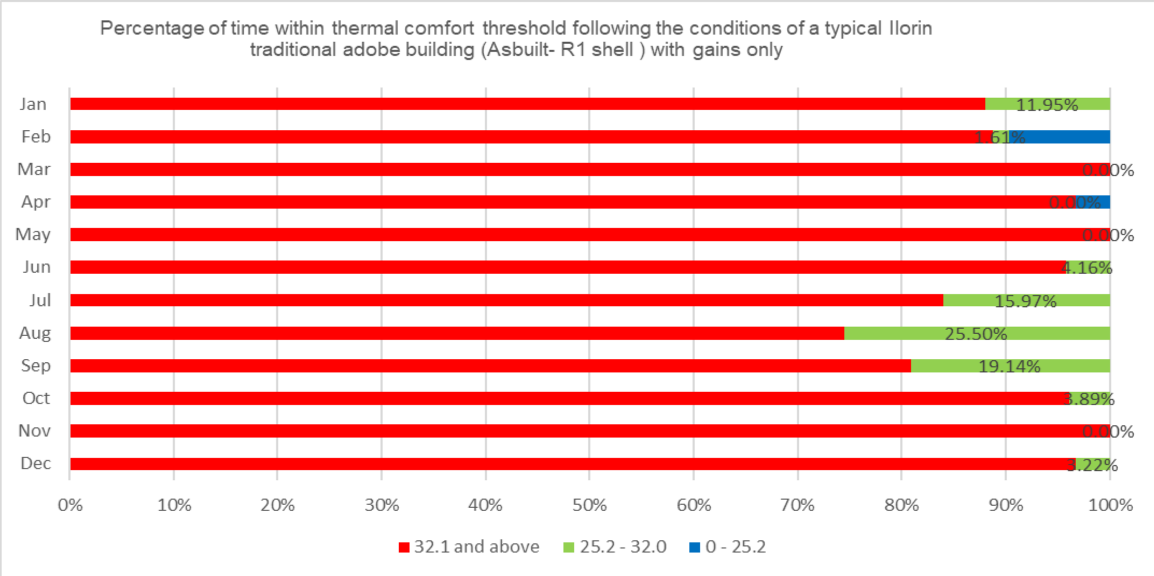

Figure 7-17: For a percentage of the time, conditions were below, within, and above thermal comfort bands, with building fabrics following the typical Ilorin adobe traditional building with external and internal gains.

In Figure 7- 17, results indicate that when internal gains were added to the base case, without ventilation, the indoor air temperature was overheated for most of the year; this also indicated that thermal comfort was not achieved at all in the months of March, April, May and November as it recorded 0% and this can be attributed to the thermal properties of the building fabrics. According to CIBSE (2016), Adobe traditional walls have a high thermal mass, which implies that the building fabric of low U-values and high thermal mass due to the thickness of the brick wall can store heat that may lead to severe overheating in the absence of ventilation. For this reason, it can be established that material properties such as U-values, thermal mass and ventilation strategies are key drivers of the heat gain or heat loss towards improving the thermal performance of a building (Zune et al., 2021).

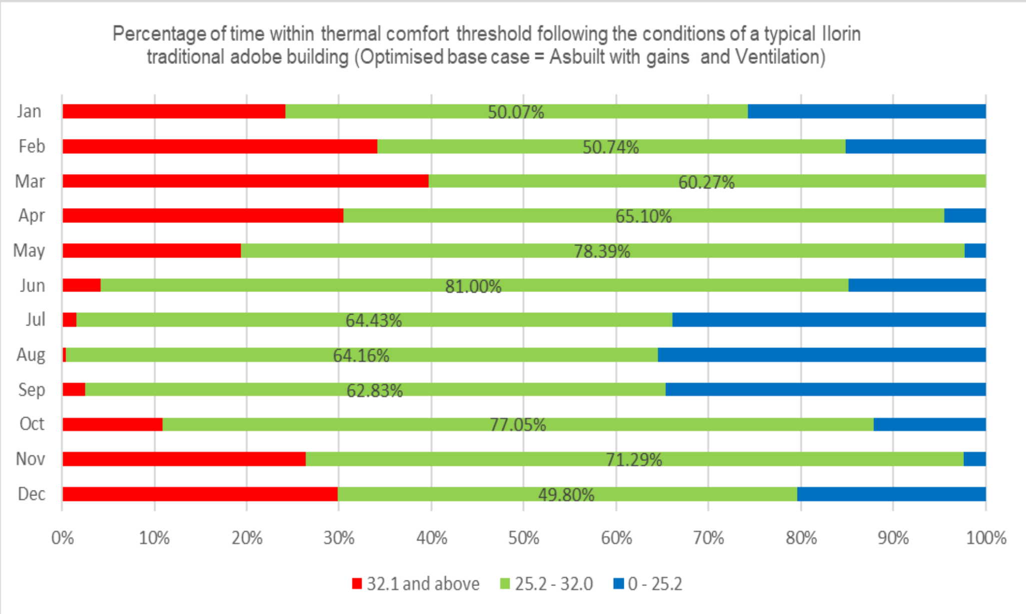

Figure 7-18:: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with gains and natural ventilation.

Ventilation was introduced into this set of simulations with the assumption that the windows of the building were permanently opened. This process had a huge effect on the indoor air temperature; it reduced indoor air thermal discomfort by almost half (from 100% to 50%) in warmer months. About 60.27% was the percentage of time achieved within thermal comfort in the hottest month, as seen in Figure 6-18. This validates natural ventilation as a crucial element in achieving effective passive design strategies in Ilorin, as suggested by the climate consultant in Chapter 2. On this basis, the As-built (base case) was considered optimised and adopted as the reference base case for the remaining fabric test simulations.

Table 7-11: Roof Fabric composition and U-value based on IES-VE (2023)

Building element	Material (mm)	U-value (W/m2. K)	R-value (m^2k/w)	Thermal mass (cm)	Weight
Roof	200mm Thatch straw	0.33	2.86	4.3200	Very lightweight
	0.8mm thick Zinc roofing sheet	7.14	0.00	1.0920	Very lightweight
	15mm thick Clay roofing tiles	6.33	0.02	11,4000	Very lightweight

Roof fabric change strategy is one of the most typical housing fabric adaptations found in Ilorin traditional homes, where the roofs have been changed from thatch to zinc roofing sheets as detailed in chapter 4. Based on results analysed in chapter 4, most respondents notably expressed dissatisfaction with the roof of their buildings when asked about how they felt about the overall building quality of their homes indicated that the occupants using the supposed popular new roofing material (Zinc) also faced challenges of overheating as a result, the researcher simulated the impact of zinc roofing sheet and clay roof tiles on the base case model. Clay tiles were chosen due to the material availability at the locality, its thermal properties, durability, and good maintenance features as detailed by (Tile Roofing Institute, 2014).

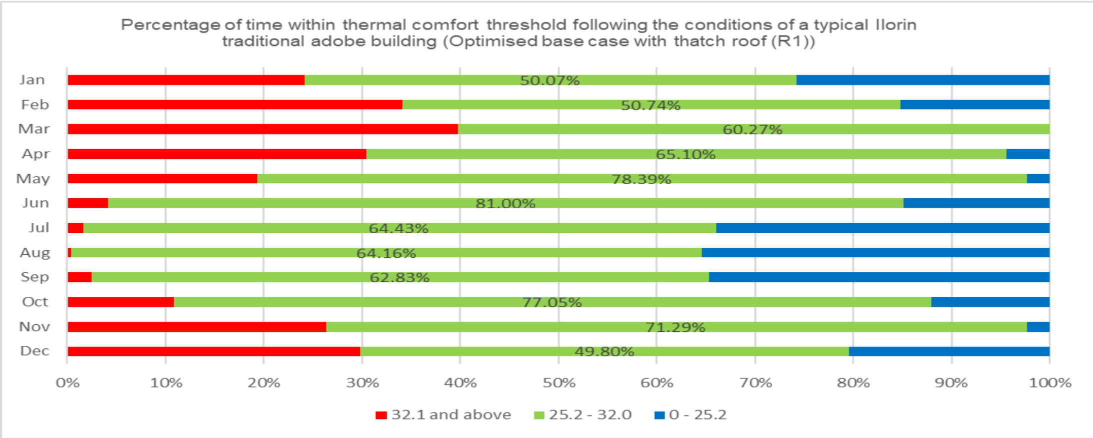

Figure 7-19:The percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with a thatch roof.

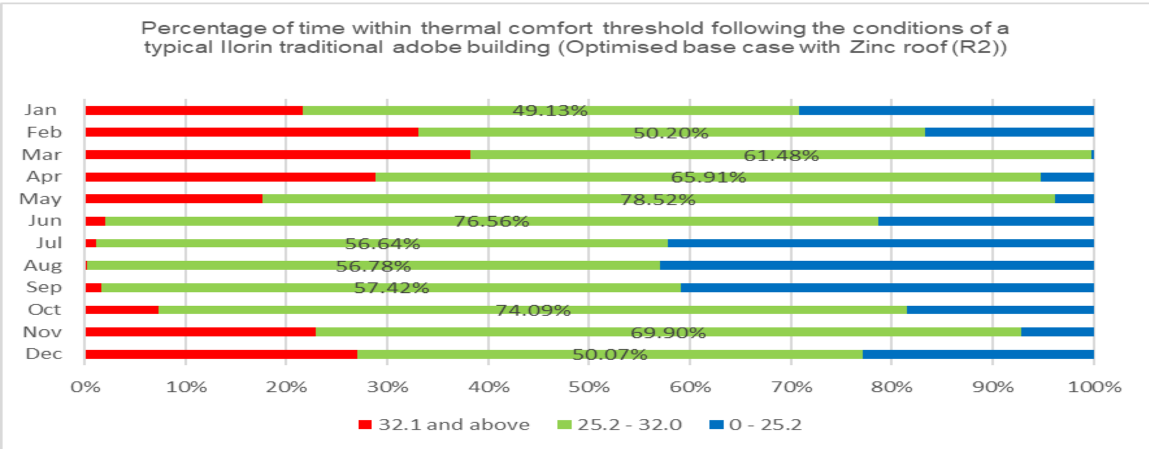

Figure 7-20: For a percentage of the time, conditions were below, within, and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with zinc roofing sheet.

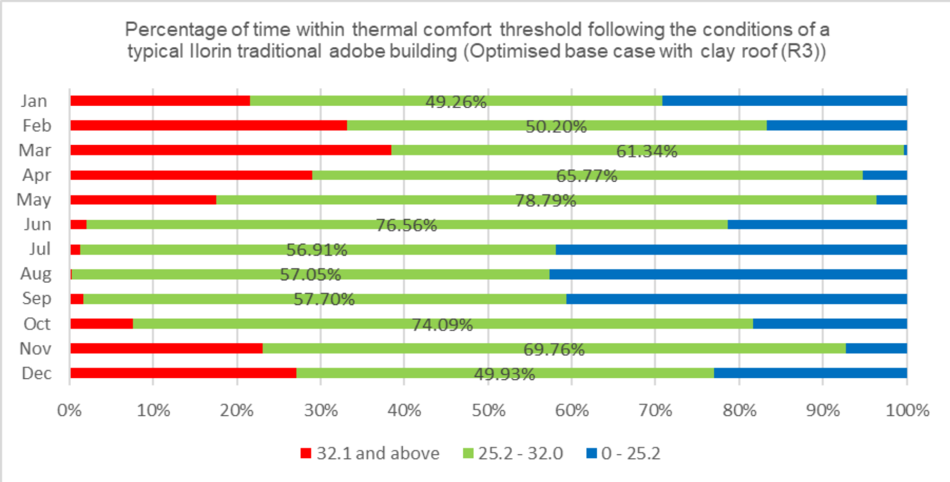

Figure 7-21: For a percentage of the time, conditions were below, within, and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with clay roof.

Figure 7-19 (R1) represents the reference base case that all other simulations will be compared to Figure 7- 20 (R2) and Figure 7- 21 (R3) reveals the impact of 0.8mm thick Zinc roofing sheet and 15mm thick clay roofing tiles as specified by Barry (1999) on indoor air temperature of a typical Ilorin adobe traditional building. It is possible to see that the results were very similar. The result from the zinc roof application showed a steady increase in the percentage of time within the thermal comfort threshold, with 61.5% in March. Comparatively, the impact of clay tiles as a form of roofing provided an increase in the percentage time of thermal comfort limits by 61.3 %. Having both slightly higher than thatch roof by 1%. Based on the results analysed, it can be established that both zinc and clay roofing provide good thermal comfort hours; however, in terms of durability, low heat conductivity from direct solar radiation and material availability (Tile Roofing Institute 2014). It is reasonable to establish that clay tiles will be ideal to represent an optimised Ilorin adobe building in the absence of thatch. Furthermore, Onyenokporo et al. (2018) emphasized the benefits of reducing solar gains in the building through the application of appropriate ceilings. It was established that to provide an effective solution to the roof of Ilorin adobe traditional buildings to curb solar heat gains and heat losses, a suitable type of roof insulation may be needed. As a result of this, ceilings made from materials with low and high conductivity were introduced to the base model to test the impact of insulating properties of the interior of the building against heat loss or gain through radiation and conduction. However, it was expected that the height of the rooms was reduced slightly in the building when the ceiling was applied. This study aimed to significantly complement other occupants' strategies and provide a tested recommendation via simulation results. Furthermore, as observed during the occupant's survey evaluation of the building, the introduction of ceilings is not totally new as arranged bamboo sticks and plywood boards have now been introduced to a few as-built Ilorin adobe traditional buildings as a form of the occupants' strategies in trying to resolve the overheating experience during the warm months due to direct solar radiation hitting on the zinc roof. An array of simulations was carried out altering only the roof types (Zinc and clay tiles) in the first two steps, followed by four different ceiling types, while other building parameters remained the same.

Table 7-12: Ceiling Fabric composition and U-value based on IES-VE (2023)

Building element	Material (mm)	U-value ($W/m^{2}.K$)	R-value (m^2k/w)	Thermal mass (cm)	Weight
Ceiling	12 mm thick plywood board	3.33	0.10	3.8880	Very lightweight
	12mm thick Asbestos board	4.53	0.02	11,400	Very lightweight
	12mm thick PVC panels	3.63	0.08	8,2800	Very lightweight
	60mm thick fibreboard	0.81	1.03	5.2200	Very lightweight

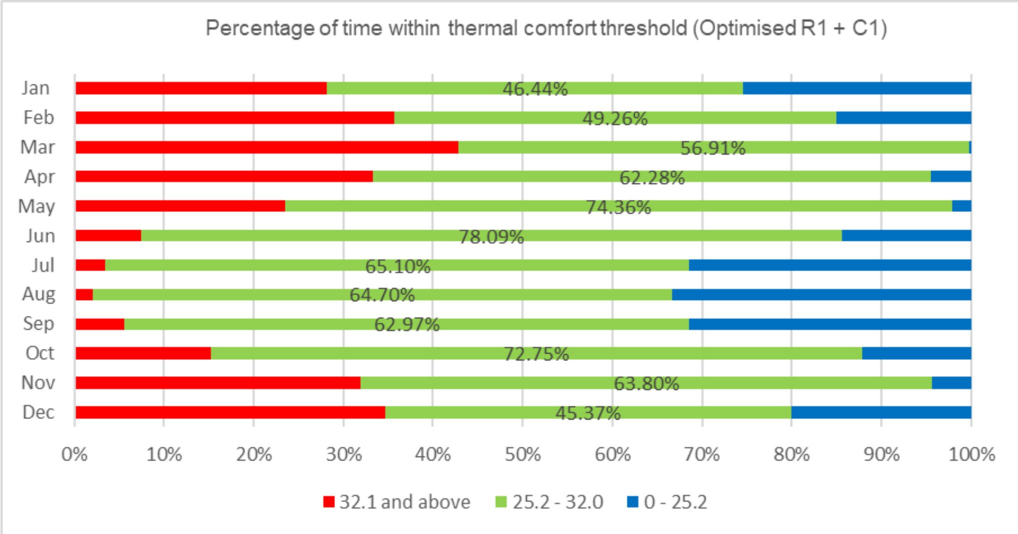

Figure 7-22: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with plywood ceiling.

Figure 7-22 displays the thermal comfort result achieved in a typical Ilorin adobe traditional building when a ceiling made from plywood is introduced. When compared to the base case, the result showed that the application of plywood ceiling boards only decreased the percentage of time within thermal comfort in the building throughout the year. Likewise, in Figure 7-23, results also show a decrease in percentage of time within thermal comfort limits when Asbestos ceiling was applied to the base case. In March, plywood ceiling, Asbestos ceiling and PVC ceiling decreased the percentage time of achieving comfort by 3.3%. This indicates that plywood and Asbestos ceiling were counterproductive in improving the comfort hours in Ilorin traditional buildings.

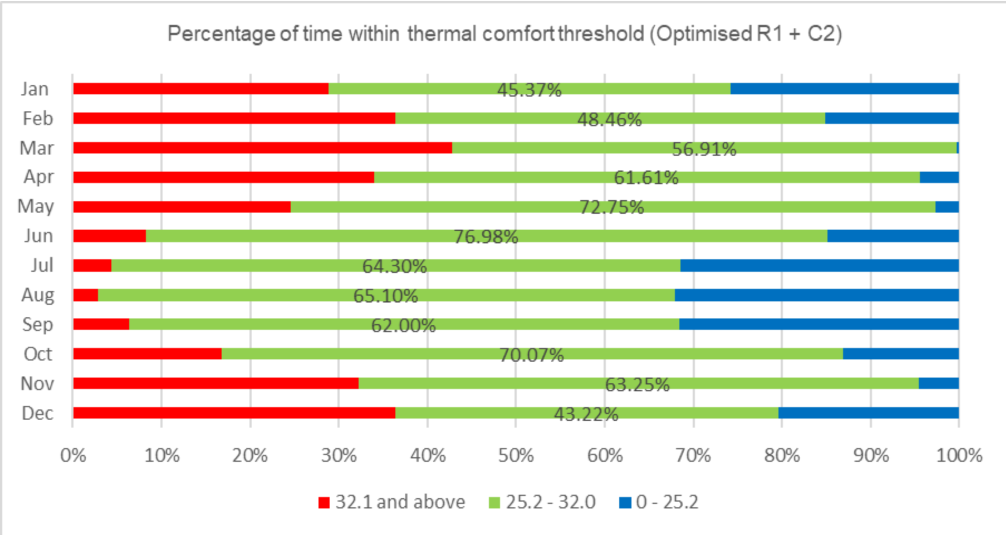

Figure 7-23: The percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with Asbestos ceiling.

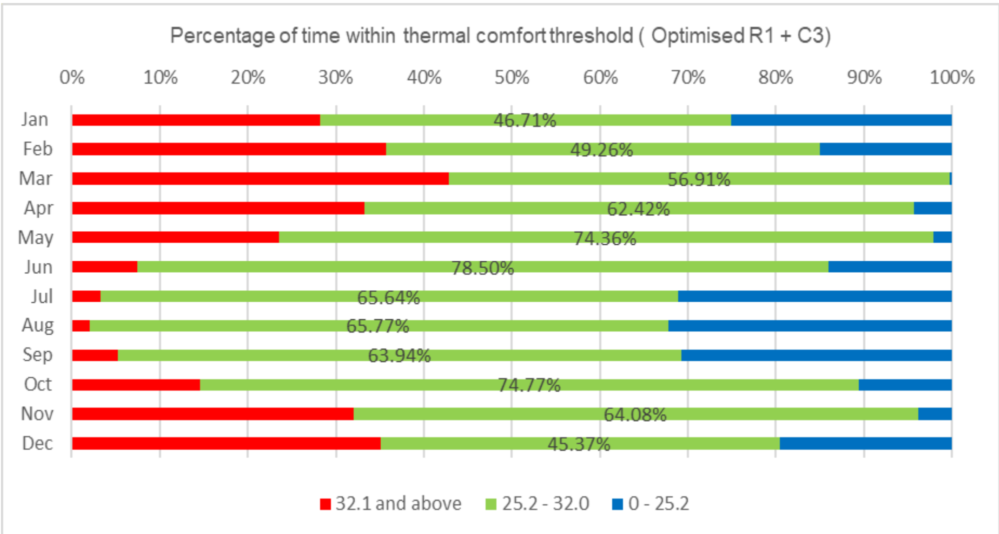

Figure 7-24: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with PVC ceiling.

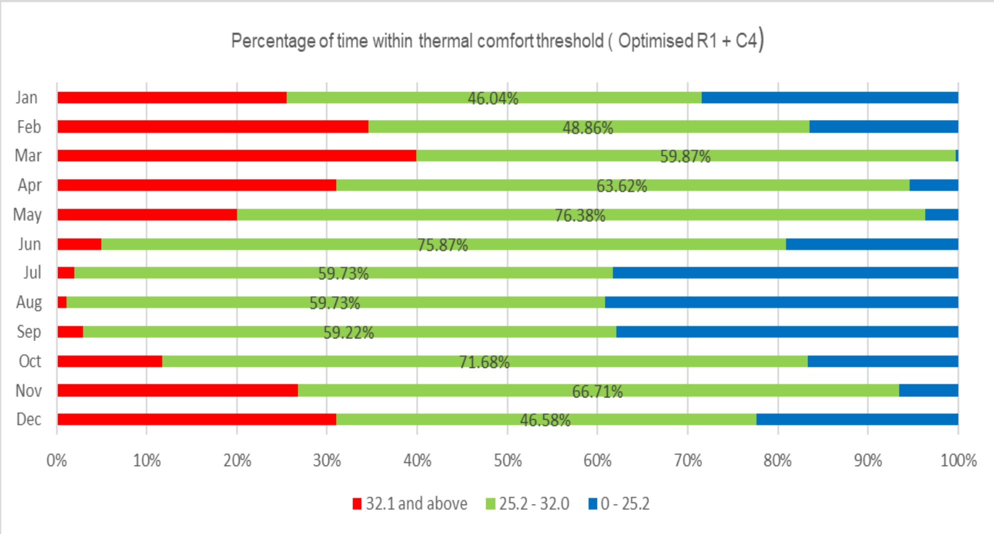

Figure 7-25: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with fiberboard ceiling.

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In Figure 7-25 results show that in the month of March, the percentage of time within thermal comfort hours was about 59.87%; however, overheating experienced was below 40%. while Figure 7- 24 indicates a minimal increase in the percentage of time within the comfort limits by 0.3%, having the percentage of time within comfort limits to be 60.27% and above in other months. Comparing the fibreboard ceiling (C4) to the other three ceilings (C1, C2 and C3), a difference in the percentage of time within comfort limit hours was 3%, which implies that materials with low U-values provide better comfort hours when applied to roofs. Moreover, the data also indicates that when the u-value is reduced, there is a reduction in overheating values, which may be beneficial, especially in hotter regions. Overall, the ceiling made from fibreboard (C4) gave the best results for percentage time within thermal comfort limits.

Walls

Table 7-13: Wall Fabric composition and U-value based on IES-VE (2023)

Building element	Material (mm)	U-value (W/m2. K)	R-value (m^2k/w)	Thermal mass (cm)	Weight
Walls	300mm thick Adobe mixed with straw	0.54	1.67	39.6000	Very lightweight
	300mm thick mud wall with 15 mm cement plaster on both sides	0.64	1.29	73.1760	Very lightweight
	300mm thick compressed earth bricks with 5% Cement	1.70	0.41	203.2500	Medium weight
	300mm thick compressed earth bricks with 5% Cement and 8% Shea meal	1.58	0.46	193.5000	Medium weight

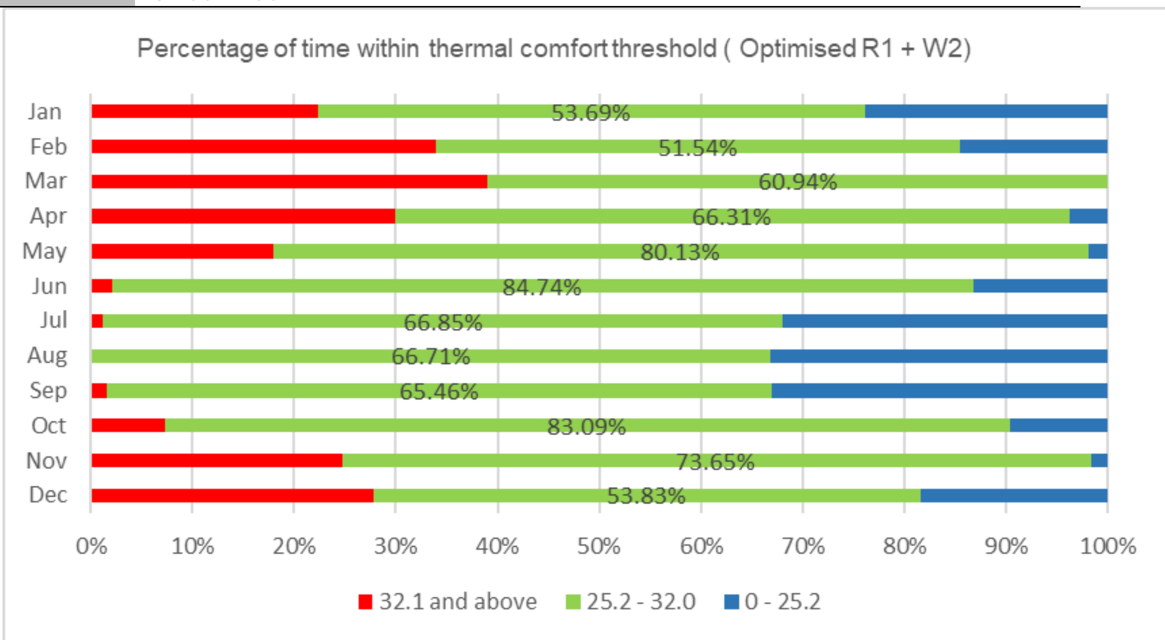

Figure 7-26: Percentage of time conditions were below, within, and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with cement-plastered mud walls.

Figure 7-26 shows the impact of the most common occupant strategy of applying 15 mm plaster cement on each side of the 300mm thick mud walls (W2). When comparing these results to the base case, as displayed in Figure 6-19, it was possible to notice that W2 performed better in the percentage amount of time within the thermal comfort threshold, almost all year round (both cold and warm months) this can be attributed to its embodied larger thermal mass. However, in March, the original base case and W2 delivered the same percentage of time within the thermal comfort threshold of 50.47%. From observations during the Post occupancy study and interview questions answered, it was noted that one of the reasons the Ilorin adobe traditional buildings lacked proper maintenance was because the cement plaster did not bind properly with the mud walls hence, the chipping of the plaster walls usually defaced the building facades. For this reason, the researcher tested the impact of two alternative wall types made from compressed earth bricks on the thermal comfort of Ilorin adobe traditional buildings. These walls were informed through a literature review. W3 – Compressed earth bricks mixed with 5%cement was suggested by Kebail et al. (2017), and W4 – named Compressed earth bricks strengthened by shea butter by Doubi et al. (2017). These two alternatives were chosen for this study based on the availability of the materials around the Ilorin community. See Table 7- 12 for wall compositions.

Figures 7-27 show the impact of compressed earth bricks mixed with 5% cement. It is possible to see that, compared to the base case, as shown in Figure 6-19, overheating was reduced minimally up to 1.07% in March. Making the percentage of time within the thermal comfort limit up to 61.34 % Similarly, Figure 6-28 demonstrates the impact of compressed earth bricks mixed with 5% cement and 8% shea meal on percentage time within thermal comfort limits to be a little effective as overheating was reduced by 0.94% and comfort time achieved was 61.21% in the hottest month. It is important to note that the increasing U-value on the external walls had positive effects on the thermal conditions inside the homes during the months with higher temperatures.

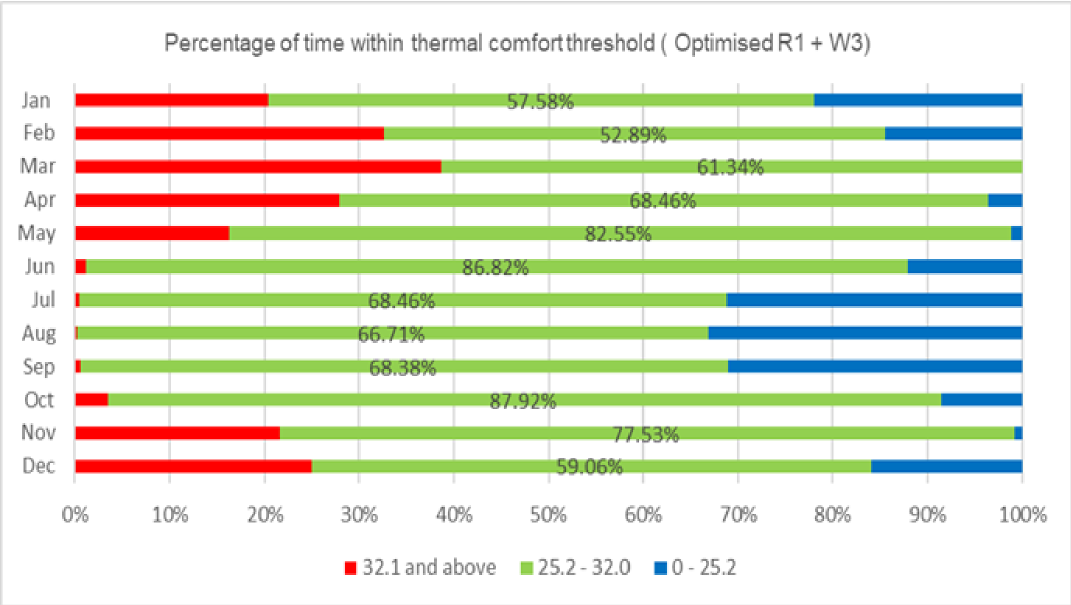

Figure 7-27: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with compressed earth bricks wall mixed with 5% cement.

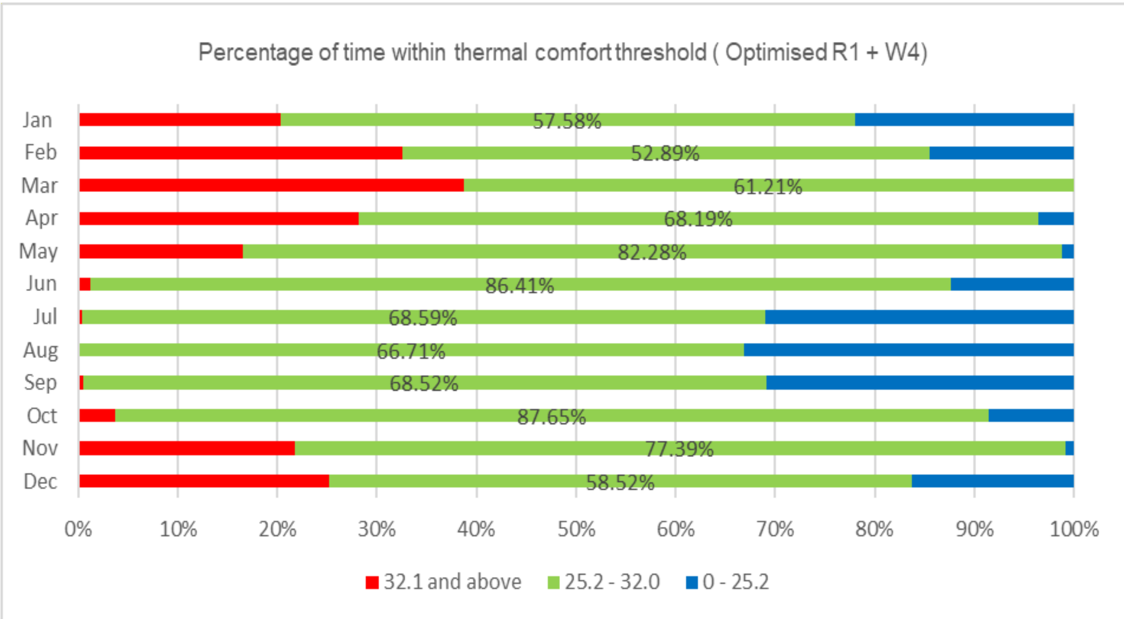

Figure 7-28: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with compressed earth bricks wall mixed with 5% cement and 8% shea meal.

Floors

Table 7-14 : Floor Fabric composition and U-value based on IES-VE (2023)

Building element	Material (mm)	U-value (W/m2. K)	R- value (m^2k/w)	Thermal mass (cm)	Weight
Floor	25mm thick mud floor	3.18	0.10	7.5000	Very lightweight
	15mm thick mud floor plastered with 10mm thick cement	3.49	0.07	16.2840	Very lightweight
	21mm wooden floor	2.54	0.18	8.1893	Very lightweight
	32mm thick Clay tiles	3.76	0.06	15.0124	Very lightweight

Figure 7-29 shows the monthly comfort achieved by including a layer of 10 mm cement plaster. Which is the most common occupant's strategy on flooring preservation in typical Ilorin adobe traditional buildings, in Figure 6-19 it is seen how the resulting comfort compares with the base case. It is seen that comfort hours increased slightly but steadily during the warm months with an increase of up to 0.4% in March and decreased during the cold months. Figure 7- 30 illustrates the result analysing the impact of wooden floors on the indoor thermal conditions of Ilorin traditional adobe building.

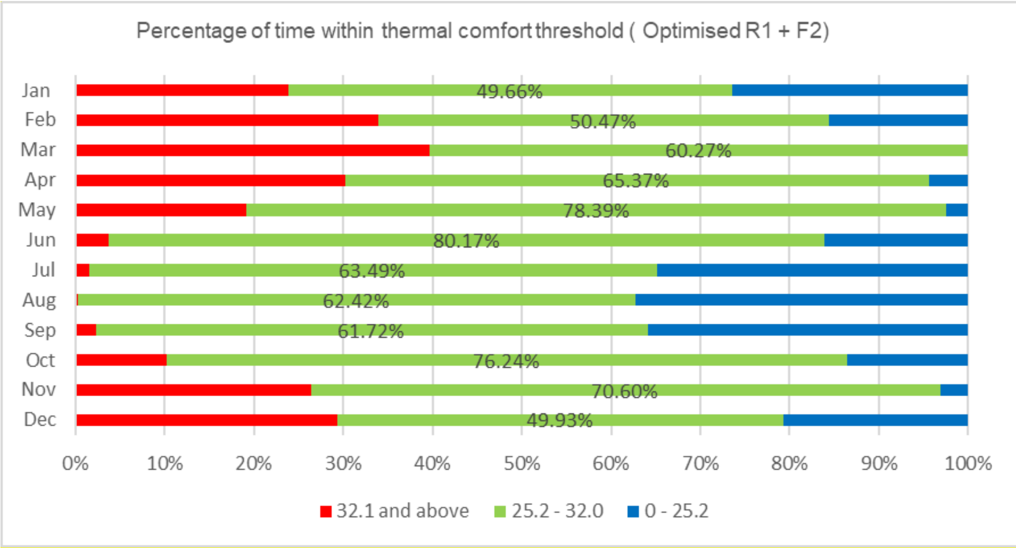

Figure 7-29:Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with cement-plastered mud floor.

Compared to the base case, the comfort percentage time achieved increased throughout the warm months and only decreased slightly from July to September and December. In March, the percentage of time within the thermal comfort limit decreased by 0.4%.

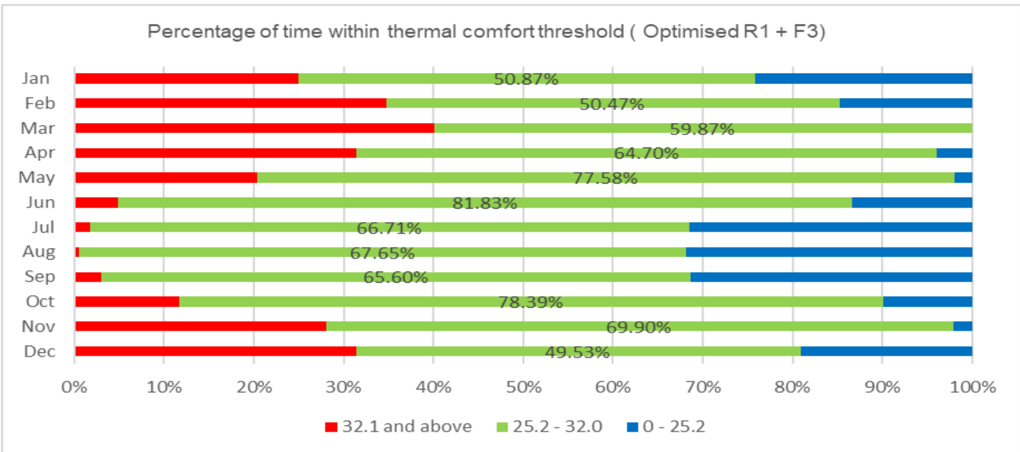

Figure 7-30: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with wooden floors.

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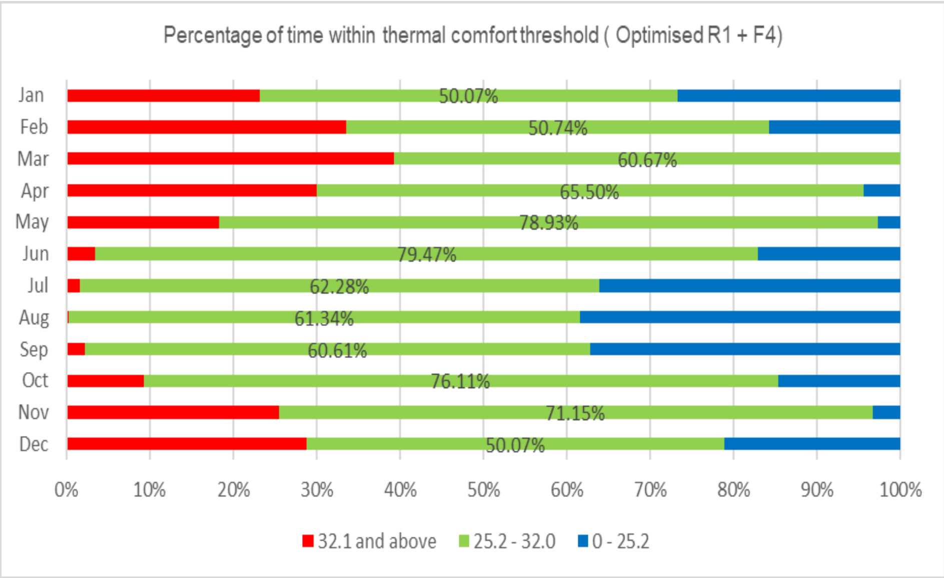

Figure 7-31: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with clay floor tiles.

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Figure 7-31 shows the effect that clay tiles have on the indoor thermal comfort of occupants living in typical Ilorin traditional buildings. Results analysed indicate that during the warm months, indoor thermal comfort decreased progressively until it picked up and increased steadily in the colder months. The slight differences observed from the results of the different floor types can be attributed to their U-values as the fabrics exhibit closely related values.

7.4.3 Potential combination of building components of Ilorin traditional buildings.

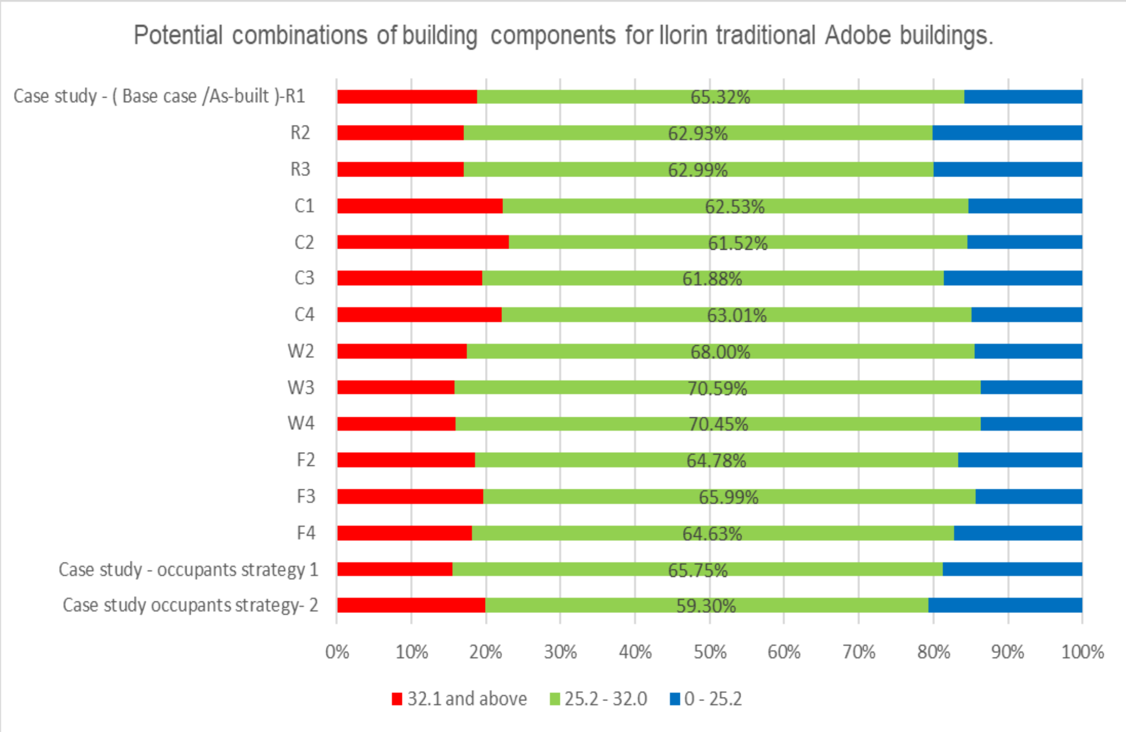


Figure 7-32: Impact of these components on the indoor air comfort temperature hours of the buildings annually.

As shown in Figure 7-32, possible combinations of building components were simulated to investigate the overall impact of these components on the indoor air comfort temperature hours of the buildings annually. Results revealed that from each category, R1, C4, W3 and F3 performed best and provided above 60% comfort hours within the comfort limits annually. However, the occupant's strategy– 2, which is the most adopted occupant's strategy, was the worst with 59%. For this reason, this study proves to be very relevant as novel research to provide guidelines on achieving good thermal performance for Ilorin adobe traditional buildings.

7.4.4 Ventilation results

In this section, three different main simulation models were considered in the proposed ventilation scenarios to observe the impact of ventilation on indoor air conditions. Ventilation scenario -V1 showed how differently operating window schedules - fully closed windows, fully opened windows, and optimized windows affect the temperature of the indoor air temperature within thermal comfort thresholds. Ventilation scenario - V2 explored with different-sized windows to assess how the indoor air temperature within thermal comfort limits was affected by the original size compared to the Optivent-informed window size, and Ventilation scenario - V3 applied varying numbers of windows in order to compare the impact of the original window units to the optivent informed number of window units on the indoor air temperature within thermal comfort limits. In section 6.4.2, natural ventilation was determined as a key factor in enhancing thermal comfort in Ilorin adobe traditional buildings.

V1 - Ventilation types (Operable schedules for windows)

The first sets of simulations for ventilation were carried out considering the as-built shell with the original window sizes and sources of heat gains mentioned earlier in section 6.3.2. The window conditions simulated were: (I) Completely closed windows (0%) (II) Optimised window schedule, and (III) completely opened windows (100% opened). Figure 6-33 shows the thermal effects of ventilation allowed by the original side-hung window included in the house design. It was noted that during the warm season, houses were expected to remain overheated over one-third of the time.

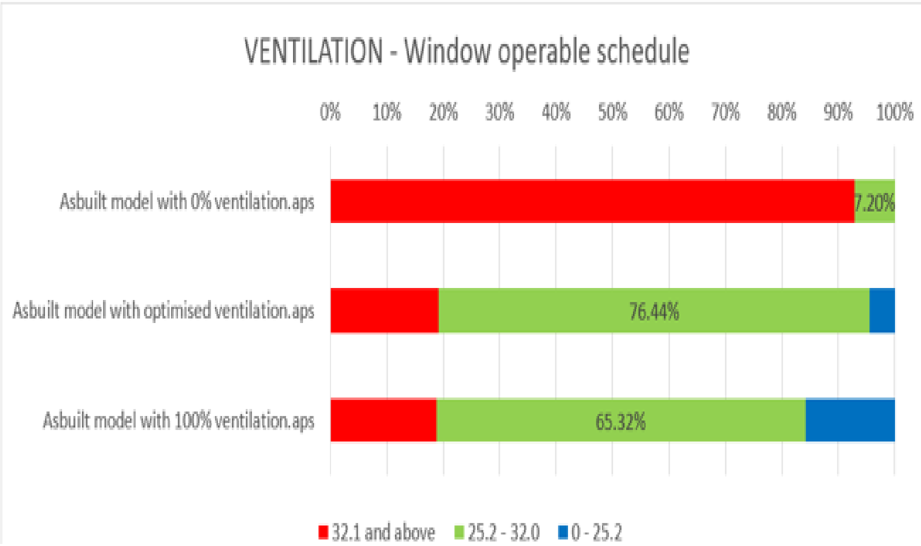


Figure 7-33: Window operable schedules.

The graph shows the percentage of time conditions that were below, within and above thermal comfort bands annually provided by the As-built side-hung windows, and how natural ventilation impacts the air temperature in typical Ilorin adobe buildings. Using an optimized schedule detailed in section 6.3.5, the thermal effects of ventilation allowed by the original side-hung window included in the house design when continuously opened and lastly when continuously closed. Compared results from the continuously closed ventilation to the optimized ventilation schedule present a comfort temperature with a massively significant difference of 40.25% comfort percentage hours in March, where 0% comfort hours was recorded under the condition that the windows were continuously closed and about 60% comfort hours was achieved when the optimised ventilation schedule was employed. More so, when the optimised ventilation schedule was compared to the fully opened ventilation supply, findings indicated more than 50% rise in percentage comfort hours was achieved in the month of April. See details in Figure 6 – 34.

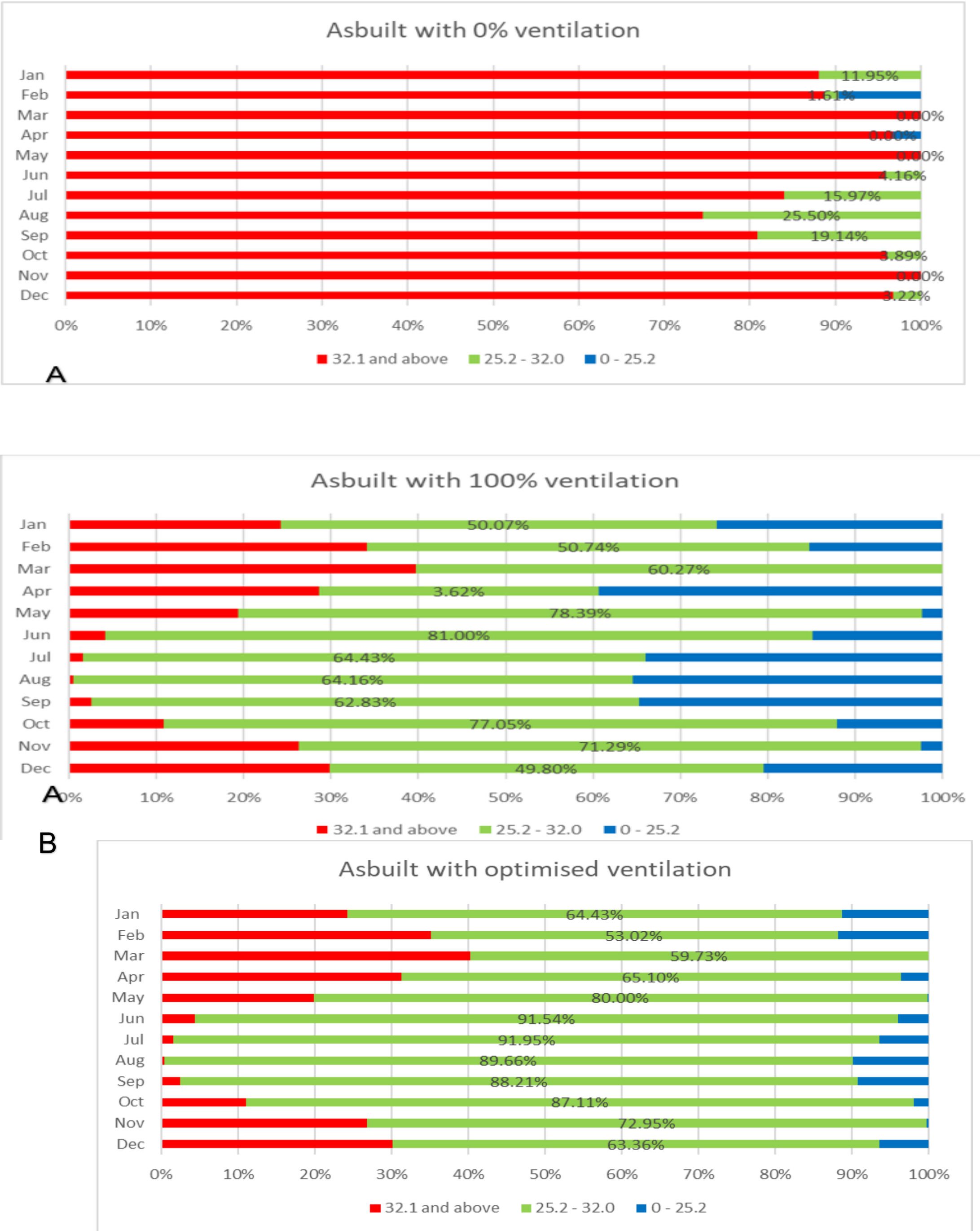


Figure 7-34:(A, B & C)- Percentage of time conditions were below, within and above thermal comfort bands with window operable schedules provided by the As-built side-hung windows under 0% ventilation, 100% ventilation and optimized ventilation schedule.

It is possible to note that the optimal schedule provides more percentage time within the thermal comfort limits of Ilorin. However, in March, the optimal schedule experienced a slight decrease in comfort percentage time due to overheating. Research suggests that it is challenging to attain ideal percentage hours in buildings located in warm, humid climates through natural ventilation alone. However, results show a significant improvement compared to the result suggested by Climate Consultant 6.0, which is that it is possible to achieve only about 44% of comfort hours in a typical year. This implies that Ilorin adobe traditional buildings deliver optimal natural ventilation with the aid of a schedule plan that encourages night purging.

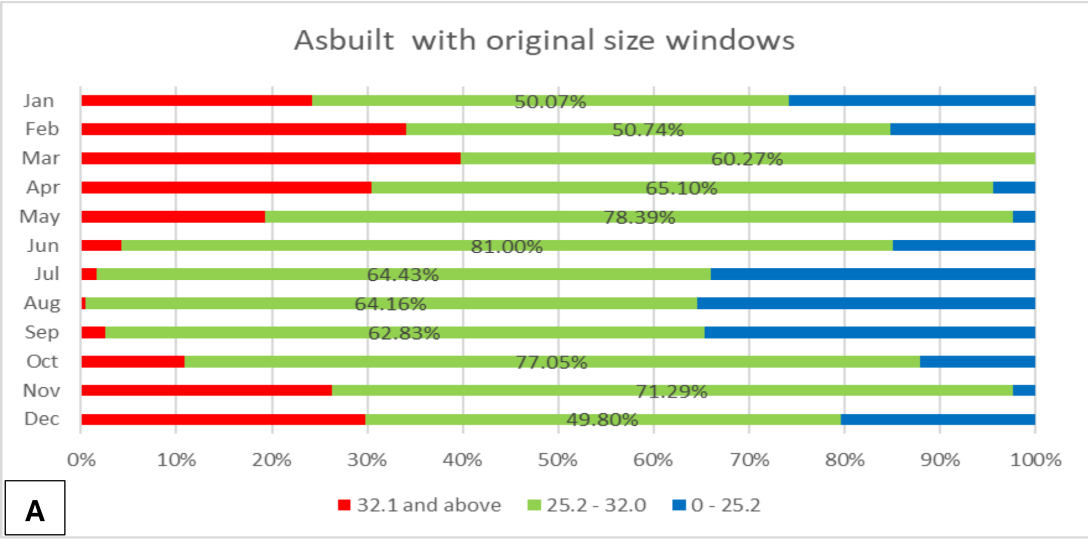
V2 - Window Type Assessment

Window size

The next set of simulations considered the As-built model with two different window sizes. The variations consisted of (I) the as-built size of windows and (II). Larger windows. The window sizes were tested to determine the effect of the original window size and the larger window sizes as previously stated in Chapter 5.

A

B



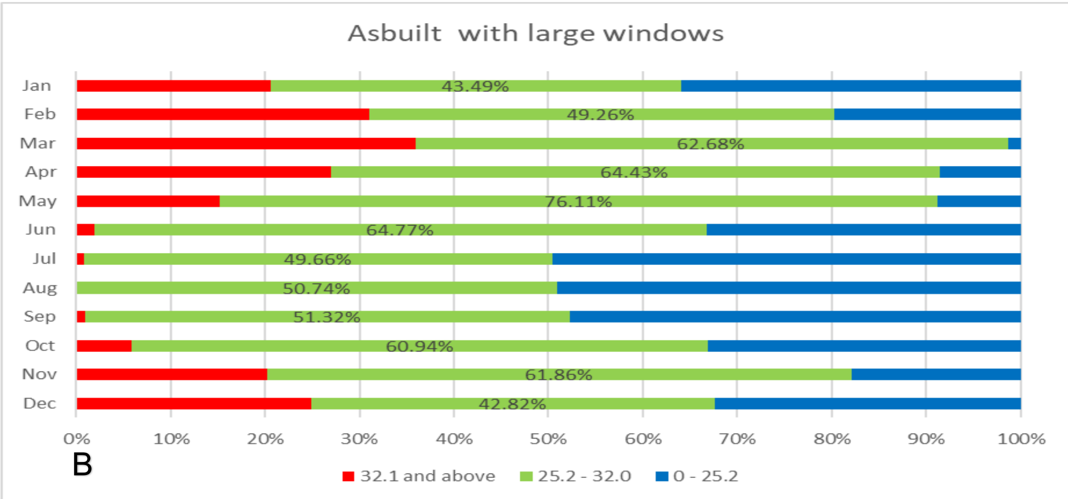


Figure 7-35 : (A & B)-Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with (a) original small-sized windows and (b) larger size windows.

Figure 7-35A Illustrates results of percentage time conditions achieved within thermal comfort limits when the original size windows (600mm *600mm) of Ilorin traditional buildings are permanently opened against the result achieved in Figure 6-35B when the windows are increased in size (1300mm * 1200mm). Results indicated that both sizes achieved slightly similar percentage time conditions within thermal comfort hours in February, March, April, and May, with a variance of about 2% when the months were compared. Overall, the original-sized windows achieved more comfort hours throughout the year, as indicated in Figure 7-36.

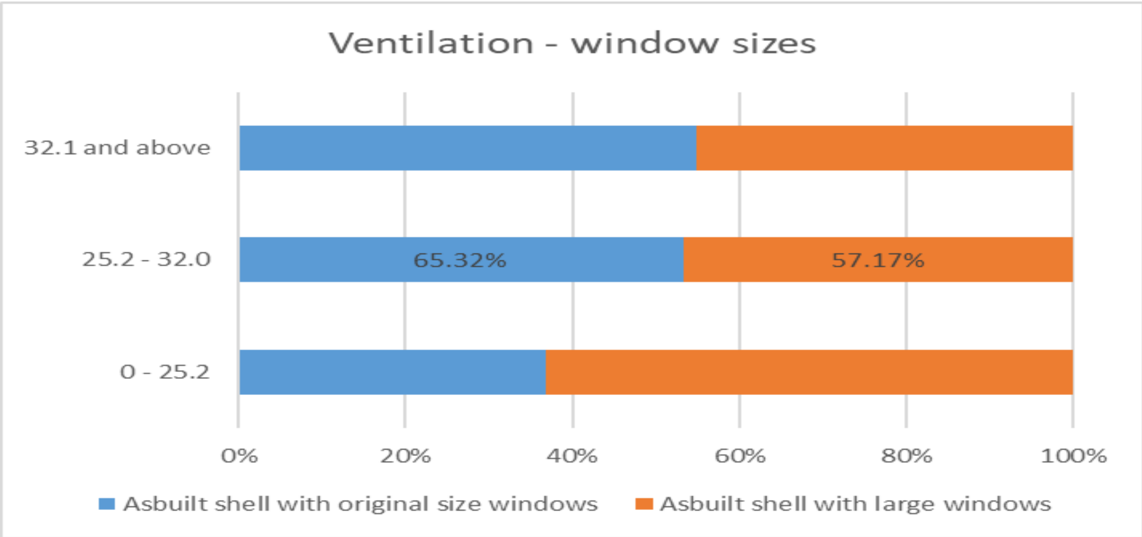


Figure 7-36: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building annually with (a) original small-sized windows and (b) larger size windows.

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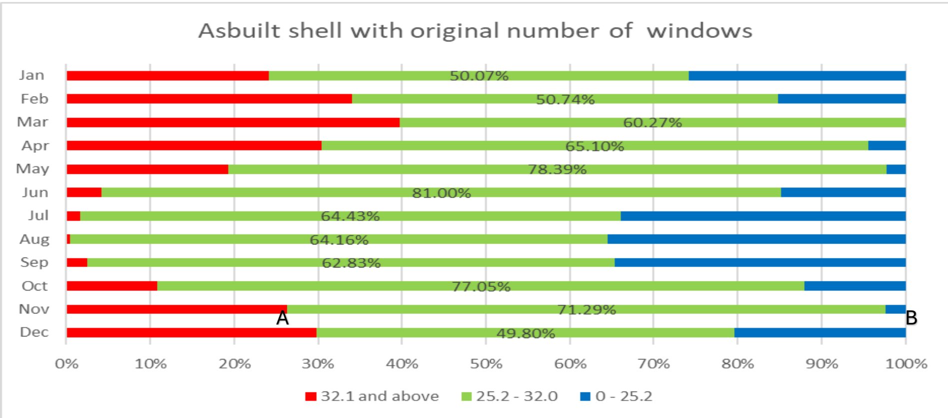
Based on the results, the original-sized windows performed better and can be structurally modified for a minor retrofit. However, for a major retrofit, it is better to use large windows with appropriate shading designs to allow for more airflow into the building.

V3 - Window units

The last set of simulations considered the As-built model with two different numbers of windows while the original window size remained unaltered. The variations consisted of (I) The As built with the two original number of windows (II). The As-built with an increased number of windows. The windows were tested to determine the impact of the original number of windows and an increased number of windows, as previously informed in Chapter 5 (Optivent calculation). See figure 6-37 (A & B)



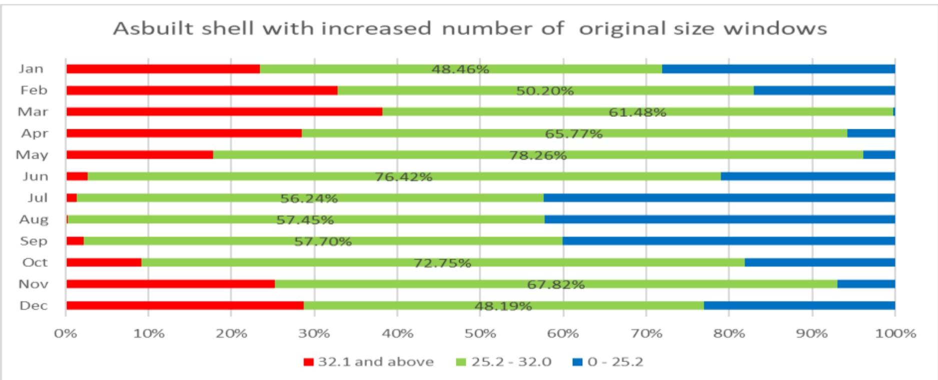


Figure 7-37:(A&B)- Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building with (a) original number (2) of windows (b) increased number (3) of windows.

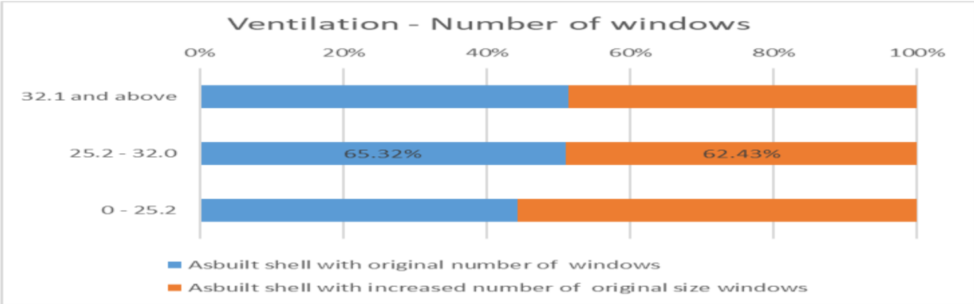


Figure 7-38: Percentage of time conditions were below, within and above thermal comfort bands with building fabrics following the typical Ilorin adobe traditional building annually with (a) original number (2) of windows and (b) Increased number (3) of windows.

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Findings indicated in Figure 6-38 show that the number of windows changed from 2 units to 3 units, with negligible significant differences of less than 5% throughout the year. The original number of windows, as seen on the As-built, performed slightly better than the increased number of units. This can be attributed to the window placement on the facades. The original 2 units were placed on the North façade as built. In contrast, an additional window was placed on the west façade in order to increase the number of window units, and this supports the building design strategies of window placement provided by climate consultant 6.0, which was discussed in detail in section 6.3.6. However, for a major retrofit, it is better to consider window placements and appropriate shading designs in order to achieve effective ventilation in the building.

7.4.5 Shading Design

In this section, shading devices were tested based on the orientation of the building, which was analysed in the earlier sections of this chapter. Solar gains were calculated using Sun Cast and Apache tools in the software IES VE (2023). As represented in Figure 6-39, each shading device was tested with the original envelope's physical characteristics. To showcase the impact of shading devices on the indoor air temperature, the building was first simulated without any shading device to serve as a reference case to compare with different shading devices. Sun altitude angles are shaded, as seen in Figure 7-40.

As seen in Figure 7-41, the shade provided by covering the roof resulted in a constant reduction of overheating in the building throughout the warm months of the year, with increasing thermal comfort percentage hour by 0.54% in March, 2.72% in April and the highest effect in February by 5.06%.

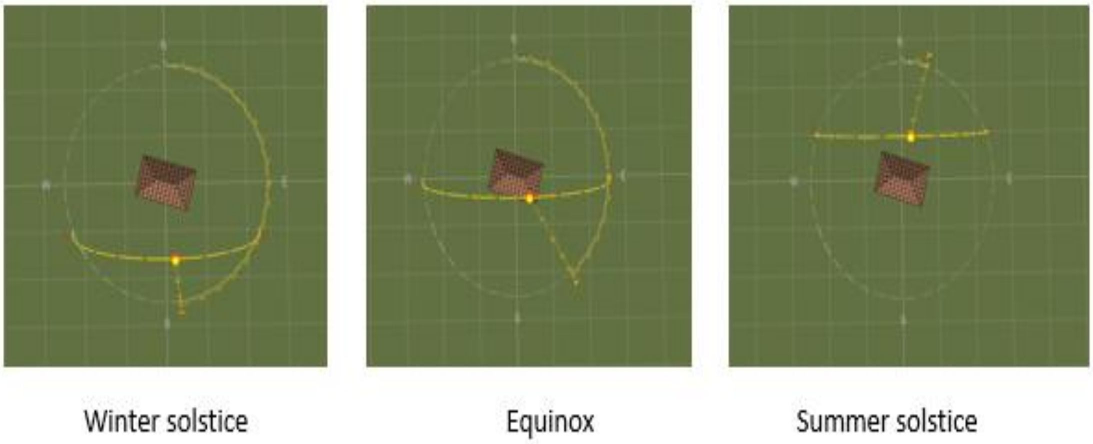

Figure 7-39:Sun Cast diagrams of the original building: Winter Solstice – Cold and wet season (left), Equinox (middle) and summer solstice warm/dry season (right).

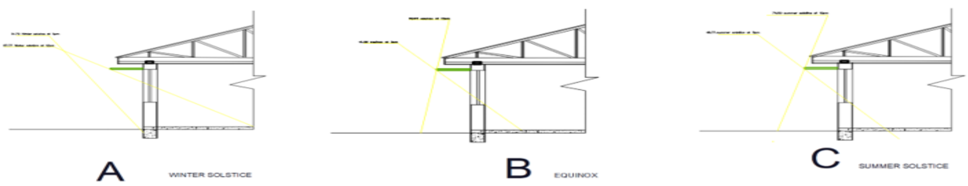

Figure 7-40: Section showing sun altitude angles

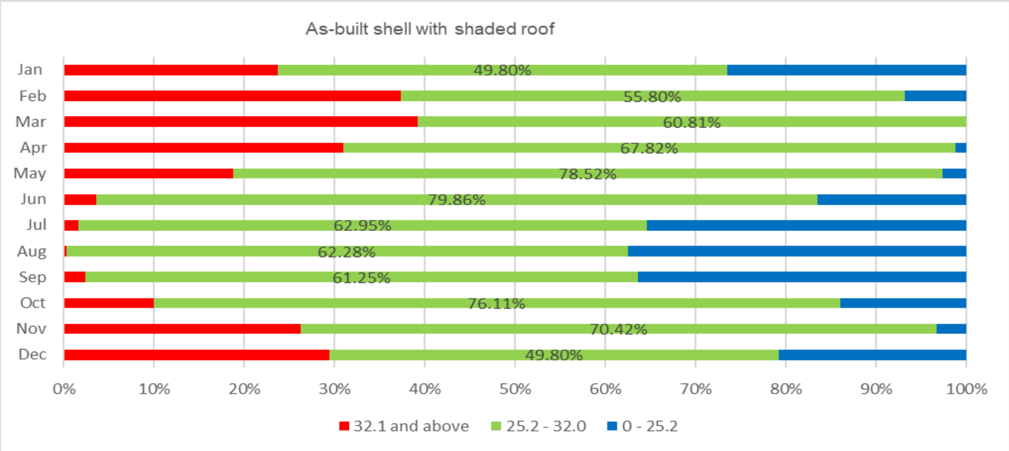

Figure 7-41: Percentage of time conditions were below, within and above thermal comfort bands following the typical Ilorin adobe traditional building with a shaded roof.

Figure 7-42 depicts the thermal comfort results obtained from simulating the impact of a 0.75mm canopy on the building's façade. This canopy size was calculated to shade angles of the sun at 3 pm – 5 pm daily on the North façade. Compared to the base case, it decreased overheating slightly throughout the year, thereby it steadily increased thermal comfort hours during the warm months from January to May. It was moderately more effective than the roof shading.

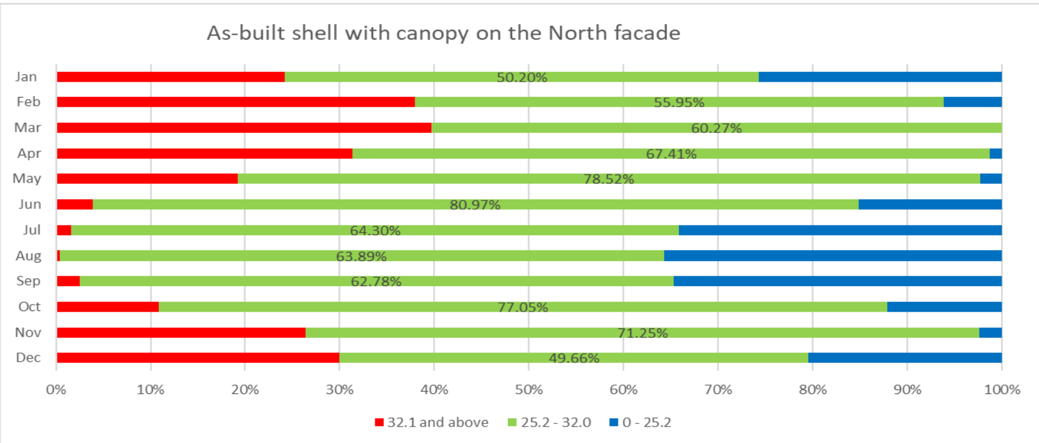

Figure 7-42:Percentage of time conditions were below, within and above thermal comfort bands following the typical Ilorin adobe traditional building with a canopy on the North façade.

Figure 7-43 demonstrates the impact of introducing calculated vertical shading devices (0.40mm) to the existing windows of the building on the indoor air temperature. In comparison with the graph shown in Figure 7-19, the result showed the most evident impact, with an increase in thermal comfort of 5.36% in February and 2.17% in April.

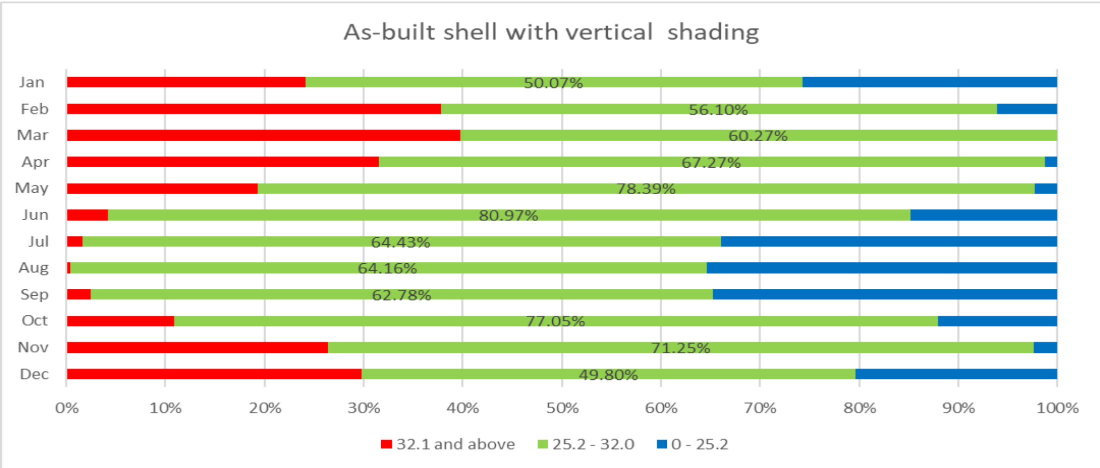

Figure 7-43: Percentage of time conditions were below, within and above thermal comfort bands following the typical Ilorin adobe traditional building with vertical shading.

In Figure 7-44, The effect of shading with trees was tested by simulating trees on each façade to determine the impact of shading on the indoor air temperature when individual facades are shaded.

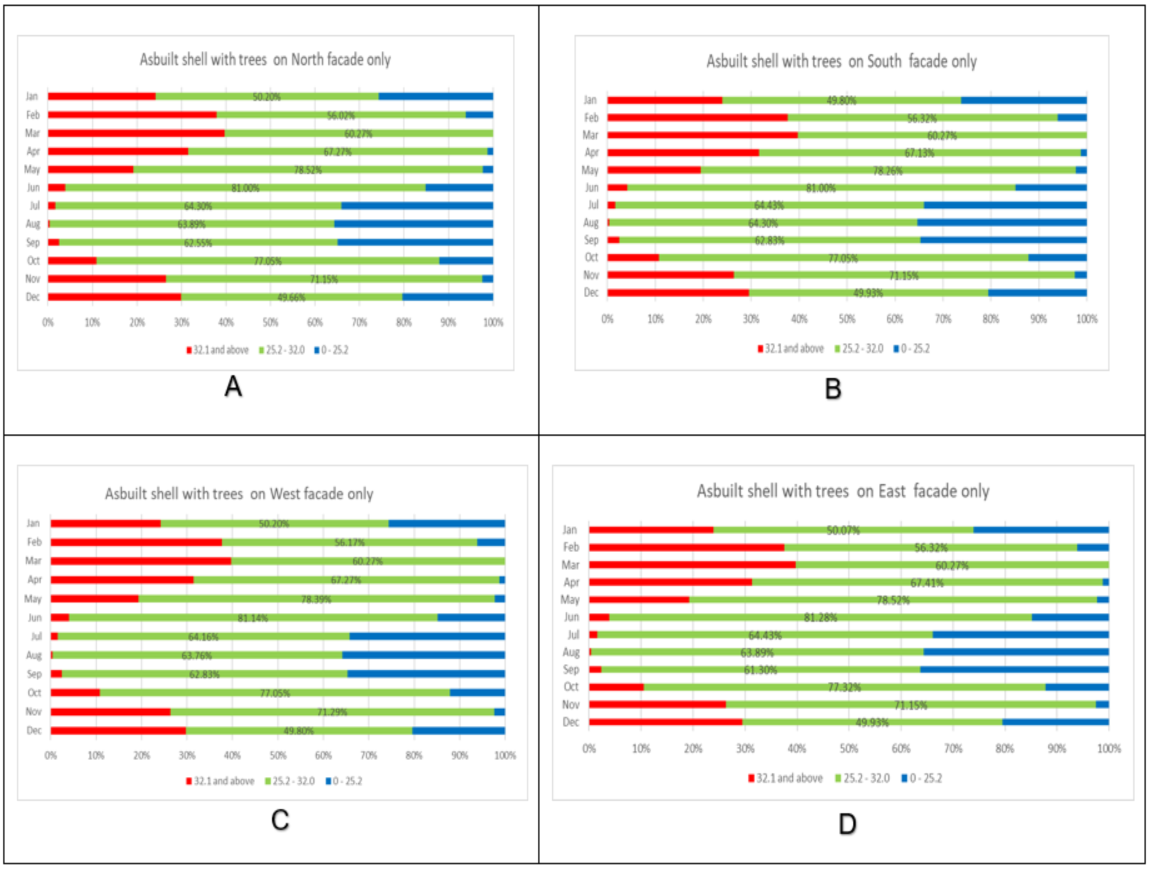

Figure 7-44: (A,B, C &D) : demonstrates shading with plants on the North, South, West, and East façade.

Results show similarities with the base case without shade in the percentage of time conditions within thermal comfort limits. However, the impact of trees as a form of shade did not have a significant impact on the comfort hours except for the Month of February. The effect of using trees as a form of shading annually depicted almost the same percentage of thermal comfort hours, with the East façade having the highest percentage hours of 65.38%, see graph in Figure 7-45.

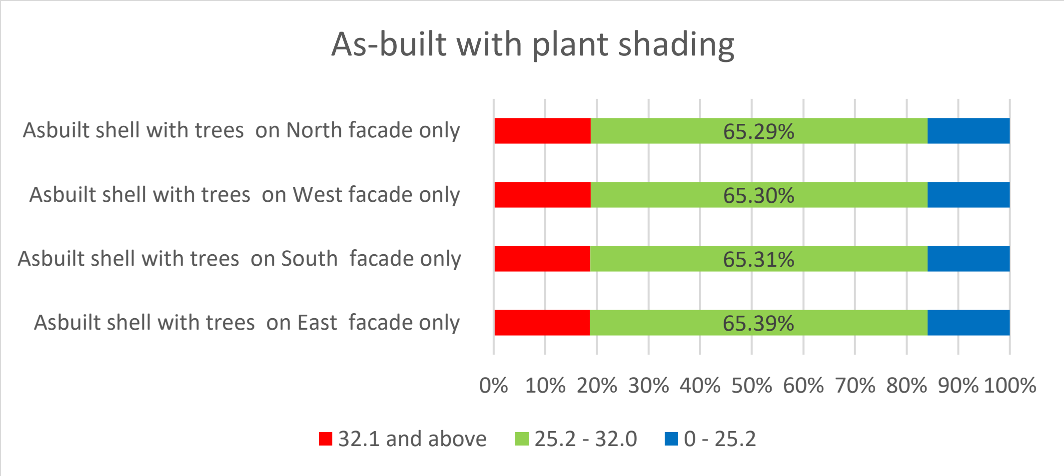

Figure 7-45: Percentage of time conditions were below, within and above thermal comfort bands following the typical Ilorin adobe traditional building with hypothetical trees on the North, South, West and East façade annually.

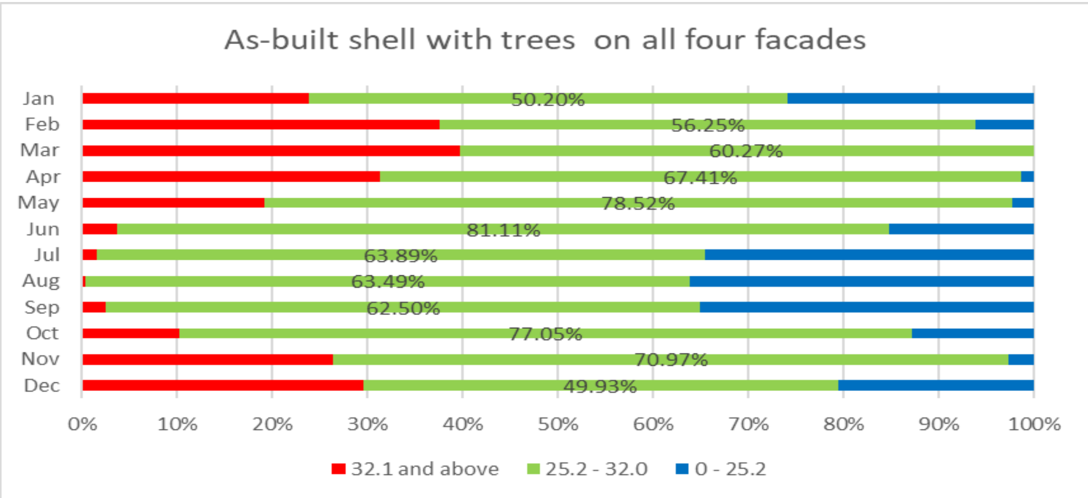

Figure 7-46: Percentage of time conditions were below, within and above thermal comfort bands following the typical Ilorin adobe traditional building with hypothetical trees on all façades of the building.

In addition to this, a combination of trees shading all four façades was tested to determine the effect of this shading type on the percentage comfort hours of the building. However, in Figure 6-46, the addition of trees showed a less noticeable impact, mostly in warmer months, January, February and April, while the percentage of hours within the comfort threshold remained the same in March. Overall, out of all the above-tested shading devices, the roof shading, horizontal shading (canopy) and the vertical shading demonstrated the most impact on the building by increasing the thermal comfort percentage. Furthermore, for an improved building, a combination of the shading devices was considered.

Combination of shading devices

The last set of simulations for shading was carried out by combining one or more shading forms previously simulated in order to achieve the best shading combination to form the optimized home. In this section, results are presented from simulations where shading parameters could be combined and tested to establish the best resulting conditions to enhance percentage hours within the thermal comfort threshold.

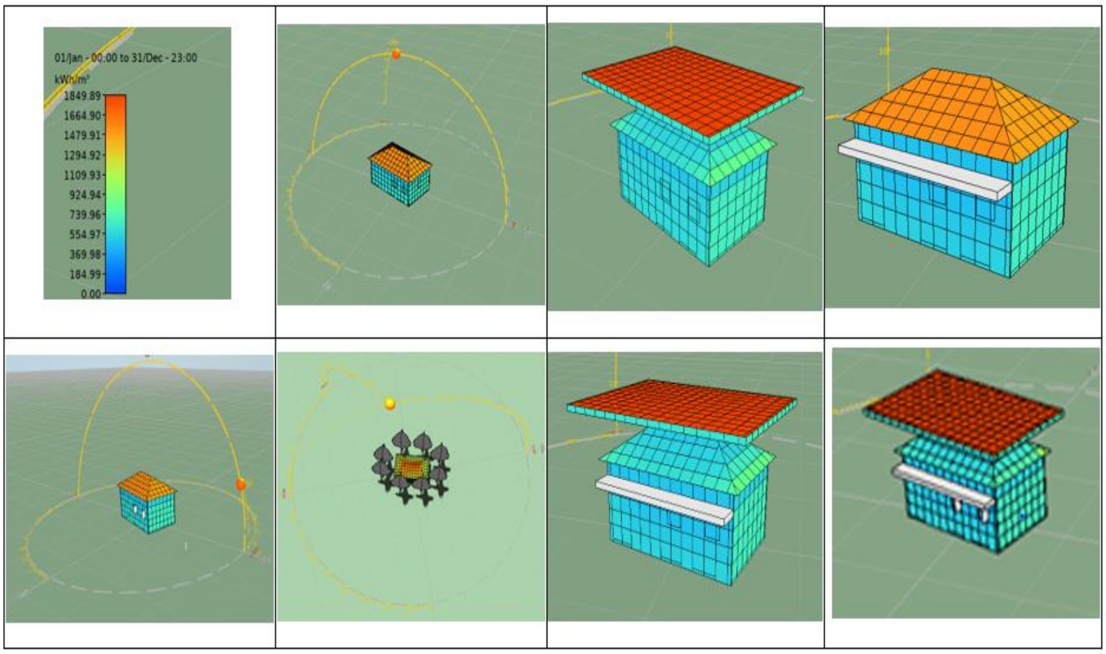

Figure 7-47:Sun Cast diagrams of the original building showing the applied shading devices.

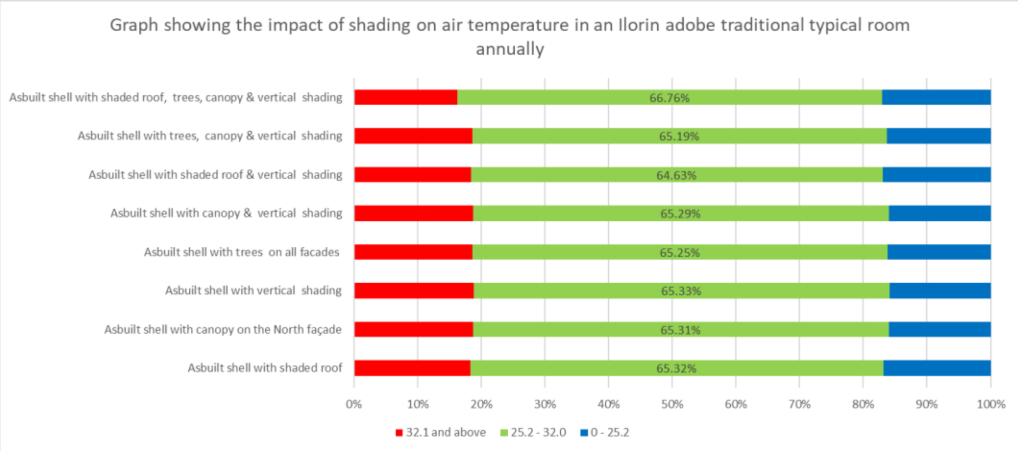

Figure 7-48:Chart showing the impact of shading on indoor air temperature in an Ilorin traditional building.

Results derived from the shading analysis determined the roof as the most exposed surface area of the building. All the tested shading devices showed improvements in decreasing overheating in the indoor temperature and increasing the percentage of hours within the determined thermal comfort threshold. The vertical shading device, the shaded roof and the canopy produced the most favourable effect on the percentage of comfort hours. However, to create an optimised adobe Ilorin traditional building, the combination of the shaded roof, trees, canopy and vertical shading will be ideal as results show a significant increase in the percentage of time within the comfort threshold of 67%.

7.5 Conclusions

This chapter investigated the application of a fabric-first approach, ventilation methods, and shading device designs in Ilorin for selected thermal simulations to provide an insight into the thermal performance assessment and the improvement of a naturally ventilated single-detached typical Ilorin adobe traditional room located in the warm-humid region of Nigeria. The research question of this chapter was addressed through a parametric simulation study, which was executed an validated using empirical data. The factor that had the greatest impact on thermal comfort in Ilorin traditional adobe buildings was ventilation, which showed the ability to reduce overheating from 100% to 39%, thereby enhancing the percentage hours of thermal comfort from 0% to 60% and above. This can also be attributed to a combination of Ilorin-inspired passive cooling design strategies in response to local climate, such as the presence of courtyards, the small window sizes, window operable schedule, and window position on the least exposed façade surface to direct solar radiation. Response to the research question (RQ2): The characteristics of a typical Ilorin traditional adobe building envelope at its original state deliver and maintain good thermal performance of above 65% comfort hours yearly. Several architectural elements are used in Ilorin adobe traditional buildings to naturally maintain thermal comfort, reducing the need for mechanical cooling devices. The use of naturally insulated elements such as thatch roofs and significant thermal mass is provided by thick adobe walls, thereby stabilizing the indoor air temperature. The well-placed small wooden side-hung windows provide ventilation without giving access to excessive heat in the building; the orientation and window-to-wall ratio of Ilorin adobe traditional buildings influence the indoor air temperature experienced by its occupants. Nevertheless, it was observed that window orientation had a greater effect than the orientation of the building surface. Proper orientation of the building minimizes solar gains, and a micro-climate that is cooler than the surrounding area is produced by central courtyards and corridors are kept cool with the use of shading elements such as minimal roof overhangs and lastly, the light-coloured building walls reflect sunlight and absorbs less heat.

In addition, it was observed that the building components could be improved by introducing

i. Roof fabrics (thatch) of low U-value, which was used as the traditional roof, provided good insulation (Madhumathi et al., 2014). Similarly, clay roofing tiles, which are also fantastic insulators, can be used to enhance the thermal performance of Ilorin traditional adobe buildings in the absence of thatch.
ii. Ceiling fabrics made from materials with low or slightly lower u-value materials, such as fibreboard, help to keep the space cooler by curbing the penetration of direct solar into the building.
iii. The thick adobe wall fabric of Ilorin traditional buildings provides substantial thermal mass, which contributes to the maintenance of a constant indoor temperature by absorbing heat during the day and releasing it at night (Dutu and Mocanescu, 2022). Findings suggest materials with high u-values and significant thermal mass, such as compressed earth bricks with a thickness of not less than 300mm, could improve the thermal performance and longevity of the building.
iv. Floor fabrics of Ilorin traditional buildings exhibited the statement “the lower the U-value, the better”, as materials such as wood made from low U-value materials provided a better percentage of time within thermal comfort limits.
v. Shading devices such as canopies, vertical shading, shaded roofs, and planting of trees can shade building surfaces and reduce solar gains during the hottest parts of the day.

Overall, utilizing the thermal mass effect, natural environmental conditions, passive cooling, and the above-mentioned integrated design principles to support and improve a typical Ilorin traditional adobe building will not only preserve the building but could also produce a thermally optimized building. This chapter establishes customized information to improve and achieve better thermal performance outcomes in Ilorin traditional adobe buildings without the application of mechanical cooling aids, it was ultimately imperative to combine the most significant influencing components. Full details of an optimized Ilorin traditional building is examined in the next chapter.

Chapter 8: Optimization, Cost and Applicability

This chapter seeks to determine the practicality and affordability of optimised traditional adobe buildings in Ilorin, focusing on delivering thermal comfort, performance, and durability through the building fabric maintenance framework for the occupants of Ilorin's traditional heritage. The aim is to study the impact of changes in fabric materials to achieve cost-effective results for the case study building. The purpose of this section is centred on maintenance and affordability as factors that must be considered relevant to sustaining the critical heritage housing infrastructure. Ilorin heritage buildings should be affordable and comfortable for its occupants. However, since the occupants of these residential buildings are low-income earners, the aim is to provide thermal comfort with minimum passive design provision, process, and conditions for occupants of Ilorin traditional buildings.

8.1 Approach and Scope

The approach concentrated on targeting vulnerable Ilorin adobe residential buildings, prone to dilapidation and overheating, which require maintenance for sustainability. The best results from each section of simulated options in Chapter 6 were selected. Key building envelope parameters investigated included materials, fenestration, and shading devices combined to enhance and optimize the passive aspects of the building envelope, using computer-aided simulations to conduct a sensitivity analysis. Following the parametric analysis, a cost-effectiveness evaluation was carried out to compare the potential cost savings and improved efficiency of adobe traditional building construction compared to both as-built traditional buildings and conventional modern buildings. This stage involved using a bill of quantities and a work order form for an effective cost analysis. Lastly, a key informant interview was conducted to gauge the acceptability and adaptability of the improved and optimized Adobe traditional building model in local communities. This information will assist local governments in making more informed decisions when planning housing policies in Nigeria.

8.2 Method

The cost-benefit analysis was established through a bill of quantities to compare the cost between the as-built traditional buildings with improved buildings: and modern buildings with optimised traditional buildings. The process was achieved by selecting a typical room in a case study building unit considering fabric improvement analysed in Chapter 6 to compare it with the representative cost benefit using two methods: (i) cost-effectiveness analysis and (ii) fabric cost improvement. For the base case selected room, a bill of quantities (BOQ) of the cost was calculated, including the constant features such as (i) preliminary work, (ii) foundations, and (iii) superstructure. Afterwards, for the base case, a cost schedule was realized from the BOQ that shows the percentage against the as-built building cost, improved traditional building cost and modern building cost. The costs presented in this chapter were in Naira but can be converted to Pounds (£). At the time of writing, £1 was equivalent to 1950.00 Nigerian Naira (₦). The results are shown in monetary values and as a percentage increase, regardless of price fluctuations over the years. The analysis considered building envelope adaptations discussed in Chapter 6, including building fabrics, orientation, window elements, and shading elements. The economic assessment of different room cases followed the evaluation of comfort provision and performance improvement. The percentage cost differences and increases can help guide affordability, sustainability, and applicability for households and the community.

The second analysis was the applicability of the improved case, where the cost increase of each case was differentiated into a potential framework for maintenance. Each building item of preliminary works, foundation, and superstructure was itemized, and costs were developed as expenses. Subsequently, the affordable scenarios of costs were compared in each of the 3 changes made considering the local price of building materials for the household. Lastly, to validate the proposed building improvement, a semi-structured interview was conducted with key informants (household owners) to gather information on the level of acceptability of the proposed improved model of traditional buildings with local materials.

8.3 Optimal techniques combined

8.3.1 Data collection

In the building fabrics section, it was observed that higher U-values reduced cooling but had an adverse impact on overheating. As a result, the optimised building fabrics retained the original characteristics of traditional Ilorin houses while incorporating adaptations to building elements. According to Chapter 6, the best-performing building elements are as follows: the optimal roof type was identified as the thatch roof, the preferred ceiling type was made from fibreboard, and the best/ top walling material was 300mm compressed earth bricks. However, the second-best walling fabric (300mm compressed earth bricks with a mixture of 5% cement and 8% shea-meal) Doubi, et al. (2017), was adopted for the optimised building because of its better strength and durability, and the ideal flooring material was 25mm wooden floor. The ventilation analysis determined that the optimised window schedule was the most effective for V1. Regarding V2 window sizes, it was found that the two simulated window sizes performed similarly. Still, the original As-built window size performed the best, so it was adopted in this section. As for V3, it was found that the original unit number of the side-hung windows was the most suitable type to enhance ventilation, and the larger size also had a positive impact on comfort.

During the shading analysis, it was determined that the roof was the most exposed surface. All tested shading devices demonstrated an improvement in reducing indoor overheating. Furthermore, the special roof shading, canopy, and vertical fins for this house had a beneficial effect on lowering overheating, despite being smaller in size, as they blocked direct solar radiation to the interior. Ventilation was the most influential factor in cooling down the building, and the current orientation did not allow for an East or West window. For that reason, the selected parameters for the optimised building simulations were:

Building fabric

a. Roof- Thatch
b. Ceiling – fibreboard
c. Wall – Compressed earth bricks
d. Floor – Wooden floor

Ventilation

e. Type – Side hung windows
f. Opening schedule – Optimised window opening schedule
g. Size – original Ilorin traditional building window sizes (600 * 600)
h. Number of units: original number of units (2 units)

Shading

i. Roof: General shading
j. North window: Integrated vertical fins and canopy
k. West window: Planting and canopy
l. South and West façades: General planting

8.3.2 Building Optimisation Process

In this section, four models of the buildings: As-built, improved and optimised traditional buildings with thatch roofs (alternative 1), improved and optimised building models with clay roofing tiles (alternative 2) and a typical modern building were subjected to simulation to determine their thermal performance. The analysis in Figure 8-1 indicates that when the As built was simulated for thermal performance during the overheating month of March, it scored 40.08%. Despite this adobe housing being in its most basic form, its performance requires enhancement when compared to other upgraded/optimised models.

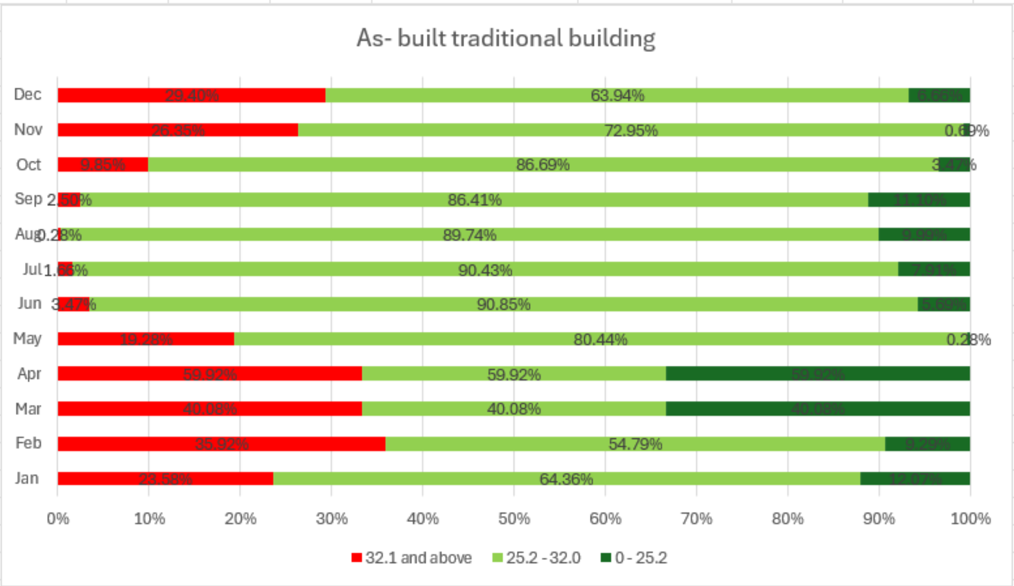

Figure 8-1:Thermal performance evaluation of As-built model.

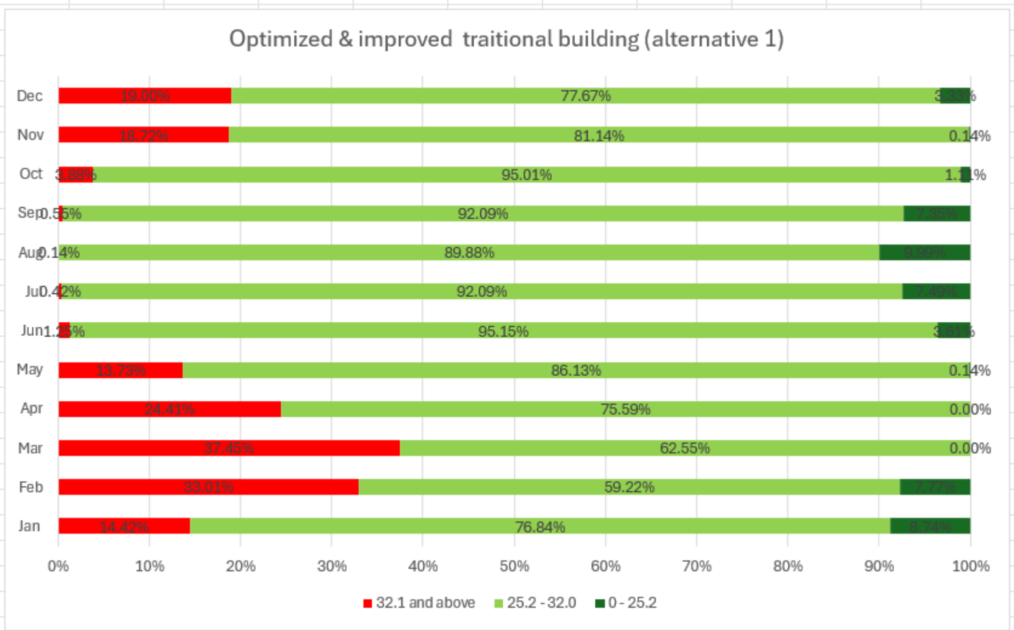

Figure 8-2: Thermal performance evaluation of optimized and improved traditional building with a thatch roof.

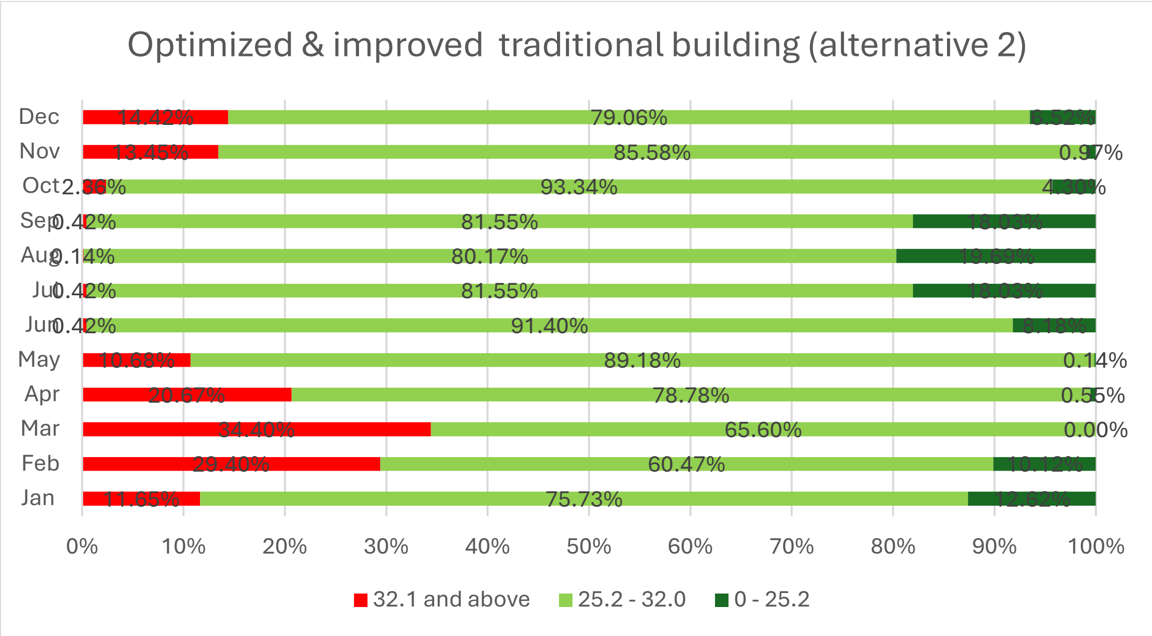

Figure 8-3: Thermal performance evaluation of optimised and improved traditional buildings with clay roofing tiles.

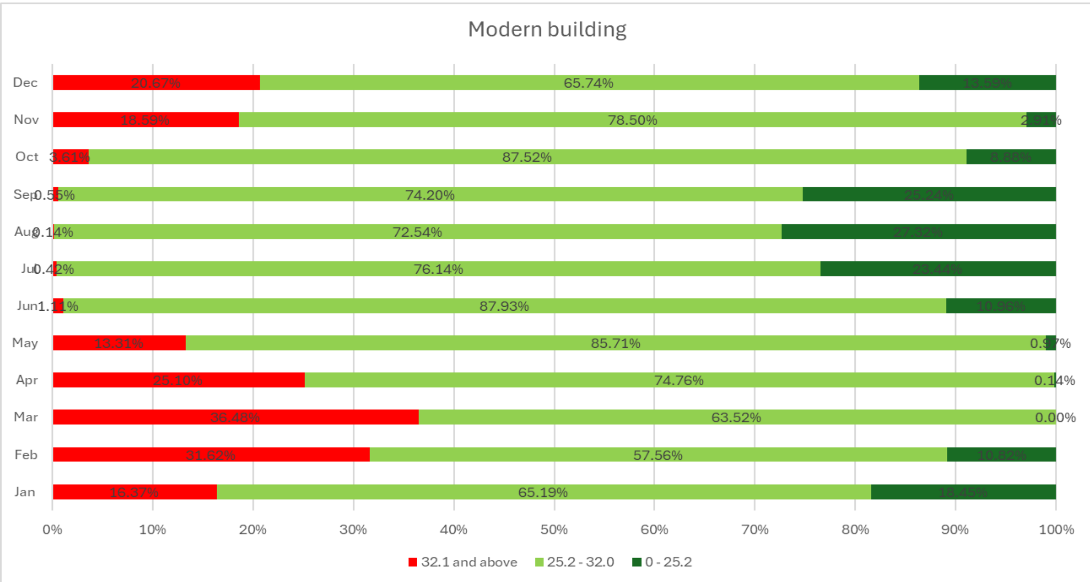

Figure 8-4: Thermal performance evaluation of a typical modern building.

The thermal performance simulation results are as follows: Figure 8-2 illustrates the performance of an optimized traditional building with a thatch roof at 62.55% during the overheating month. Figure 8-3 indicates a thermal performance result of 65.60%, while Figure 8-4 shows the performance of a modern building at 63%. Annually, optimization and retrofitting changes result in 65.6% performance improvement for traditional buildings with clay roofing tiles. However, thatch roof-optimized buildings show a 62.55% performance increase. Judging from the overall performance in the hierarchy, the improved clay roofing tiles building had the best performance (25.5%), followed by the thatch roof improved building (22.47%), showing a thermal performance difference compared to the As-built.

8.3.3 Economic value of optimised building strategy (Affordability)

8.3.3.1 Cost Analysis

In this section, a summary of the cost of four buildings was analysed and presented based on the preliminary, Substructure, and superstructure and the total cost reflected in Naira and pounds. The cost comparison and the difference across the buildings were further analysed to establish the cost per square meter. Later, that information was used to calculate the percentage cost increase of improvements made to the buildings.

8.3.3.2 Construction cost comparison of a typical Ilorin traditional building, an optimized Ilorin adobe traditional building, and a conventional building.

The study on affordability involves a data collection procedure in two stages that is proceeded by a comparison study. This approach sought to determine how much more cost-effective and potentially cost-saving Ilorin adobe traditional building construction is compared to conventional techniques. The stages are described as (1) cost analysis of As-built Ilorin adobe traditional buildings (2) Alternative 1-Improved optimized Ilorin adobe traditional buildings (3) Alternative 2- Improved optimized Ilorin adobe traditional building, and (4) cost analysis of a Modern building (conventional building)

Step 1: Methodology of cost analysis of adobe traditional building

Conducting a cost analysis of a traditional building involves obtaining data through email. A practical approach is to get quotes from a professional building estimator in a company. This approach includes requesting specific quotes from selected companies that cover materials, labour, and other related costs. The researcher carefully examines extracts and groups cost data to conduct a thorough study. This method not only provides an affordable way to gather data but also allows for a comprehensive examination of the financial implications of traditional Adobe buildings.

Step 2: Cost Analysis process of traditionally Built Home

The process involves providing the quantity surveyor (professional building estimator) with the building model to prepare a bill of quantities (BOQ) for four types of buildings: As-built, Modern, Improved and Optimized traditional building, and Alternative two. The estimator prepares a comprehensive BOQ that details the financial components of the building by itemizing these expenses in detail, which involves breaking down each section of the document and assigning prices to each item. The building materials prices were compiled in a detailed bill by utilising and calculating the costs of the building materials, labour, and other components needed, such as contingencies. This method gives a clear picture of how expenses are broken down, enables well-informed decision-making, and provides insightful information about the financial costs associated with the traditional Adobe housing models. Table 8-1 presents the working hours and hourly rates for artisans and service providers based on their job functions. Skilled labour works 7-8 hours daily and earns 625-714 naira per hour.

Table 8-1: Salaries of labour

Services/labour	Hours/per day	Rate (N)	Total
Mason	8hrs	687.50	5,500
Roofer 1	8hrs	625.00	5,000
Roofer Thatcher	7hrs	714.2	5,000
Roofer (2) for clay tiles	8hrs	625.00	5,000
Plumber	8hrs	687.50	5,500
Carpenter	7hrs	785.70	5,500
Tiler	8hrs	687.50	5,500

i. Cost analysis for as-built traditional building

The original cost estimation for the building in its current state, known as the original base case study, was determined without factoring in any modifications to the thatch roof, 300mm thick mud walls, and 25mm mud floors. It was assumed that the building would be maintained in its original traditional state. Table 7-2 shows the summary of the as-built case study building BOQ with a substructure costing ₦ 249,358 and a superstructure of ₦ 395,56 Naira. The total cost of the building was ₦ 644,92, making it the least costly building compared with the other 3- subsequent iterations and improvements. However, the as-built case study building has the lowest cost per square meter of ₦ 27,800, equivalent to 14.26 GPB.

Table 8-2: Cost summary of As-built traditional building Table

	Traditional building		
No	Description of work	Cost (₦)	Cost (£)
	Substructure	**249,358**	**127.88**
	superstructure	**395,560**	**202.85**
	Grandtotal	**644,918**	**330.73**

Area of building = 23,200m^2

Total cost of building in Naira = 644,918, Total cost of building in GBP = 330.73

The cost per floor area in Naira = 27,800, The cost per floor area in GBP 14.26.

ii. Cost analysis for improved Traditional building (Alternative 1)

In this instance, the roof was left in its natural state (thatch), while the wall material was changed from 300mm thick adobe blocks to 300mm compressed earth bricks mixed with 5% cement and 8% shea meal. Additionally, the floor material was transformed from a 25mm thick mud floor to a 25mm thick wooden floor. The improved and optimised alternative-1 case building in Table 7-3 has ₦ 55,284 as the cost per square meter. Although costly, building improvements with thatched roofs are not as expensive as those of modern buildings. It's estimated BOQ costs ₦ 1,281,61 as the grand total cost.

Table 8-3: Cost summary of improved and optimized building with thatch roof

	Improved Traditional Building (Alternative 1)		
No	Description of work	Cost(N)	Cost (£)
	Thatch roof		
	Substructure	**403,338**	**206.84**
	superstructure	**878,272**	**450.40**
	Grand total	**1,281,610**	**657.24**

Area of building = 23,200m^2

Total cost of building in Naira = 1,282,610, Total cost of building in GBP = 657.24

The cost per square meter in Naira = 55,284. The cost per square meter is GBP= 28.32.

iii. Cost analysis for improved Traditional building (Alternative 2)

The building experienced some upgrades to its materials. The thatch roof was replaced with clay roofing tiles, the 300mm thick adobe walls were exchanged for 300mm thick compressed earth bricks mixed with 5% cement and 8% shea meal, and the 25mm thick mud floor was upgraded to a 25mm thick wooden floor. Table 7-4 shows the total cost figures of ₦ 1,281,61 was for the improved and optimized building with clay roofing tiles. However, the difference between the thatch and clay roofing tiles is minimal. This case alternative costs ₦ 55,000 per square meter.

Table 8-4: Cost summary of improved and optimised building with clay roofing tiles.

	Improved Traditional Building (Alternative 2)		
No	Description of work	Cost(N)	Cost (£)
	Clay tiles roof		
	Substructure	**402,678**	**206.50**
	superstructure	**873,314**	**447.85**
	Grandtotal	**1,275,992**	**654.35**

Area of building = 23,200m^2

Total cost of building in Naira = 1,275,992, Total cost of building in GBP = 654.35.

The cost per square meter in Naira = 55,000. The cost per square meter is GBP= 28.21.

iv. Cost analysis for improved Modern building

The modern building features 0.8mm aluminium roofing sheets, 225mm thick sandcrete blocks, and 60mm x 60mm floor tiles. The modern building is roofed with aluminium, as Table 7-5 indicates. This case is built with modern building materials and has a total cost of ₦ 1,826,269. It is the most expensive facility, with the price per square meter of ₦ 78,718 and 40.31 GBP.

Table 8-5: Cost summary of a typical modern building roofed with aluminium roofing sheet.

	Modern building		
No	Description of work	Cost (N)	Cost (£)
	Substructure	**615,369**	**315.57**
	superstructure	**1,210,900**	**620.97**
	Grandtotal	**1,826,269**	**936.54**

Area of building = 23,200m^2

Total cost of building in Naira = 1,826,269, Total cost of building in GBP = 936.54

The cost per square meter in Naira = 78,718. The cost per square meter is GBP= 40.37. The median costs were obtained from the optimised case buildings (Thatch and clay roofed), which indicates the promising potential in terms of cost affordability and applicability and is proven to be generally sustainable. The full details of the cost analysis for each scenario can be seen in the bill of quantities in Appendix VII. When analysing the cost variances for the three buildings compared to the As built, the improved thatch, costing ₦ 1,281,610, has a cost variance of ₦636,692. In contrast, the clay roofing tiled building has a cost variance of ₦631,074, indicating a marginal difference between the two buildings. This represents almost double the cost of the As-built. However, modern buildings have the highest cost due to the expense of fabric materials.

8.4 Applicability and Acceptability

Semi-structured Interview 2

A semi-structure interview with the heads of household (Occupants) who are conversant with the building background issues affecting the traditional adobe building materials used to construct the various building components, the preservation techniques commonly used for maintenance, and other important information concerning the study was conducted. The interview was held on the 21st of June 2024 after the simulations and cost analysis of the proposed improved optimized Ilorin adobe traditional building was done to validate and verify the acceptability of the proposed adobe building model. The key-informant interview process was carried out in the local dialect (Yoruba language) for clarity with a total of five (5) house owners, and the structure of the questions was centred on the following.

Results

Findings from the key informant interview gave an insight into the acceptability of the proposed optimized Ilorin traditional buildings as follows:

Question 1. The key informants were asked if there was a possibility of replacing the original adobe traditional buildings with the improved thatched-roof-optimized traditional building model

Answer 1: Four out of five respondents unanimously agreed by answering ‘Yes’ that they were positive about the proposal to adopt Adobe building fabric elements. They strongly believed that these materials were readily available in the local environment. This demonstrates that local artisans and masons can easily source Adobe materials and apply logical handling techniques to implement the traditional construction process in an alternative application efficiently. Their views demonstrate acceptability and ease of application.

Question 2: Do you accept clay roofing tiles as an alternative to thatch roofs?

The question aimed to gather respondents' opinions on their preferences between two roofing systems. The researcher identified challenges associated with natural building materials, such as their proneness to dilapidation as discussed in Chapter 2, and the need for recurrent maintenance, including rethatching after every rainy season, as mentioned in Chapter 4. These problems are no longer sustainable and require constant costs to maintain traditional building materials.

Answer 2: Initially, most of the respondents preferred thatch roofs to protect the originality of their homes and cultural pride, but they also expressed concerns about the sustainability and availability of thatch roofing due to the scarcity of Elephant grass used, as analysed in Chapter 4. In addition, the rest of the respondents opined that thatch was obsolete and preferred clay roofing tiles because they looked modern and they reflected their social status. This aligns with the analysis in Chapter 4, which sampled individual opinions on dissatisfaction with the traditional roofing system. Due to these reasons, all respondents agreed on the need to accept clay roofing tiles as an alternative roofing system due to the moderate cost of clay roofing tiles and availability, as indicated in the cost analysis in Chapter 7. Furthermore, the results obtained from the parametric study in Chapter 6 also validate the efficient thermal characteristics of clay as an alternative roofing material. In general, it was said that the building owners were solely responsible for its maintenance and repairs.

Question 3: "Do you agree with the necessity of using window shading devices in traditional buildings?"

Answer 3: There was overwhelming support regarding the need to implement shading devices (vertical and horizontal) on windows. Only one out of five respondents objected to the process of that alteration because it may change the character of the building when shading devices are introduced. However, these devices will further protect the solar insolation and affect the provision of comfort in the room interiors, as detailed in Chapter 6.

Question 4. Over the years of occupancy, have you observed any form of building degradation?

Answer 4: All the respondents reported experiencing some level of building degradation. The improved compressed lateritic earth bricks have good thermal properties, smooth external finishes, strong durability, and are relatively waterproof. These appealing qualities are detailed in Chapter 1, which discusses the physical appearance of the bricks, their local manufacturing, and their use in construction. They produce smooth and stable structures, making them a viable alternative to using dung, which can attract maggots if not applied correctly. However, this does not entirely replace cultural practices. However, it can still be maintained to harness its benefits and uphold the cultural Ilorin wall rendering practice with properly applied cow dung.

The findings revealed three major agents of degradation: atmospheric, biological, and human. Atmospheric agents caused problems such as dampness, stains, chipping of walls, cracks, and building collapse due to lack of waterproof floor material and erosion from rainfall and wind. Moreover, biological agents contributed to issues such as mold, lichens, the development of vegetation, holes, and the absence of suitable grass species for thatched roofs, cracks caused by insects that bore holes in floors and walls, maggots in wet cow dung used as wall and floor finish and overgrazing of cows. These findings are consistent with Akinkunmi (2016), who also emphasized the impact of moisture, lack of maintenance culture, substandard construction techniques, leaking roofs, inappropriate eaves overhangs, and poor rainwater drainage on traditional buildings. Furthermore, the study revealed that traditional buildings experience fast deterioration, including plaster spalling, cracks, and partial or total collapse of walls. Akinkunmi (2016) suggested that the preservation of existing traditional buildings is the most affordable and low-impact solution for providing housing in rural communities in Nigeria. Additionally, human agents contributed to degradation by introducing unsuitable elements and using incompatible materials due to a lack of skilled artisans and proper preservation techniques.

Question 5. The respondents were asked if they would support the proposed improvements to traditional Adobe buildings and if they would like to see these changes implemented in their buildings and communities.

Answer 5: All participants expressed their willingness to promote and support heritage infrastructural development in their communities and local government areas. They recommended that the government play a key role in providing financial support, input for national policy documents, and areas of research and training to improve skills and technical know-how in building materials production, procurement, and preservation processes. This aligns with Karakul (2015), who emphasized the need to address the disappearance of traditional craftsmanship by proposing an "integrated conservation methodology" to revive the master-apprentice relationship for the sustainability of conventional craftsmanship. Karakul's methodology considers both the intangible and tangible aspects of preservation through user assessment and experimental processes, as highlighted in the relevant chapters of the study. The simulation results in Chapter 6 validated the application of the methodology to verify some of the physical characteristics of the building materials and instrumentation. Furthermore, Chapter 5 provided some insights into achieving thermal comfort in traditional Adobe buildings. Moreso, the cost analysis in Chapter 7.2.3 offers valuable information on the most cost-effective improvements among all the assessed buildings in terms of applicability, acceptability, and affordability.

8.5 Discussion

This chapter has examined the application of the study findings highlighted in Chapter 6 to a typical Ilorin traditional room, which is applicable to a whole adobe traditional building in a warm-humid climate zone. A step-by-step approach has been adopted to demonstrate how a designer can combine suitable building parameters to produce a proposed optimised, improved Adobe traditional building through simulation and experiment. The simulation has significantly reduced conditions above thermal comfort with the proposed optimisation strategies.

This study also guides designers on quantifying the effect of applying effective ventilation parameters, top thermal performing fabrics on building components, and appropriate external shading elements on thermal comfort and energy use. Upon thorough analysis of each case, encompassing the construction cost impact, it was determined that the initial construction cost of a traditional as-built building was the lowest. However, it incurred higher running costs due to frequent maintenance and greater energy consumption compared to the improved and optimized Adobe traditional buildings. The latter cost slightly more than the as-built option but significantly less than a conventional modern building in terms of both initial and running expenses. Additionally, the optimized improved adobe traditional buildings required less effort in preservation and offered excellent thermal performance as naturally ventilated structures. The cost analysis indicated that enhancing thermal comfort in the houses was the most effective decision in terms of retrofitting and maintenance initiatives. Key findings highlighted that ventilation resulted in the most substantial improvements in naturally ventilated homes, with windows ranking as one of the most expensive components to consider after building fabrics, especially roof and ceiling fabrics. The application of external shading devices was considered as a means of mitigating solar heat gain; appropriate types of ventilation methods and suitable building fabric were carried out to intervene to reduce discomfort hours significantly and, in so doing, increase energy savings, be cost-effective and deliver improved thermal performance as well as helping to preserve Ilorin cultural heritage building designs without compromising privacy and the Ilorin culture. Lastly, the key informant interview results show that the Ilorin community is open to adopting the proposed improved optimized Ilorin adobe traditional building and integrating the framework into the housing policy.

8.6 Conclusion

The survey found that 80% of the interview respondents support the use of Adobe building materials due to their local availability and ease of use. Respondents recognised sustainability concerns and favoured clay roofing tiles for their durability, modern appearance, and cost-effectiveness. The as-built traditional building, with a thatch roof and mud walls, cost N 644,920, making it the least expensive option. Its cost per square meter was N 27,800 (14.26 GBP), highlighting its cost-effectiveness. The improved traditional building, with compressed earth brick walls and a wooden floor, costs N 1,281,610 and N 55,284 per square meter, making it more expensive than the original but cheaper than a modern building. The improved traditional building, with upgrades including clay roofing tiles, compressed earth bricks, and a wooden floor, costs N 1,281,610 total or N 55,000 per square meter. For a 23,200m² area, the cost is N 1,275,992 or GBP 654.35, with a per square meter cost of GBP 28.21. The cost difference between thatch and clay roofing tiles is minimal. The improved modern building, featuring aluminium roofing sheets and sandcrete blocks, costs N 1,826,269 total or N 78,718 per square meter. For a 23,200m² area, the cost is GBP 936.54, with a per square meter cost of GBP 40.37. Median costs from optimized buildings show promising affordability and sustainability. The comparison of vernacular architecture in terms of fabric materials performances highlights how the climate and local conditions influence buildings. While their physical structure is objectively linked to the earth and air, the choice of building materials and design in response to climate and context can lead to different thermal results. Passive buildings need to be able to adapt to changing climates. If the original design does not meet comfort requirements, adjustments may need to be made to ensure better thermal performance. According to Garcia and Vale, 2017, p. 45, resilience in this context involves understanding change and taking adaptable and transformative actions. The subjective opinion indicated that shading devices on windows were widely accepted to enhance comfort. There were concerns about building degradation, leading to the identification of improved compressed lateritic earth bricks as a durable alternative. All participants advocated for the development of heritage infrastructure and recommended government support. The study underscored the importance of preserving cultural practices while ensuring sustainable housing in Nigeria.

Chapter 9: Conclusion, Limitations and Future Work

The Nigerian government and policymakers are tackling the impact of climatic conditions on traditional adobe buildings to prevent their deterioration and eventual extinction. Efforts by the government and researchers to maintain, preserve, and provide comfort for occupants have gained significant attention nationwide. Support from organizations like UNESCO and the UNFCCC have sustained these initiatives through climate action interventions. There is a strong governmental aspiration to promote the maintenance and retrofitting of adobe buildings, which are vulnerable to climate exposure but hold significant historical value. Rapid preservation efforts are driven by climate change and the need to reduce the carbon footprint. As a member of various global organizations advocating climate action, the Nigerian government focuses on sustainable development to combat global warming. This research aims to evaluate the thermal comfort provided by traditional adobe residential buildings in Ilorin's warm, humid climate, addressing the unique challenges posed by local conditions.

9.1 General conclusion

The study identified problems and provided policy guidelines to preserve and enhance these vital infrastructures. The following objectives of the research are sustained with the aim. To examine and characterize Ilorin adobe traditional buildings. In conclusion, the research objective from Chapter 3, elaborates on the process of achieving the objectives. The chapter reviews the first phase of investigating Ilorin, Nigeria's historically significant traditional adobe buildings. It emphasizes the need to address the deterioration of these culturally important structures, particularly those owned by district heads. The study assessed the thermal performance of the buildings, identifying critical variables affecting heat transfer and solar gains. The architectural characteristics, such as thick adobe bricks, wooden structural elements, central courtyards, and small windows, were documented through fieldwork due to a lack of accessible written information. These features contribute to thermal efficiency and energy conservation without mechanical cooling. Understanding these elements aids in preserving the buildings' thermal performance and cultural heritage, setting the stage for further investigation into occupants' perceptions in the next chapter.

To evaluate the thermal performance of traditional adobe buildings in Nigeria, the selected case study buildings in Ilorin were used for research. Analysis of the thermal performance of traditional building materials in Chapters 2 and 6. This chapter explores processes of achieving thermal comfort for building occupants in Nigeria and the crucial requirement of adopting comprehensive strategies, including suitable design techniques and thorough research. Traditional Nigerian buildings, using materials like adobe, cob, rammed earth, and wattle and daub, provide sustainable and energy-efficient solutions while preserving indigenous traditions. These buildings perform better thermally than modern constructions, even in warm, humid climates. Effective strategies consider factors such as temperature, humidity, clothing, activity levels, and air movement, with researchers using models like Fanger's to quantify comfort. Further research on adapting traditional adobe buildings to various climates and indoor conditions will enhance knowledge in this area. This section lays the groundwork for investigating adobe buildings and their materials to ensure thermal comfort and sustainability. The thermal performance of Ilorin traditional adobe buildings focuses on a fabric-first approach, ventilation, and shading designs. The study, validated by empirical data, shows that effective ventilation can significantly reduce overheating and enhance thermal comfort. Traditional architectural elements, such as thick adobe walls, thatch roofs, small windows, and proper building orientation, naturally maintain comfortable indoor temperatures. Improvements suggested including using low U-value materials for roofs and ceilings, enhancing wall thickness with compressed earth bricks, and adding shading devices. These strategies can optimize thermal performance without mechanical cooling, preserving the cultural heritage of Ilorin adobe buildings.

To determine the minimum thermal comfort conditions for occupancy in Ilorin adobe traditional residential buildings. Subjective and objective (qualitative and quantitative) evaluations of the traditional buildings were achieved in Chapters 4 and 5. These survey and monitoring methodologies deliver to achieve this set objective. Surveys and interviews with occupants revealed high satisfaction with the buildings' thermal performance, ventilation, and cultural significance despite maintenance challenges and issues like poor lighting and heat discomfort from corrugated zinc roofing. The study highlighted the importance of air movement and operable windows for ventilation. Most occupants found the indoor temperatures satisfactory, even in warmer months, aligning with the ASHRAE benchmark for comfort. The findings provide valuable insights into improving thermal comfort in traditional adobe buildings and inform future design strategies for better occupant satisfaction and well-being. Further investigations will focus on objective methods to enhance thermal comfort in Ilorin's adobe buildings. This study, involving adobe residential houses across three local government areas, found that adobe buildings effectively regulate temperature and provide comfort. The experimental process in this section was accomplished, identifying the causes of visual discomfort in traditional adobe buildings in Ilorin, primarily linked to small window sizes and inadequate daylight factors. Increasing window sizes can improve lighting and reduce the need for artificial light. Ventilation analysis reveals low airflow during peak warm months, indicating a need for cooling to prevent overheating. Simulations show that improving the window-wall ratio can enhance visual comfort, with a recommended daylight factor of at least 2% in 80% of the area. Thermal comfort limits for these buildings range from 25.2ºC to 32.1ºC, with a standard effective temperature of 28.6ºC in warm-humid climates. These findings provide a foundation for further studies on improving thermal and visual comfort in Ilorin adobe buildings.

To investigate the causes of deterioration in traditional Adobe building elements to provide preservation solutions. The processes that determine the causes of adobe building deterioration were obtained through literature in Chapter 1, and the solutions were implemented in Chapter 6 under parametric analysis. It can be concluded that understanding the climatic environment in architectural design is important, particularly for traditional buildings in Ilorin, Nigeria. It highlights the urgent need to sustain adobe buildings threatened by climate vulnerability based on historical background. Suggestions were made for further investigation into passive and energy-efficient design strategies, such as natural ventilation, shading devices, and light-coloured materials for improved thermal comfort. It also recognised the challenges in preserving Nigeria's traditional heritage buildings, emphasising the need for regular maintenance, rapid repairs, and adequate drainage to ensure their stability and longevity. This section lays the groundwork for further exploration of the political, cultural, and environmental influences on Nigeria's vernacular architecture, particularly in warm and humid zones.

To develop a maintenance framework accessible to the public and professionals in the built environment and integrate it into the nation's building policy documents. In conclusion, the survey revealed strong support (80%) for using Adobe building materials due to their local availability and ease of use. Respondents favoured clay roofing tiles for their durability and cost-effectiveness. The study highlighted how vernacular architecture adapts to climate and local conditions, emphasising the need for buildings to be resilient and adaptable. Improved compressed lateritic earth bricks were identified as a durable alternative to traditional materials. Participants advocated for heritage infrastructure development and government support. Effective strategies that emphasized the maintenance and preservation of cultural heritage buildings were achieved as the objective. The research developed a framework that provides recommendations for integration into the nation’s environmental policy document by the government for the benefit of professionals and individuals for the sustainable development of traditional infrastructure.

Recommendation to Government: The national building code and BEE guideline document are two major policy documents governing the built environment. These documents do not cover all aspects of indoor environmental quality, IEQ, maintenance of vernacular Architecture and thermal comfort. To ensure minimum standards are met. Major findings from this research can be a viable recommendation to refill and strengthen the provisions in the documents.

Recommendations to Professionals: This research provides a crucial base for a deep understanding of various methods of building assessment for the professionals of the built environment through its multi-objective methodologies, which are used and applied in building information software, simulations, and experimental processes.

Recommendations to Individuals in the Community: The research provides valuable recommendations for community and individual housing owners. It serves as a practical guide for residents and professionals collaborating on the technical and initial implementation of conservation, restoration, and maintenance of traditional buildings; the framework centres on addressing, management and intervention strategies.

9.2 Summary of Achievements and Design Strategy

a) The literature review highlighted a significant research gap that unfounded the need for the maintenance of earthen (adobe) buildings, which was recommended through applications of desirable methodologies that increased their structural and physical strength while maintaining their traditional essence, symbolic characteristics and sustainability.

b) The research findings indicated that air temperature and humidity are the main comfort parameters affecting occupants of the Ilorin adobe buildings. High solar radiation leads to overheating in the tropical warm-humid climate.

c) A standard effective temperature (SET) of 32.1ºC (upper) and 25.2ºC (lower) temperature was established for the Adobe buildings, and comfort temperatures of 28.6ºC were obtained and recognised to be the provisional comfort temperature for the occupants living in Ilorin traditional adobe houses.

d) The parametric optimisation process led to an enhanced clay roofed building model that excels in thermal performance. It achieved a 65.6% performance rating for the overheating period in March. Following this, an optimised and improved thatched roof attained a performance rating of 62.55%. In relation to the annual percentage of hours within the comfort threshold (25.2 – 32.1), the enhanced and optimised traditional building with thatch scored 82%, followed by the improved and optimised traditional building with clay (80%).

e) In terms of cost analysis, the improved and optimised traditional building with clay roofing tiles incurred lower costs, while the improved and optimised traditional building with a thatch roof had slightly higher costs.

f) The analysis of the current windows indicates that none of the buildings meet the minimum daylighting factor standard of > 1.5. Nevertheless, it is noted that small windows effectively provide ventilation for adobe buildings in the climate zone and should, therefore be preserved for sustainability.

Therefore, the effective environmental concern for maintenance and sustainability of these traditional buildings should be ensured through passive techniques and strategies by the built environment professionals.

9.3 Thesis Key Findings

The findings presented in this thesis offer significant contributions to academic literature and understanding within the field. Through rigorous analysis and comprehensive research methodologies, the study explains key insights as follows

a) **Value Added to Heritage and Culture**

This thesis highlights traditional Nigerian architectural practices as a foundation for creating sustainable and thermally efficient designs. Traditional adobe buildings in Ilorin showcase architectural ingenuity deeply rooted in Nigeria's cultural heritage, employing materials and techniques that enhance both sustainability and comfort (Chapters 1, 4, 5). The research illustrates that preserving these traditional practices not only honors Nigeria's cultural identity but also offers viable solutions for modern construction. By incorporating passive design elements such as thick adobe walls, small wooden side-hung windows, and central courtyards, this study effectively bridges historical knowledge with contemporary building requirements, reinforcing the significance of heritage-based architectural practices.

b) Value Added to Building Constructions

The findings directly inform current construction practices by promoting the integration of passive cooling techniques and materials with significant thermal mass into modern homes (Chapters 6, 7). For example, the use of adobe walls and clay roofing tiles, which offer considerable thermal mass, can help regulate indoor temperatures without the need for mechanical cooling. Furthermore, incorporating ventilation strategies, such as strategic window placement and adjustable schedules, can mitigate overheating by as much as 61% (Chapter 7). These approaches provide a solid framework for improving the thermal performance of both current and future dwellings, ensuring enhanced comfort and sustainability.

c) **Value Added to Regional Applications**

The upgrade adobe traditional solutions presented in this study contribute significantly to enhancing thermal comfort while simultaneously preserving cultural heritage (Chapters 5, 7, 8). Innovations such as compressed earth bricks, clay roofing tiles, and fiberboard ceilings not only optimize thermal performance but also represent cost-effective alternatives to contemporary building materials. The research findings indicate that these solutions are particularly relevant to the warm-humid climate of Ilorin, where effective thermal regulation is of paramount importance. By emphasizing affordable and sustainable construction methods rooted in traditional practices, this study offers substantive pathways for the enhancement of local housing conditions.

d) Value Added to Retrofitting for Thermal Comfort:

To enhance comfort levels in existing buildings, this research proposes a retrofit model incorporating passive cooling strategies inspired by traditional adobe architecture in Ilorin (Chapters 6, 7). Key strategies include improving ventilation through optimized window placement, increasing window-to-wall ratios to enhance daylighting, and introducing shading devices such as canopies and trees to reduce solar heat gain. The importance of the thermal mass effect from thick adobe walls is emphasized as a vital element for stabilizing indoor temperatures. Together with cost analysis data presented in Chapter 8, these strategies offer a clear pathway for integrating traditional materials and techniques into modern construction, thereby improving comfort while preserving cultural heritage. Moreso, the thesis successfully bridged Identified Gaps: This thesis addresses several important gaps in the study of Ilorin adobe traditional buildings. It explores architectural practices, cultural significance, and sustainability, helping us understand the historical and current importance of these structures in relation to local heritage and urban development.

Overall, this thesis synthesizes concepts of heritage preservation, scientific research, and sustainable design principles to address existing gaps in the field. It establishes a comprehensive framework aimed at enhancing thermal comfort in traditional adobe buildings of Ilorin, all while ensuring the preservation of Nigeria's architectural heritage.

9.4 Limitations of the Study

Time constraints and limited funding restricted the monitoring and experimentation of the case study buildings. The number of instruments for data logging and testing climatic parameters in the buildings were also limited. Additionally, there was a restricted choice of buildings for the case study due to initially identified buildings being sold, demolished, or put out of use before the assessment process began. This indicates the rapid rate at which these unique adobe traditional buildings are becoming extinct, thereby limiting accessibility for extensive vernacular architectural research. Overall, this has affected the incorporation of evaluating more buildings to gather data for the research. Additional data could benefit the parametric simulation using the IES-ve by obtaining more indices in different climatic zones.

9.5 Future Work

a) **Development of Enhanced Maintenance Techniques:** Investigate and develop innovative maintenance techniques that align with the traditional essence and sustainability of adobe buildings, while exploring modern materials and methods that do not compromise the symbolic characteristics of these structures.

b) **Optimization of Thermal Performance:** Exploring additional parametric optimisation processes to improve the thermal performance of adobe buildings further. This could include experimenting with different roof materials (in addition to those already studied in this research), insulation techniques, and construction methods to achieve higher performance ratings.

c) **Cost-Benefit Analysis of Building Materials:** Perform a comprehensive cost-benefit analysis of various roofing and construction materials used in adobe buildings by assessing the long-term economic and environmental impacts of using alternative roofing materials and identifying cost-effective and sustainable options.

d) **Improvement of Daylighting and Ventilation:** Further research can investigate alternative window designs and types to improve the daylighting factor while maintaining effective ventilation. This would help in the development of guidelines for window size types and configurations that balance lighting and ventilation needs in adobe buildings. As indicated in

e) **Community Engagement and Education:** Technical engagement of individuals in local communities could be another aspect for further research and development, that will ensure that maintenance techniques and design strategies are culturally appropriate accepted and implemented. The process will provide education and training for local builders and homeowners on and maintenance of sustainable building practices.

f) **Policy and Regulatory Framework:** Further research is required to advocate for the integration of traditional Adobe building techniques and maintenance practices into local building codes and regulations. This will facilitate the advancement and translation of results into formal codes and regulations. This process will also support the establishment of policy guidelines and laws based on recommendations to enhance the preservation and sustainability of adobe buildings.

g) **Technological Integration:** This will explore how modern technology, like sensors and smart home systems, can be integrated to monitor and control the internal environment of adobe buildings, assessing the feasibility and benefits of using technology to enhance comfort and sustainability.

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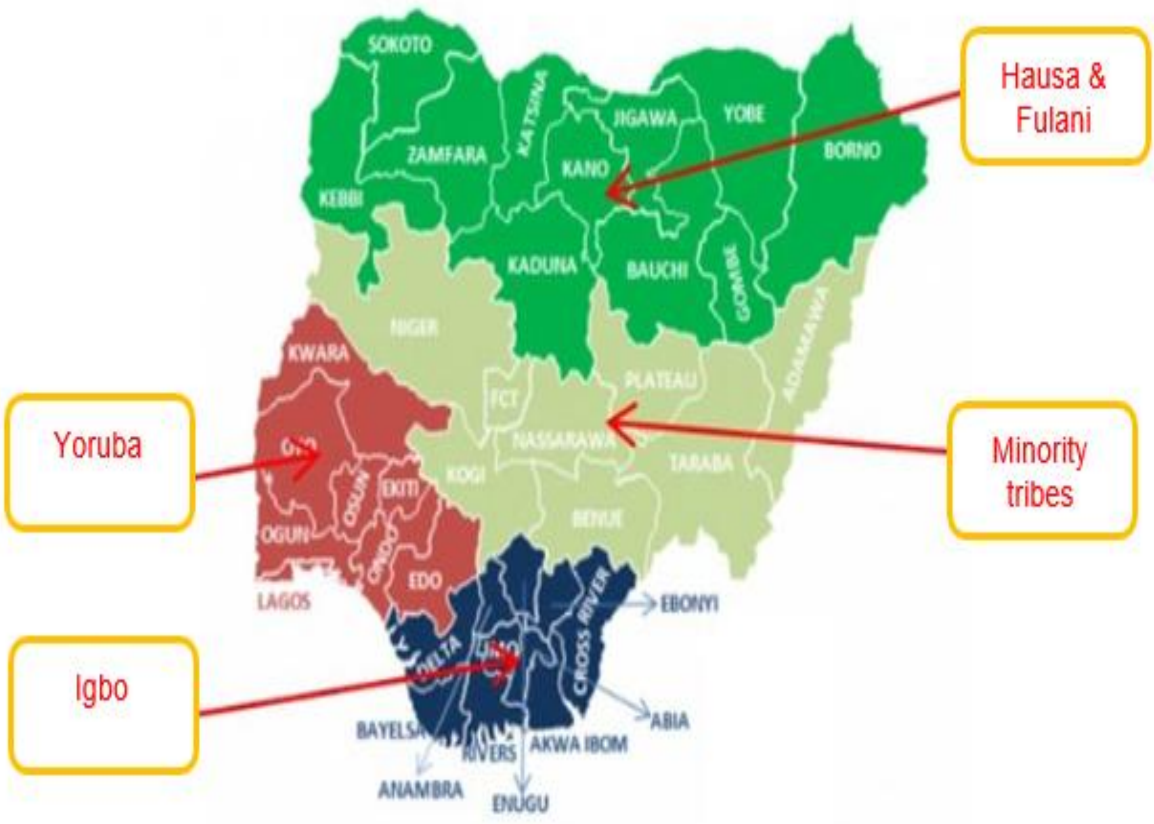
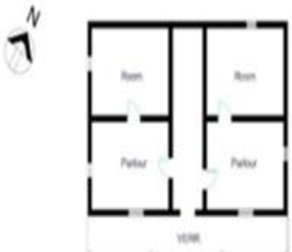
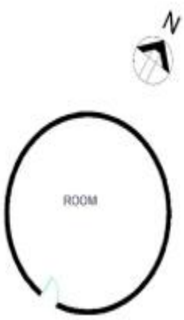
APPENDIX I :

Map of Nigeria showing the main ethnic groups of Nigeria.



APPENDIX II:

Typical Ilorin traditional house types

	House type	Plan	Façade	subtype
Urban/city house	Courtyard House			Includes an open courtyard, an internal verandah, and an external verandah.
Rural House	Row house			simple rows with a central hall
	Unit house			Units either single or several

Case study A



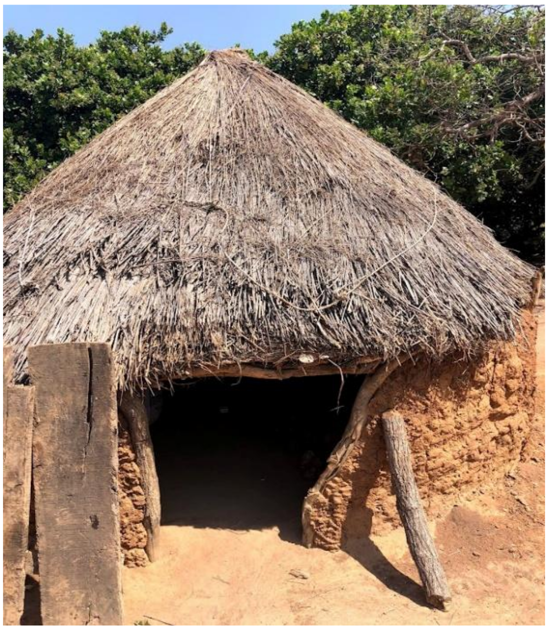

Case study B


Case study C

Case study D




Case study E

Case study F

APPENDIX III:

Documentation guide

1. Name of the Domestic Building

[Provide the current, not historic, name of the resource. Resource names cannot begin with articles (The, A, An). Names must also be unique and therefore specific.]

2. Location

a. Street:

b. Additional locational information:

c. City:

d. State:

e. Postal Code:

f. Residential District [Tick applicable]: Core [ ] Transitional/mixed zone [ ]

G. R. A. [ ] Housing Estate [ ]

3. Identity of the Domestic Building

a. Variant or former name:

[Include the original name of the building if its name has changed over time. Also include any other names which have been given to the building due to change in ownership or function, as well as any variants of its current name.]

b. Primary & Secondary Classification / Typology:

[To what other use is the building put?]

4. History of Building

a. Original Brief / Purpose:

[The early history of the building. Describe the events leading up to the commission, the selection of the architect, the original design programmeme, and a brief history of the client and their involvement (if any) in the design and construction process.]

Other questions and issues to address here include:

- Was there a design competition?
- Why was the architect selected?
- Why was the design chosen?
- Were the clients forward-thinking?
- Did they allow full creative license to the architect?
- Was the design selected for its pure functionality?
- Was the architect's original design altered to accommodate the needs/preferences of the clients?

<u>b. Dates: Commission/Completion</u>

Official date of the commission:

Official date of the completion:

Other dates (if applicable/available)

Competition date:

Dates of design revisions:

Date of completed phases:

Dates of inaugural events (before or after the building was completed):

[Dates should be precise and researched. They should be noted either "exactly known" (e), "approximate" (a), or (c) "circa" per item. List in chronological order, with "/" between each separate date.]

c. Architectural and Other Designer(s)

List all known architects:

Landscape architects:

Structural engineers:

Interior designers:

Building contractors/Masons:

d. Others Associated with Building

[List relevant persons associated with the site]

All owners:

All politicians involved:

Associated famous persons:

e. Significant Alteration(s) with Date(s)

[Describe in as much detail known all significant alterations to the interior and exterior of the site in this section.] Include:

Type of alteration:

Date of the alteration:

Who (individual, firm, agency, organization) was in charge of the alteration:

What precipitated the alteration (need for additional space, existing structural damage, deterioration of architectural elements, desire to change aesthetic of building, etc.).

Other questions and issues to address here include:

- What historic material was subtracted from the resource?
- Is there more new material than original?
- How were the restoration firms selected?
- Was a master plan for restoration created?
- Did the structure undergo an adaptive reuse?
- If, and how, did these alterations affect the historic and architectural integrity of the site?

<u>f. Current Use</u>

Describe the current use of the building:

If the current use differs from the original use, explain the sequence of events which led to the shift in its function and/or ownership:

If there are any threats to its continued current use list them here:

<u>g. Current Condition</u>

Describe the current condition of the building [Reference alterations discussed in the *Significant Alteration(s) with Date(s)* section if relevant to the site's current condition]:

Provide an objective and specific assessment of the building, as opposed to using subjective descriptors such as "good" or "fair." Include potential or future threats to the building's current condition:

5. Description

[This section is a means to illustrate the physical features of the building and site]

a. General description

[Focus on describing the physical and architectural features of the building. Be as specific as possible]

Description of the site's location and landscape:

Design schematic:

Formal arrangements:

Architectural details:

Materiality:

Structural systems:

Exterior facade by façade:

Interior (if applicable):

b. Construction Period

[Construction process of the building]

Building technologies:

Structural systems:

Materiality:

Any innovative or unusual approaches to modern construction:

c. Original Physical Context

[Description of surrounding project site, as is relevant to the understanding of the resource and its place in its surrounding physical context]

Nearby buildings:

Neighbourhoods:

Landscapes:

6. Evaluation

[Provide an overall assessment of the significance of the building in the context of the city, in addition to Ilorin history. The evaluations must stress the innovatory aspects of the resource; e.g. in cutting-edge building materials, new structural systems, in commission, use or typology, and in overall design. The intent is to emphasize the value of the resource through an objective voice, so please do not use this section of the as a forum for criticism]

a. Technical

[The use of new materials and techniques was a credo for architects of modernism, so this aspect must be examined very carefully]

Building materials and finishes:

Building methods:

Structural systems:

<u>b. Social</u>

Evaluate the intended programmeme of the building according to social and economic issues present at the time of design:

Evaluate the social influence on the design:

Evaluate the design's influence on the social milieu:

<u>c. Cultural & Aesthetic</u>

Evaluate here the formal programmeme of the design:

How is the building emblematic of the modern?

[Include interpretations, praise, and criticism by the architect, colleagues, architectural critics, and historians as relevant]

<u>d. Historical</u>

[Evaluate the place of the resource in Architectural History and its canonical status]

What was the project's impact on design practice, on an international and/or local level?

Was it recognized at the time of its construction as a major contributor to what was considered modern, or was it considered a derivative?

Did the resource contribute to establish new architectural principles, and further, did it become a model?

e. General Assessment

Conclude with an overarching statement of significance, which can discuss:

Context of the resource in the architect's/designer's career:

Major impacts the resource had on its surrounding area:

Design of buildings that were influenced by the resource:

Assessment of how the building has maintained its architectural integrity over time:

7. Visual Documentation

a. Sketches for:

___Plan ___Section ___Elevation

___Site Layout Showing Other Buildings at the edges and the spaces between them

b. Photographs:

___Front ___Sides ___Rear

___Interior ___Special Features ___Perspective

Reporter / date:

APPENDIX IV:

Questionnaire

House ID

QUESTIONNAIRE (Available in English or Yoruba)

Part 1: About yourself

1. What is your age? Please choose one:

☐ < 18 years ☐ 18 – 30 years ☐ 30 -50 years ☐ >50 years ☐ Prefer not to say

2. Please let me know your gender by choosing an option or ticking 'prefer not to say':

☐ Male ☐ Female ☐ Prefer not to say

Part 2: About your home

3. What local government area of Kwara state do you reside in? Please choose one:

☐ Ilorin Central ☐ Ilorin West ☐ Ilorin South ☐ Ilorin East ☐ I don't know

4. How long have you lived in your present house? Please choose one:

☐ < 10 years ☐ 10 – 20 years ☐ 20 – 30 years ☐ > 30 years ☐ I don't know

5. Is the property owned or rented?

☐ Privately owned ☐ Rented ☐ Prefer not to say ☐ Other (please specify):

6. How old is your house? Please choose one:

☐ < 25 years ☐ 25-50 years ☐ 50-75 years ☐ > 75 years ☐ I don't know

7. How many people live in your household? Please choose an option:

☐ 1-2 ☐ 3-4 ☐ 5-10 ☐ >10 ☐ I don't know

8. How often people are in your home on a regular weekday? Please tick the times when they are at home:

	0:00-1:00	1:00-2:00	2:00-3:00	3:00-4:00	4:00-5:00	5:00-6:00	6:00-7:00	7:00-8:00	8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20 :00	20:00-21:00	21:00-22:00	22:00-23:00	23:00-0:00
Person 1																								
Person 2																								
Person 3																								
Person 4																								
Person 5																								
Person 6																								
Person 7																								
Person 8																								
Person 9																								
Person 10																								

9. How often is the property maintained? Please choose an option:

☐ Never ☐ < 2 years ☐ 2-10 years ☐ >10 years ☐ I don't know

House ID

10. How satisfied are you with your building? Please tick one box per line:

	Extremely satisfied	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied	Extremely dissatisfied	Not applicable
Wall finishing								
Windows and doors								
Roof								
Overall maintenance								
Overall quality of building								

Part 3: About your comfort

11. How satisfied are you with the following items? Please tick one box per line:

	Extremely satisfied	Very satisfied	Satisfied	Neutral	Dissatisfied	Very dissatisfied	Extremely dissatisfied	Not applicable
Natural lighting in general								
Access to natural ventilation								
Noise levels								
Temperatures in harmattan (Dec-Mar)								
Temperatures in the rain season(Mar-Novr)								
Humidity in harmattan (Dec-Mar)								
Humidity in the rain season (Mar-Novr)								
Thermal comfort conditions now								

12. Typically, when you feel dissatisfied with your thermal comfort levels it is because the space is:

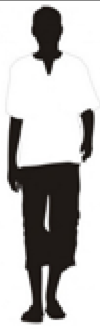
☐ Too dark	☐ Dark	☐ Neutral	☐ Bright	☐ Very bright
☐ Too drafty	☐ Drafty	☐ Neutral	☐ Stuffy	☐ Too stuffy
☐ Too noisy	☐ Noisy	☐ Neutral	☐ Quiet	☐ Very quiet
☐ Too cold	☐ Cool	☐ Neutral	☐ Warm	☐ Too hot
☐ Too humid	☐ Slightly humid	☐ Neutral	☐ Slightly dry	☐ Too dry
☐ Too breezy	☐ Slightly breezy	☐ Neutral	☐ Slightly still	☐ Too still

13. If you are not satisfied with the comfort in your home, how do you think it could be improved?

House ID

20. Please provide us with information regarding your clothing at this moment

 < 0.5	 0.6 -1.2	 1.3 -1.7	 1.8-2.4	 2.5 - < 3.5
☐	☐	☐	☐	☐

 < 0.5	 0.6 -1.2	 1.3 -1.7	 1.3 -1.7	 2.5 - < 3.5
☐	☐	☐	☐	☐

Part 3: Cultural Heritage

15. How important are the following factors for being considered a true Ilorin indigene? Please answer using the scale provided to agree or disagree with the following statements:

Survey	Very important	Somewhat important	Not very important	Not at all important	Prefer not to say
Do you appreciate Ilorin traditional buildings?					
What type of residence do you live in, modern or heritage?					
How challenging is it to live in traditional buildings?					
To feel Ilorin (Afonja /Alimi)					
To be able to speak Yoruba					
To be able to speak Hausa					

APPENDIX V

POE Survey – Interview 1

SEMI -STRUCTURED INTERVIEW

Project: Quantifying the Potential of Traditional Adobe Buildings to Deliver Thermal Comfort in the Warm-Humid Climate of Ilorin Nigeria.

Building name/ location:

Time & Date:

Brief: This interview is conducted within the post-occupancy stage with the heads of household (Occupants) who are conversant with the building background issues affecting the building materials used to construct the various building components, the preservation techniques commonly used for maintenance, and other important information concerning the study.

Outline:

1. Building envelope character

2. Building material degradation perceived/experienced

3. Building construction

4. Preservation techniques commonly administered

5. Any other information

Thank you

1. What type of building materials were used for your building envelope? (This would include materials used for walls, roofs & floors)

2. What are the various types of material degradation you have perceived/experienced over the years? (This would include Atmospheric, Biological & Human factors)

3. What type of construction technique and wall finish did you use for your building?

A Method of construction:

b. Type of wall finish:

4. What technique/strategies have you used to maintain and preserve your adobe buildings over the years, which have either been able to meet changing needs so far arising from material degradation or are likely to meet future needs?

5. Any other relevant information

POE Survey – Interview 2

SEMI -STRUCTURED INTERVIEW

Project: Quantifying the Potential of Traditional Adobe Buildings to Deliver Thermal Comfort in the Warm-Humid Climate of Ilorin Nigeria.

Building name/ location:

Time & Date:

Brief: This interview is conducted after the performance evaluation process to ascertain the acceptability and applicability of changes made to the adobe buildings. The following questions were asked:

1. Is there a possibility of replacing the original Adobe traditional building with the improved thatched roof optimised traditional building model?
2. Do you accept clay-roofing tiles as an alternative to thatch roofs?
3. Do you agree with the necessity of using window-shading devices in traditional buildings?
4. Over the years of occupancy, have you observed any form of building degradation?
5. Would you support the proposed improvements to traditional adobe buildings, and would you like to see changes implemented in your buildings and communities?
6. Any other relevant information

Thank you for being so cooperative.

APPENDIX VI

Case study A Door and Window schedule.

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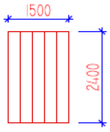
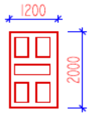
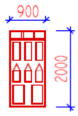
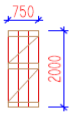
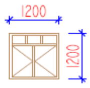
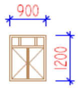
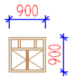
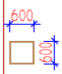
TYPE								
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IMAGE								

Case study B Door and Window schedule

DOORS SCHEDULE					WINDOWS SCHEDULE			
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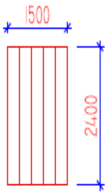
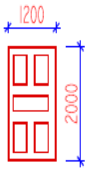
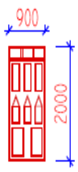
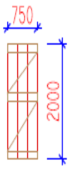
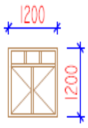
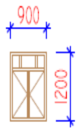
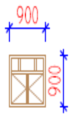
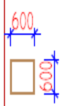
TYPE								
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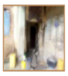
IMAGE								

Case study C Door and Window schedule

	DOORS SCHEDULE			WINDOWS SCHEDULE		
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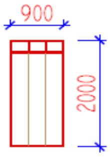
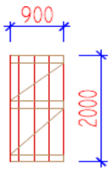
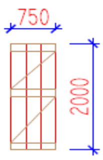
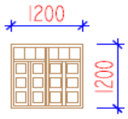
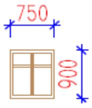
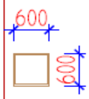
TYPE						
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IMAGE						

Case study D Door and Window schedule

	DOORS SCHEDULE			WINDOWS SCHEDULE		
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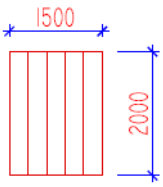
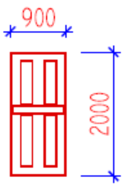
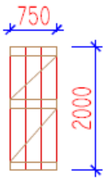
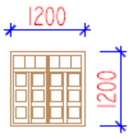
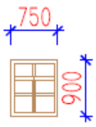
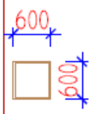
TYPE						
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IMAGE						

APPENDIX VII

Bill of Quantities and Work order

	Modern building				
No	Description of work	Unit	Quantity	Rate (N)	Cost (N)
1	**PRELIMINARY WORK**				
I	Excavation of foundation trenches	M3	19.6	600	11,700
2	**FOUNDATION**				
i	Blinding concrete	M3	1.323	57,445	76,000
ii	Sandcrete block		81	600	48,600
Iii	Earth filling	tons	16.7	8,000	133,600
Iv	Damp proofing course	M3	3.48	57,445	199,909
V	60 x60 floor tiles	M2	23.2	6300	146,160
3	**SUPER STRUCTURE**				
i	Brick work from foundation to final course		566	600	339,600
ii	Mortar	M3	5.303		80,600
iii	Labour(masonary)				60,000
Iv	Windows	2nos		25,000	50,000
V	Door	1no		35,000	35,000
Vi	Roofing structure				
	2x 3 hardwood	Pcs	19	800	15,200
	2x 2 hardwood	Pcs	25	600	15,000
	2x4 hardwood	Pcs	12	1000	12,000
	Labour (carpentry)				15,000
	Nail	Bag	¾		12,000
Vii	Roofing sheet (0.8 guage aluminum)	M2	47.56	7,000	332,900
	Ceiling pop/pvc	M2	23.2	10,500	243,600
	Substructure				**615,369**
	superstructure				**1,210,900**
	Grandtotal				**1,826,269**
	Traditional building				
No	Description of work	Unit	Quantity	Rate (N)	Cost (N)

1	**PRELIMINARY WORK**				
I	Excavation of foundation trenches	M3	19.6	600	11,700
2	**FOUNDATION**				
i	Blinding concrete	M3	1.323	57,445	76,000
ii	Sun dried adobe mixed with straw(30mm thick)		81	110	8,910
Iii	Earth filling	tons	16.7	8,000	133,600
Iv	Mud floor(25mm thick screed)	M3	0.58	11,106	19,148
3	**SUPER STRUCTURE**				
i	Sun dried adobe mixed with straw(30mm thick)		566	110	62,260
ii	Mortar	M3	5.303		80,600
iii	Labour(masonary)				60,000
Iv	Windows	2nos		25,000	50,000
V	Door	1no		35,000	35,000
Vi	Roofing structure				
	2x 3 hardwood	Pcs	19	800	15,200
	2x 2 hardwood	Pcs	25	600	15,000
	2x4 hardwood	Pcs	12	1000	12,000
	Labour (carpentry)				15,000
	Nail	Bag	¾		12,000
Vii	Thatch (200mm thick) & installation	M2	47.56	816	38,850
	Ceiling N/A				
	Substructure				**249,358**
	superstructure				**395,560**
	Grandtotal				**644,918**
	Improved Traditional building				
No	Description of work	Unit	Quantity	Rate (N)	Cost (N)
1	**PRELIMINARY WORK**				
I	Excavation of foundation trenches	M3	19.6	600	11,700
2	**FOUNDATION**				
i	Blinding concrete	M3	1.323	57,445	76,000
ii	Compressed earth with 5% cement & 8% of shear meal		81	388	27,378

	residue of butter(300mm thick)				
Iii	Earth filling	tons	16.7	8,000	133,600
Iv	Wooden floor(25mm thick)	M3	23.2	4,500	154,666
3	**SUPER STRUCTURE**				
i	Compressed earth with 5% cement & 8% of shear meal residue of butter(300mm thick)		566	388	219,608
ii	Mortar	M3	5.303		80,600
iii	Labour(masonary)				60,000
Iv	Windows	2nos		25,000	50,000
V	Door	1no		35,000	35,000
Vi	Roofing structure				
	2x 3 hardwood	Pcs	19	800	15,200
	2x 2 hardwood	Pcs	25	600	15,000
	2x4 hardwood	Pcs	12	1000	12,000
	Labour (carpentry)				15,000
	Nail	Bag	¾		12,000
Vii	Thatch (200mm thick) & installation	M2	47.56	816	38,850
	Ceiling fibre board(60mm thick)	M2	23.2	14,035	325,614
	Substructure				**403,338**
	superstructure				**878,272**
	Grandtotal				**1,281,610**
	Improved building				
No	Description of work	Unit	Quantity	Rate (N)	Cost (N)
1	**PRELIMINARY WORK**				
I	Excavation of foundation trenches	M3	19.6	600	11,700
2	**FOUNDATION**				
i	Blinding concrete	M3	1.323	57,445	76,000
ii	Compressed earth with 5% cement & 8% of shear meal residue of butter(300mm thick)		81	388	27,378
Iii	Earth filling	tons	16.7	8,000	133,600
Iv	Wooden floor(25mm thick)	M3	23.2	4,500	154,666

3	**SUPER STRUCTURE**				
i	Compressed earth with 5% cement & 8% of shear meal residue of butter(300mm thick)		566	388	219,608
ii	Mortar	M3	5.303		80,600
iii	Labour(masonary)				60,000
Iv	Windows	2nos		25,000	50,000
V	Door	1no		35,000	35,000
Vi	Roofing structure				
	2x 3 hardwood	Pcs	19	800	15,200
	2x 2 hardwood	Pcs	25	600	15,000
	2x4 hardwood	Pcs	12	1000	12,000
	Labour (carpentry)				15,000
	Nail	Bag	¾		12,000
Vii	Clay roofing tiles	M2	47.56	700	33,292
	Ceiling fibre board(60mm thick)	M2	23.2	14,035	325,614
	Substructure				**402,678**
	superstructure				**873,314**
	Grandtotal				**1,275,992**

RADIAN SKETCHES CONSULT

Aloba community, Egbejila Road,

Off Asadam, Ilorin Kwara State.

Date:6th June ,2024

WORK ORDER

Services/labour	Hours/per day	Rate (N)	Total
Mason	8hrs	687.50	5,500
Roofer 1	8hrs	625.00	5,000
Roofer Thatcher	7hrs	714.2	5,000
Roofer (2) for clay	8hrs	625.00	5,000
tiles	8hrs	687.50	5,500
Plumber	7hrs	785.70	5,500
Carpenter	8hrs	687.50	5,500
Tiler			

Olarewaju Emmanuel olawale

Architect /M.D

Work Order

Work Order : WO 1
W.O Date: 03/07/2024

Structured Spaces Nigeria Limited
Mamman Kontogora
Crescent katampe
extension
Mobile: +234818805984
Email: structuredspacesng@gmail.com

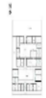
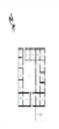
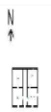
Labor And Services	Hours	Rate / HR	Amount
Mason	8	₦ 1,050	₦ 8,400
Roofer 1	8	₦ 1,250	₦ 10,000
Roofer Thatcher	8	₦ 1,300	₦ 10,400
Roofer 2 (for clay tiles)	8	₦ 1,400	₦ 11,200
Plumber	8	₦ 1,100	₦ 8,800
Carpenter	8	₦ 1,500	₦ 12,000
Tiler	8	₦ 1,450	₦ 11,600
		Subtotal	₦ 72,400

Subtotal	₦ 72,400
Total	₦ 72,400

Thank you

APPENDIX VIII

Characteristics of Ilorin traditional adobe buildings

s/no	Location	Name of building	Age	Height of building	Occupancy	No. of floors	wall fabric	Roof material	Typical floor plan	Typical section	courtyard location	Net internal area	Gross external area	No of courtyards	Totalcourtyard area	Typical floor plate effiecency	Typical floor plate	Lease span	Floor to ceiling	Exposed skin area	Exposed skin area/floor area	Shading	Ventilation	Heat loss Form factor	Aprox. U-Value of Roof/	Aprox. U-Value of wall	Aprox. U-Value of Floor	Wall thickness (mm)
1	Case A		102	5	Private	1	Adobe sun dried bricks with plaster cement	Zinc covering with wooden frame			centre	263.31	590.155	2	A=56.64, B=24.09. T otal = 80.73	44.61%	26.2 x 22.525	1.5	2.7	963.00	1.6	HSD	Combination	2.8	7.14	1.635	4.905	300
2	Case B		172	3.9	Private from forefathers	1	Adobe sun dried bricks with plaster cement	Zinc covering with wooden frame			centre	626.4	1511.58	2	A=128.0 B=120.9 Total = 248.9	41.44%	42.7 x 35.4	1.8	2.2	1,398.30	0.9	HSD	Single sided	2.2	7.14	1.635	4.905	300
3	Case C		85	3.9	private	1	Adobe sun dried bricks with plaster cement	Zinc covering with wooden frame			centre	272.36	424.32	1	80.65	64.19%	22.1 x 19.2	1.5	2.2	694.5	1.6	HSD	Single sided	2.8	7.14	1.635	4.905	300
4	Case D		171	3.9	Private	1	Adobe sun dried bricks with plaster Cowdung	Zinc covering with frames made from sticks			Center	239.8	537.25	1	86.67	44.63%	24.31 x 22.1	1.5	2	705.5	1.3	HSD	Single sided	2.7	7.14	1.635	4.905	300
5	Case E		47	3	Private	1	Adobe sun dried bricks with plaster cowdung	Zinc covering with frames made from sticks			N/A	66.5	111	0	N/A	60%	12 x 9.25	0	N/A	145.8	1.3	HSD	cross	3.15	7.14	1.754	5.263	300
	Case F		25	3.8	private	1	Adobe sun dried bricks with plaster Cowdung	Thatch covering			N/A	7	7.4	0	N/A	94.59%	23.24	0	N/A			N/A	Single sided	3.4	0.334	1.987	5.263	250

APPENDIX IX

Faculty of Engineering

Process for approval of research study involving human participants

Introduction

This document describes the process to be followed when planning and obtaining approval for studies involving human participants within the Faculty of Engineering. This process is based on one previously run within the School/Dept. M3. The process is administered by the Faculty Research Ethics Committee, and managed by the Chair of the Ethics Committee and the Faculty Research Ethics Officer. All queries regarding the process should be initially sent to ez-eng-ethics@nottingham.ac.uk

What is Ethics Approval?

When conducting any study or observation or collecting data about individuals, it is essential that full consideration is given to ethical issues and that steps are taken to ensure participant well-being throughout the study.

Participants involved in research studies have a right to:
- Know the goals of the study and who is funding the work
- Make an informed decision about whether or not they wish to participate
- Leave the study at any time if they do not wish to continue
- Know what will happen to them during the study and how long it will take
- Know if they may experience any discomfort
- Know what will happen to the findings
- Privacy of personal information
- Be treated courteously

The University of Nottingham and Faculty of Engineering have an ethics procedure that requires all staff and students to submit an application for ethical approval before conducting any research study involving human participants. Members of the Ethics Committee read through study proposals to check that the researcher has demonstrated that they have given full consideration to ethical issues and that they have provided participants with appropriate and sufficient information.

Who needs Ethics Approval?

ANY member of staff or registered student of the University of Nottingham involved in conducting any study or observation or collecting data about individuals **MUST** adhere to the University Code of Research Conduct and Research Ethics. Those affiliated with the Faculty of Engineering **MUST ALSO** comply with the Faculty ethical approval process before commencing their study.

Ethics application procedure

The attached document outlines the ethics approval process within the Faculty of Engineering. For all applications required to undergo formal review, applications must be submitted to the **Ethics Administrator**, ez-eng-ethics@nottingham.ac.uk The application will then be reviewed by the ethics committee. We aim to return a decision to applicants within two weeks but the procedure may be delayed if the ethics committee require further information. It is the applicant's responsibility to make sure that applications are submitted in good time.

THE STUDY MAY **NOT** START UNTIL ETHICAL APPROVAL HAS BEEN AWARDED

Information you should give to ALL participants

The following list describes the information that should be given to all participants. Normally this should be given in a participant information sheet at the beginning of the study, and participants should be required to confirm that they have understood the nature of the study, and that they are happy to participate.

The following information should be included:

Details of who will be conducting the study.

- Details about who is sponsoring the study and what the terms of the sponsorship are (i.e. who will 'own' the data and how the data will be used).

Details about the nature, purpose and duration of the study. (Participants whose first language is NOT English may need further explanation of what is involved as their understanding of some of the terminology may be limited).

What kinds of procedures will be used and what participant will be asked to do.

- Details about any hazards, inconveniences and risks associated with the study.
- What procedures will be followed if a participant is injured. (only needed if risk of injury has been identified)
- What benefits (payments, expenses etc) are attached to the study.
- What they need to do in order to receive the payments described above.
- What procedures will be employed to maintain confidentiality and anonymity (e.g. removing personal details from data/reports, keeping data in locked files)

What will happen to the data (how it will be used, how it will be stored, in what form it will be disseminated and if it is likely to be used for further analysis).

- How you will use photographs or video records (data analysis, illustration purposes, displayed to sponsors/ non-public academic audiences, printed in public domain documents etc).

Details about who to contact if questions or problems arise.

- ALL participants must be told that any involvement in the study is voluntary and they are free to withdraw at any time. You should also explain any consequences for the participant of withdrawing from the study and indicate what will be done with the participant's data if they withdraw.

Faculty of Engineering

Application for approval of research study involving human participants

ALL applicants must provide the following information

The applicant must be the person who will conduct the investigations; each application must be made by one applicant:

- usually the student in the case of taught or research courses,
- usually the researcher (the member of university research or academic staff) who will conduct the study in the case of funded research projects,
- usually the principal investigator in the case of applications for ethics approval in advance of submission of a research proposal

If the applicant is an Undergraduate or Postgraduate taught or research student please complete the information below. The application must be approved by a Supervisor.

Name of student:	Olutola Adekeye	Student No:	20115228
Course of study:	Ph.D. Architecture	Email address:	ezxoa5@nottingham.ac.ul
Supervisor:	Prof. Lucelia Rodrigues	PGR ■	PGT ☐
		MSc ☐	UG ☐

If the applicant is a member of university research or academic staff, please complete the information below: For research staff, the application must be approved by the Principal Investigator

Name:		Principal Investigator	
Email address:		PI Signature:	

Title of investigation: ...

Quantifying the Potential of Traditional Adobe Buildings to Deliver Thermal Comfort in the Warm-Humid Climate of Ilorin Nigeria...

Planned date for study to begin .... June 2022 - June 2023 .... Duration of Study ......1year......

Please state whether this application is:

New ☐ Revised ☐ A renewal ☐ For a continuation study

Selection of review process

Please indicate whether the application is required to go forward to the ethics committee for formal review, or, in the case of projects completed by ***taught undergraduate and postgraduate students only***, whether the application can be approved by the supervisor under the expedited review process*.

■ Formal review, application will be supervisor*

submitted to ethics committee Supervisor is a

Expedited review, application is approved by

* This option can only be selected if the

member of the Faculty Ethics committee

Approval by supervisor: expedited review

I approve the application as supervisor of this project, under the expedited review procedure.

Name of supervisor Signature…………………………………………………… Date………………..

■

Office use only

Date form received: Date decision returned to applicant:

Passed to reviewers: 1. Name…………………………………………………………………… Date……………………….

(formal review only) 2. Name…………………………………………………………………… Date……………………….

Ethical Issues Checklist

The purpose of this Checklist is to facilitate the review process and to identify any ethical issues that may concern the Committee. It is meant to be an aid to both the researcher and the Committee. Listed below are areas which require some justification and attention on your part in specifying your study protocol. Please answer each question honestly, giving full details where required. Answering "YES" to any of the questions will not necessarily lead to a negative response to your application but it will draw issues to your attention and give the reviewers the opportunity to ensure appropriate steps are being taken. In expedited review, supervisors should ensure that for any questions where the answer "YES" has been given, appropriate measures have been taken to maintain ethical compliance.

Applicant's full name ...... Olutola Funmilayo Adekeye ....

You must complete ALL of this section before submitting your application

1 Who is the population to be studied?

The population for qualitative interview comprises Ilorin community people both the elderly house occupants and house owners of Ilorin traditional buildings made from adobe building materials in Kwara state Nigeria.

The population for the quantitative survey will include both female and male participants who are Ilorin adobe traditional building occupants and are between the ages of 18 and above (Further details are provided in the attachments)

2 Please give details of how the participants will be identified, approached, and recruited. (Include any relationship between the investigator and participants e.g. instructor-student).

- The researcher has been working closely with a volunteer who is an indigene, has a passion for community development, and is also the Ilorin central community youth leader to Identify case study buildings and their owners / main occupants using a snowball approach.

- Users/owners of adobe traditional buildings in Ilorin will be administered questionnaires and interviews on thermal comfort perception, health, and wellbeing of the indoor environment. The interview will be conducted on house owners, occupants (head of household or knowledgeable house member) who live in Ilorin adobe traditional buildings.

-A volunteer translator who resides in Ilorin would help in communicating with the local indigenous language to provide a better understanding, communication and to make the participants comfortable.

3 Will the population studied include any vulnerable members of the public? **YES** ☐ **NO** ■

Note: for the purpose of ethics approval this includes participants who are under 18, people who are disabled or in poor health, and also those who are non-English speakers and may not be able to understand the consent forms. (If YES, please give further details)

The research will involve field research on adobe traditional residential buildings and it's indoor environment measurement such as temperatures, indoor air quality, relative humidity, and air-velocity e.t.c.

4 Will it be possible to associate specific information in your records with specific participants on the basis of name, position or other identifying information contained in your records? **YES** ☐ **NO** ■

- The use of GPS coordinates will be employed to identify information on specific locations of the case study buildings/ house compounds but not individuals.

5 What steps have you taken to ensure confidentiality of personal information and anonymity of data both during the study and in the release of its findings?

- Paperwork: Hard copy data collection such as questionnaire answers will be anonymized and kept in secure files and lockers, names will be kept separate from observation forms and participants will be assigned an ID numbers and also household codes.
- Electronic data will be stored on my password-protected personal laptop.
- Individual participant's names will not be used in the questionnaire but House ID codes will be given and used to represent those buildings. Also, data will be anonymised when used in publications of thesis, journal, and conference papers.

6 Describe what data will be stored, where, for what period of time, the measures that will be put in place to ensure security of the data, who will have access to the data, and the method and timing of disposal of the data.

Paper records should be stored in a locked filing cabinet. Digital data should be stored only on a password-protected computer and/or on a secure server. In accordance with the Data Protection Act, the data needs to be kept securely for seven years following publication kept securely for seven years following publication of results. After this time, electronic files will be deleted and any hard copies will be destroyed.

At the end of a student project, students are responsible for ensuring that all data from the study is passed on to their academic supervisor/s. The supervisors/s will then have responsibility for the storage of that data.

- Paperwork will be stored in a locked cabinet in Prof. Lucelia Rodrigues's office for 7 years following any publication arising from this work.
- Electronic data from interviews will be anonymized and stored on a password-protected computer and another copy saved on an external drive that is also password protected.
- The measured data (room temperature, Relative humidity, and airflow velocity, etc) will be stored on my University PC for the period of my Ph.D. study.

7 Will persons participating in the study be subjected to physical or psychological discomfort, pain or aversive stimuli which is more than expected from everyday life? (If YES, please give further details) **YES** ☐ **NO** ■

....

8 Will participants engage in strenuous or unaccustomed physical activity? (If YES, please give further details) **YES** ☐ **NO** ■

....

9 Will the investigation use procedures designed to induce participants to act contrary to their wishes? (If YES, please give further details) **YES** ☐ **NO** ■

....

10 Will the investigation use procedures designed to induce embarrassment, humiliation, lowered self esteem, guilt, conflict, anger, discouragement or other emotional reactions? (If YES, please give further details)

YES ☐ **NO** ■

………

11 Will participants be induced to disclose information of an intimate or otherwise sensitive nature? (If YES, please give further details)

YES ☐ **NO** ■

………

12 Will participants be deceived or actively misled in any manner? (If YES, please give further details)

YES ☐ **NO** ■

………

13 Will information be withheld from participants that they might reasonably expect to receive? (If YES, please give further details)

YES ☐ **NO** ■

………

14 Will the research involve potentially sensitive topics? (If YES, please give further details)

YES ☐ **NO**

………

15 Will data be collected which requires potentially invasive procedures (eg attaching electrodes to the skin) and/or other health-related information to be identified (eg heart rate). If yes please give details

YES ☐ **NO** ■

………

If you require space for additional information, please add it here and identify the question to which it refers:

Checklist of information to include with your application:

Please tick the boxes below to confirm that you have included the following information with your submission. Failure to include the required information may result in your ethics application and approval for start of your research to be delayed.

☑ A brief description of the study design:

The research is to assess adobe traditional buildings on thermal performance and to delineate possible strategies for the preservation of adobe traditional buildings in the warm humid climate of Nigeria.

- It will involve the survey and measurement of adobe traditional buildings (4 case study buildings) within the Ilorin emirate area of Kwara State, Nigeria.
- Installation and monitoring of required instruments on selected buildings for data collection of key indicators of thermal comfort.
- The research will involve measuring the indoor environment such as temperatures, indoor air quality, relative humidity, and air velocity and data loggers will be used at various locations in the selected buildings.
- Data collection (Climate data, building drawings, and electricity consumption bills): Electricity pay slips shall be used to compute the monthly consumption rates. Climatic data readings will be obtained from the Nigerian meteorological station and readings from the data loggers.
- Questionnaires will be administered to adults above the age of 18years who are occupants of selected buildings on the perception of thermal comfort and wellbeing in the indoor environment.
- The analysis process of data gotten from the questionnaires will be carried out.

  - number and type of participants
- A total of 100 participants above the age of 18 years who reside in adobe traditional buildings.
  - number and duration of activities participants will be involved in
- The duration will be for eight months.
  - equipment and procedures to be applied

Three small pieces of equipment as demonstrated in the figure below

1. Tinytag Ultra 2 — TGU-4500 Datalogger will be used to measure the indoor temperature and humidity.

2. Portable Wind Meter Hand-held LCD Wind Speed Gauge Air Velocity Meter Digital Anemometer Thermometer will be used to measure indoor air velocity and wind temperature.

3. CD Digital Anemometer Wind Speed Meter Air Flow Measuring Tester HYELEC MS6252Awill be used to measure outdoor wind speed.

- The equipment set up will be prepared and placed in specific locations in the interior of selected adobe traditional buildings, it will be sealed with strong tape and kept out of reach to kids.

  - ➢ information about how participants will be recruited
- The head of the house will grant access to the relevant building to set up the measuring tools, hand over questionnaires to other household members, and also grant the audience for interviews.

- A volunteer translator who resides in Ilorin would help in communicating with the local indigenous language to provide a better understanding, communication and to make the participants comfortable.

  - ➢ whether participants will be paid (state how this will be done)
    N/A

  - ➢ plans to ensure participant confidentiality and anonymity
    Data gotten from questionnaires and interviews will be anonymized.

  - ➢ plans for storage and handling of data
- Paperwork: Hard copy data collection such as questionnaire answers will be anonymized and kept in secure files and lockers
- The indoor environment weather data will be stored in the data logger then transferred to my university PC for analysis.

  - ➢ information about what will happen to the data after the study
- The information gotten from the study will be used in my Ph.D. thesis

  - ➢ information about how any data and images may be used
- The data will be transferred to word documents, excel spreadsheets, climate consultant tool and analyzed for the Ph.D. research.
- The readings gotten from the weather data will be transferred and used as parameters for thermal comfort simulation through the use of a simulation tool - Integrated environment system (IES-VE).

- ➢ state whether it will be possible to identify any individuals.

- N/A (individuals will be addressed as anonymous and selected houses will be given house ID codes).

☑ Copies of any information sheets to be given to participants (include recruitment information (e.g. adverts, posters, letters, etc)

☑ A copy of the participant consent form

☑ Copies of data collection sheets, questionnaires, etc

I confirm that all of the above is included in the application:

As the applicant I confirm that I have read and understand the Ethical requirements for my study and have read and complied with the University of Nottingham Code of Research Conduct and Research Ethics.

Signature of applicant ...... [signature] .... Date ......04/01/2022...............................

As supervisor, I confirm that I have checked the details of this application.

Signature of supervisor Lucelia Rodrigues Date 01.03.21

NB The signature of the supervisor on this part of the application DOES NOT indicate supervisor approval for expedited review. If supervisor approval is granted then the front page of the application MUST be signed for approval to be confirmed.

The scientific instruments measurents tools which will be uesd in the reaserch

1. Tinytag Ultra 2 — TGU-4500

Indoor temperature and relative humidity data logger with built-in sensors

Product description: - The TGU-4500 monitors temperatures ranging from -25 to +85°C, and relative humidity from 0 to 95% using built-in sensors. It is primarily suited to indoor monitoring. However, it can be used outdoors with appropriate protection such as a Stevenson Screen. Like the rest of the Ultra 2 range, this accurate and reliable unit has a lightweight, splash-proof design.

Source :- https://www.geminidataloggers.com/data-loggers/tinytag-ultra-2/tgu 4500?gclid=CjwKCAjwq_D7BRADEiwAVMDdHnAES1IBWwVNGREuADzWrZXy8zQd0jE1Ljq7slQDJO2efnCpn39bIBoCSoIQAvD_BwE

2. Portable Wind Meter Hand-held LCD Wind Speed Gauge Air Velocity Meter Digital Anemometer Thermometer

Product description: - Current/max/average wind speed reading. Auto/manual power off. Wind temperature range: -10 - 45 (14-113F) Powered by a 3V CR2032 battery. Wind chill indication. Wind speed range: 0-30m/s High precision pressure sensor. Measures wind speed and temperature.

Source:
https://www.wish.com/product/5d79fdd941646336a3ccebd6?from_ad=goog_shopping&_display_country_code=GB&_force_currency_code=GBP&pid=googleadwords_int&c=%7BcampaignId%7D&ad_cid=5d79fdd941646336a3ccebd6&ad_cc=GB&ad_curr=GBP&ad_price=13.00&campaign_id=6493229882&guest=true&gclid=CjwKCAjwq_D7BRADEiwAVMDdHpwIBwBdW6L47DQz7seHSjtozyVCGh8rbFLRAchz_UBkT8h0KuxntxoCQ4gQAvD_BwE&share=web.

3. CD Digital Anemometer Wind Speed Meter Air Flow Measuring Tester HYELEC MS6252A.

Product description:- 100% brand new and high quality. This meter is a portable, professional measuring instrument with large-screen LCD and backlight, multi-unit switching functions. This meter can be used for hand-held or fixed measurements. This meter has the functions of reading hold, maximum, minimum, etc. It has a low battery indicator.

Source: -
https://www.wish.com/product/5678f9fe7885e92e6492cb9f?hide_login_modal=true&from_ad=goog_shoppin
g&_display_country_code=GB&_force_currency_code=GBP&pid=googleadwords_int&c=%7BcampaignId%7D&
ad_cid=5678f9fe7885e92e6492cb9f&ad_cc=GB&ad_curr=GBP&ad_price=21.00&campaign_id=8703990225&r
etargeting=true&gclid=CjwKCAjwq_D7BRADEiwAVMDdHhZLT8g68S11_4ZnWLYXJEGSLx1YelJLmLbohGoIfq6mjr8
zM2ExRRoCu0IQAvD_BwE&share=web

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator (Donna Astill-Shipman) from a University of Nottingham email address, or may be completed in paper form and delivered to the APM Hub

Applicant full name ………

Reviewed by:

Name……………………………………………………………………………………………………

Signature (paper based only) ………………………………………………………………………………………………

Date ……………………………………………

☐ Approval awarded - no changes required

☐ Approval awarded - subject to required changes (see comments below)

☐ Approval pending - further information & resubmission required (see comments)

☐

Approval declined – reasons given below

Comments:

………

………

………

………

………

………

………

………

Please note:

1. The approval only covers the participants and trials specified on the form and further approval must be requested for any repetition or extension to the investigation.
2. The approval covers the ethical requirements for the techniques and procedures described in the protocol but does not replace a safety or risk assessment.
3. Approval is not intended to convey any judgement on the quality of the research, experimental design or techniques.
4. Normally, all queries raised by reviewers should be addressed. In the case of conflicting or incomplete views, the ethics committee chair will review the comments and relay these to the applicant via email. All email correspondence related to the application must be copied to the Faculty research ethics administrator.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee

APPENDIX X

Faculty of Engineering

Process for approval of research study involving human participants

Introduction

This document describes the process to be followed when planning and obtaining approval for studies involving human participants within the Faculty of Engineering. This process is based on one previously run within the School/Dept. M3. The process is administered by the Faculty Research Ethics Committee, and managed by the Chair of the Ethics Committee and the Faculty Research Ethics Officer. All queries regarding the process should be initially sent to ez-eng-ethics@nottingham.ac.uk

What is Ethics Approval?

When conducting any study or observation or collecting data about individuals, it is essential that full consideration is given to ethical issues and that steps are taken to ensure participant well-being throughout the study.

Participants involved in research studies have a right to:

- Know the goals of the study and who is funding the work
- Make an informed decision about whether or not they wish to participate
- Leave the study at any time if they do not wish to continue
- Know what will happen to them during the study and how long it will take
- Know if they may experience any discomfort
- Know what will happen to the findings
- Privacy of personal information
- Be treated courteously

The University of Nottingham and Faculty of Engineering have an ethics procedure that requires all staff and students to submit an application for ethical approval before conducting any research study involving human participants. Members of the Ethics Committee read through study proposals to check that the researcher has demonstrated that they have given full consideration to ethical issues and that they have provided participants with appropriate and sufficient information.

Who needs Ethics Approval?

ANY member of staff or registered student of the University of Nottingham involved in conducting any study or observation or collecting data about individuals MUST adhere to the University Code of Research Conduct and Research Ethics. Those affiliated with the Faculty of Engineering MUST ALSO comply with the Faculty ethical approval process before commencing their study.

Ethics application procedure

The attached document outlines the ethics approval process within the Faculty of Engineering. For all applications required to undergo formal review, applications must be submitted to the Ethics Administrator, ez-eng-ethics@nottingham.ac.uk The application will then be reviewed by the ethics committee. We aim to return a decision to applicants within two weeks but the procedure may be delayed if the ethics committee require further information. It is the applicant's responsibility to make sure that applications are submitted in good time.

THE STUDY MAY NOT START UNTIL ETHICAL APPROVAL HAS BEEN AWARDED

Information you should give to ALL participants

The following list describes the information that should be given to all participants. Normally this should be given in a participant information sheet at the beginning of the study, and participants should be required to confirm that they have understood the nature of the study, and that they are happy to participate.

The following information should be included:

Details of who will be conducting the study.

Details about who is sponsoring the study and what the terms of the sponsorship are (i.e. who will 'own' the data and how the data will be used).

Details about the nature, purpose and duration of the study. (Participants whose first language is NOT English may need further explanation of what is involved as their understanding of some of the terminology may be limited).

What kinds of procedures will be used and what participant will be asked to do.

Details about any hazards, inconveniences and risks associated with the study.

What procedures will be followed if a participant is injured. (only needed if risk of injury has been identified)

What benefits (payments, expenses etc) are attached to the study.

What they need to do in order to receive the payments described above.

What procedures will be employed to maintain confidentiality and anonymity (e.g. removing personal details from data/reports, keeping data in locked files)

What will happen to the data (how it will be used, how it will be stored, in what form it will be disseminated and if it is likely to be used for further analysis).

How you will use photographs or video records (data analysis, illustration purposes, displayed to sponsors/ non-public academic audiences, printed in public domain documents etc).

Details about who to contact if questions or problems arise.

ALL participants must be told that any involvement in the study is voluntary and they are free to withdraw at any time. You should also explain any consequences for the participant of withdrawing from the study and indicate what will be done with the participant's data if they withdraw.

Faculty of Engineering

Application for approval of research study involving human participants

ALL applicants must provide the following information

The applicant must be the person who will conduct the investigations; each application must be made by one applicant:

usually the student in the case of taught or research courses,

usually the researcher (the member of university research or academic staff) who will conduct the study in the case of funded research projects,

usually the principal investigator in the case of applications for ethics approval in advance of submission of a research proposal

If the applicant is an Undergraduate or Postgraduate taught or research student please complete the information below. The application must be approved by a Supervisor.

Name of student:	Olutola Adekeye	Student No:	20115228
Course of study:	Ph.D. Architecture	Email address:	ezxoa5@nottingham.ac.uk
Supervisor:	Prof. Lucelia Rodrigues	PGR ■	PGT ☐
		MSc ☐	UG ☐

If the applicant is a member of university research or academic staff, please complete the information below: For research staff, the application must be approved by the Principal Investigator

Name:		Principal Investigator (Budget Holder)	
Email address:		PI Signature: …………………………………………………………	

Title of investigation: ...

Quantifying the Potential of Traditional Adobe Buildings to Deliver Thermal Comfort in the Warm-Humid Climate of Ilorin Nigeria……………………………………………………

Planned date for study to begin ………… June 2022 - June 2023 ……………… Duration of Study ……1year……

Please state whether this application is:

New ☐ Rev☐d ☐ A re☐val ☐ For ☐ontinuation study

Selection of review process

Please indicate whether the application is required to go forward to the ethics committee for formal review, or, in the case of projects completed by *taught undergraduate and postgraduate students only*, whether the application can be approved by the supervisor under the expedited review process*.

F■al review, application will be submitted to ethics committee

Expedited review, application is approved by supervisor*

* This option can only be selected if the Supervisor is a member of the Faculty Ethics committee

Approval by supervisor: expedited review

I approve the application as supervisor of this project, under the expedited review procedure.

Name of supervisor Signature…………………………………………………… Date……………….

■

Office use only

Date form received: Date decision returned to applicant:

Passed to reviewers: 1. Name…………………………………………………………………………… Date……………………….

(formal review only) 2. Name…………………………………………………………………………… Date……………………….

Ethical Issues Checklist

The purpose of this Checklist is to facilitate the review process and to identify any ethical issues that may concern the Committee. It is meant to be an aid to both the researcher and the Committee. Listed below are areas which require some justification and attention on your part in specifying your study protocol. Please answer each question honestly, giving full details where required. Answering "YES" to any of the questions will not necessarily lead to a negative response to your application but it will draw issues to your attention and give the reviewers the opportunity to ensure appropriate steps are being taken. In expedited review, supervisors should ensure that for any questions where the answer "YES" has been given, appropriate measures have been taken to maintain ethical compliance.

Applicant's full name ...... Olutola Funmilayo Adekeye ....

You must complete ALL of this section before submitting your application

1 Who is the population to be studied?

The population for qualitative interview comprises Ilorin community people both the elderly house occupants and house owners of Ilorin traditional buildings made from adobe building materials in Kwara state Nigeria.

The population for the quantitative survey will include both female and male participants who are Ilorin adobe traditional building occupants and are between the ages of 18 and above (Further details are provided in the attachments)

2 Please give details of how the participants will be identified, approached, and recruited. (Include any relationship between the investigator and participants e.g. instructor-student).

- The researcher has been working closely with a volunteer who is an indigene, has a passion for community development, and is also the Ilorin central community youth leader to Identify case study buildings and their owners / main occupants using a snowball approach.

- Users/owners of adobe traditional buildings in Ilorin will be administered questionnaires and interviews on thermal comfort perception, health, and wellbeing of the indoor environment. The interview will be conducted on house owners, occupants (head of household or knowledgeable house member) who live in Ilorin adobe traditional buildings.

-A volunteer translator who resides in Ilorin would help in communicating with the local indigenous language to provide a better understanding, communication and to make the participants comfortable.

3	Will the population studied include any vulnerable members of the public?	YES ☐	NO ■
	Note: for the purpose of ethics approval this includes participants who are under 18, people who are disabled or in poor health, and also those who are non-English speakers and may not be able to understand the consent forms. (If YES, please give further details)		

The research will involve field research on adobe traditional residential buildings and it's indoor environment measurement such as temperatures, indoor air quality, relative humidity, and air-velocity e.t.c.

4	Will it be possible to associate specific information in your records with specific participants on the basis of name, position or other identifying information contained in your records?	YES ☐	NO ■

The use of GPS coordinates will be employed to identify information on specific locations of the case study buildings/ house compounds but not individuals.

5 What steps have you taken to ensure confidentiality of personal information and anonymity of data both during the study and in the release of its findings?

Paperwork: Hard copy data collection such as questionnaire answers will be anonymized and kept in secure files and lockers, names will be kept separate from observation forms and participants will be assigned an ID numbers and also household codes.

Electronic data will be stored on my password-protected personal laptop.

Individual participant's names will not be used in the questionnaire but House ID codes will be given and used to represent those buildings. Also, data will be anonymised when used in publications of thesis, journal, and conference papers.

6 Describe what data will be stored, where, for what period of time, the measures that will be put in place to ensure security of the data, who will have access to the data, and the method and timing of disposal of the data.

Paper records should be stored in a locked filing cabinet. Digital data should be stored only on a password-protected computer and/or on a secure server. In accordance with the Data Protection Act, the data needs to be kept securely for seven years following publication kept securely for seven years following publication of results. After this time, electronic files will be deleted and any hard copies will be destroyed.

At the end of a student project, students are responsible for ensuring that all data from the study is passed on to their academic supervisor/s. The supervisors/s will then have responsibility for the storage of that data.

Paperwork will be stored in a locked cabinet in Prof. Lucelia Rodrigues's office for 7 years following any publication arising from this work.

Electronic data from interviews will be anonymized and stored on a password-protected computer and another copy saved on an external drive that is also password protected.

The measured data (room temperature, Relative humidity, and airflow velocity, etc) will be stored on my University PC for the period of my Ph.D. study.

7 Will persons participating in the study be subjected to physical or psychological discomfort, pain or aversive stimuli which is more than expected from everyday life? (If YES, please give further details) YES ☐ NO ■

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...

8 Will participants engage in strenuous or unaccustomed physical activity? (If YES, please give further details) YES ☐ NO ■

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...

9 Will the investigation use procedures designed to induce participants to act contrary to their wishes? (If YES, please give further details)

YES ☐ NO ■

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...

10 Will the investigation use procedures designed to induce embarrassment, humiliation, lowered self esteem, guilt, conflict, anger, discouragement or other emotional reactions? (If YES, please give further details)

YES ☐ NO ■

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...

11 Will participants be induced to disclose information of an intimate or otherwise sensitive nature? (If YES, please give further details)

YES ☐ NO ■

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...

12 Will participants be deceived or actively misled in any manner? (If YES, please give further details)

YES ☐ NO ■

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...

13 Will information be withheld from participants that they might reasonably expect to receive? (If YES, please give further details)

YES ☐ NO ■

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...

14 Will the research involve potentially sensitive topics? (If YES, please give further details)

YES ☐ NO

....

15 Will data be collected which requires potentially invasive procedures (eg attaching electrodes to the skin) and/or other health-related information to be identified (eg heart rate). If yes please give details

YES ☐ NO ■

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...

If you require space for additional information, please add it here and identify the question to which it refers:

Checklist of information to include with your application:

Please tick the boxes below to confirm that you have included the following information with your submission. Failure to include the required information may result in your ethics application and approval for start of your research to be delayed.

☑ A brief description of the study design:

The research is to assess adobe traditional buildings on thermal performance and to delineate possible strategies for the preservation of adobe traditional buildings in the warm humid climate of Nigeria.

It will involve the survey and measurement of adobe traditional buildings (4 case study buildings) within the Ilorin emirate area of Kwara State, Nigeria.

Installation and monitoring of required instruments on selected buildings for data collection of key indicators of thermal comfort.

The research will involve measuring the indoor environment such as temperatures, indoor air quality, relative humidity, and air velocity and data loggers will be used at various locations in the selected buildings.

Data collection (Climate data, building drawings, and electricity consumption bills): Electricity pay slips shall be used to compute the monthly consumption rates. Climatic data readings will be obtained from the Nigerian meteorological station and readings from the data loggers.

Questionnaires will be administered to adults above the age of 18years who are occupants of selected buildings on the perception of thermal comfort and wellbeing in the indoor environment.

The analysis process of data gotten from the questionnaires will be carried out.

number and type of participants

A total of 100 participants above the age of 18 years who reside in adobe traditional buildings.

number and duration of activities participants will be involved in

The duration will be for eight months.

equipment and procedures to be applied

Three small pieces of equipment as demonstrated in the figure below

1. Tinytag Ultra 2 — TGU-4500 Datalogger will be used to measure the indoor temperature and humidity.

2. Portable Wind Meter Hand-held LCD Wind Speed Gauge Air Velocity Meter Digital Anemometer Thermometer will be used to measure indoor air velocity and wind temperature.

3. CD Digital Anemometer Wind Speed Meter Air Flow Measuring Tester HYELEC MS6252Awill be used to measure outdoor wind speed.

The equipment set up will be prepared and placed in specific locations in the interior of selected adobe traditional buildings, it will be sealed with strong tape and kept out of reach to kids.

information about how participants will be recruited

The head of the house will grant access to the relevant building to set up the measuring tools, hand over questionnaires to other household members, and also grant the audience for interviews.

A volunteer translator who resides in Ilorin would help in communicating with the local indigenous language to provide a better understanding, communication and to make the participants comfortable.

whether participants will be paid (state how this will be done)

N/A

plans to ensure participant confidentiality and anonymity

Data gotten from questionnaires and interviews will be anonymized.

plans for storage and handling of data

Paperwork: Hard copy data collection such as questionnaire answers will be anonymized and kept in secure files and lockers

The indoor environment weather data will be stored in the data logger then transferred to my university PC for analysis.

information about what will happen to the data after the study

The information gotten from the study will be used in my Ph.D. thesis

information about how any data and images may be used

The data will be transferred to word documents, excel spreadsheets, climate consultant tool and analyzed for the Ph.D. research.

The readings gotten from the weather data will be transferred and used as parameters for thermal comfort simulation through the use of a simulation tool - Integrated environment system (IES-VE).

state whether it will be possible to identify any individuals.

N/A (individuals will be addressed as anonymous and selected houses will be given house ID codes).

☑ Copies of any information sheets to be given to participants (include recruitment information (e.g. adverts, posters, letters, etc)

☑ A copy of the participant consent form

☑ Copies of data collection sheets, questionnaires, etc

I confirm that all of the above is included in the application:

As the applicant I confirm that I have read and understand the Ethical requirements for my study and have read and complied with the University of Nottingham Code of Research Conduct and Research Ethics.

Signature of applicant ……  ……………………………… Date ……04/01/2022…………………………

As supervisor, I confirm that I have checked the details of this application.

Signature of supervisor Lucelia Rodrigues   Date 01.03.21

NB The signature of the supervisor on this part of the application DOES NOT indicate supervisor approval for expedited review. If supervisor approval is granted then the front page of the application MUST be signed for approval to be confirmed.

The scientific instruments measurents tools which will be uesd in the reaserch

1. Tinytag Ultra 2 — TGU-4500

Indoor temperature and relative humidity data logger with built-in sensors

Product description: - The TGU-4500 monitors temperatures ranging from -25 to +85°C, and relative humidity from 0 to 95% using built-in sensors. It is primarily suited to indoor monitoring. However, it can be used outdoors with appropriate protection such as a Stevenson Screen. Like the rest of the Ultra 2 range, this accurate and reliable unit has a lightweight, splash-proof design.

Source :- https://www.geminidataloggers.com/data-loggers/tinytag-ultra-2/tgu 4500?gclid=CjwKCAjwq_D7BRADEiwAVMDdHnAES1IBWwVNGREuADzWrZXy8zQd0jE1Ljq7slQDJO2efnCpn39bIBoCSoIQAvD_BwE

2. Portable Wind Meter Hand-held LCD Wind Speed Gauge Air Velocity Meter Digital Anemometer Thermometer

Product description: - Current/max/average wind speed reading. Auto/manual power off. Wind temperature range: -10 - 45 (14-113F) Powered by a 3V CR2032 battery. Wind chill indication. Wind speed range: 0-30m/s High precision pressure sensor. Measures wind speed and temperature.

Source:
https://www.wish.com/product/5d79fdd941646336a3ccebd6?from_ad=goog_shopping&_display_country_code=GB&_force_currency_code=GBP&pid=googleadwords_int&c=%7BcampaignId%7D&ad_cid=5d79fdd941646336a3ccebd6&ad_cc=GB&ad_curr=GBP&ad_price=13.00&campaign_id=6493229882&guest=true&gclid=CjwKCAjwq_D7BRADEiwAVMDdHpwIBwBdW6L47DQz7seHSjtozyVCGh8rbFLRAchz_UBkT8h0KuxntxoCQ4gQAvD_BwE&share=web.

3. CD Digital Anemometer Wind Speed Meter Air Flow Measuring Tester HYELEC MS6252A.

Product description:- 100% brand new and high quality. This meter is a portable, professional measuring instrument with large-screen LCD and backlight, multi-unit switching functions. This meter can be used for hand-held or fixed measurements. This meter has the functions of reading hold, maximum, minimum, etc. It has a low battery indicator.

Source: -
https://www.wish.com/product/5678f9fe7885e92e6492cb9f?hide_login_modal=true&from_ad=goog_shopping&_display_country_code=GB&_force_currency_code=GBP&pid=googleadwords_int&c=%7BcampaignId%7D&ad_cid=5678f9fe7885e92e6492cb9f&ad_cc=GB&ad_curr=GBP&ad_price=21.00&campaign_id=8703990225&retargeting=true&gclid=CjwKCAjwq_D7BRADEiwAVMDdHhZLT8g68S11_4ZnWLYXJEGSLx1YeIJLmLbohGoIfq6mjr8zM2ExRRoCu0IQAvD_BwE&share=web

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator (Donna Astill-Shipman) from a University of Nottingham email address, or may be completed in paper form and delivered to the APM Hub

Applicant full name ....
....

Reviewed by:

Name...

Signature (paper based only) ....

Date ....

☐ Approval awarded - no changes required

☐ Approval awarded - subject to required changes (see comments below)

☐ Approval pending - further information & resubmission required (see comments)

☐ Approval declined – reasons given below

Comments:

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Please note:

The approval only covers the participants and trials specified on the form and further approval must be requested for any repetition or extension to the investigation.

The approval covers the ethical requirements for the techniques and procedures described in the protocol but does not replace a safety or risk assessment.

Approval is not intended to convey any judgement on the quality of the research, experimental design or techniques.

Normally, all queries raised by reviewers should be addressed. In the case of conflicting or incomplete views, the ethics committee chair will review the comments and relay these to the applicant via email. All email correspondence related to the application must be copied to the Faculty research ethics administrator.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee

APPENDIX XI

Department of Architecture and Built Environment

Faculty of Engineering,

University of Nottingham,

University Park,

Nottingham, NG7 2RD,

United Kingdom.

Request for Participation in the Study on Quantifying the Potential of Traditional Adobe Buildings to Deliver Thermal Comfort in the Warm-Humid Climate of Ilorin Nigeria.

Dear Sir/Ma,

I am a Ph.D. researcher in the above-named institution researching on quantifying the potential of traditional Adobe Buildings to deliver thermal comfort in the warm-humid climate of Ilorin Nigeria.

I am seeking your consent to participate in a survey designed to investigate the need to quantifying and preserving existing adobe traditional buildings based on the thermal comfort performance of adobe traditional buildings in the Warm-Humid Climate of Ilorin Nigeria. This study is sponsored by the Tertiary Education Trust Fund (TETFund) as part of its mandate to support the re-training of government tertiary academic staff to improve organization capability. effectiveness.

Kindly find attached to this letter a participant information form for you to review ,fill and sign as a sign of your consent to participate in this survey.

I will be honored to work with you, and for the project to benefit from your contribution to produce design preservation strategies for adobe traditional buildings in the warm humid climate regions of Nigeria and present original models accessible to people in restoring and preserving their vernacular buildings in the local context.

Yours sincerely,

Olutola Funmilayo Adekeye

(olutola.adekeye@nottingham.ac.uk)

An overview of the research

Quantifying the Potentials of Traditional Adobe Buildings to Deliver Thermal Comfort in the Warm-Humid Climate of Ilorin Nigeria aims to support the preservation and provide appropriate maintenance strategies of traditional adobe buildings by identifying and quantifying their importance as exemplar vernacular design for warm and humid climate zones.

Hypothesis: Do their vernacular architectural strategies appropriately address cultural, materiality, and climatic issues and could help to inform the design of more sustainable contemporary buildings.

Objectives:

- To Identify adobe heritage buildings that have been successfully preserved and their preservation strategies. This will cover Nigeria and other parts of the world through a thorough literature review to understand examples of good practices of the adobe preservation process.
- To investigate and gain an understanding of local climate conditions and related comfort considerations in addition to identifying elements related to the cause of deterioration and decay of adobe heritage buildings.
- To measure the thermal performance of Ilorin adobe traditional buildings using an experimental research approach to obtain data on environmental and human parameters. This will be obtained through field studies via interviews, questionnaires, and data loggers. The goal of this process is to ascertain the maximum period a building can be run using only passive cooling measures within the local warm humid climate and thermal comfort requirements without the interference of mechanical cooling aids. This critical investigation could help inform the design of more sustainable contemporary buildings.
- To explore and quantify the existing situation of adobe traditional buildings in Nigeria, using the selected case study buildings as a research medium to collect information on thermal sensation and thermal preference of the occupants of the traditional residential buildings. This will also identify and produce suitable design strategies for adobe traditional buildings to fit within the warm humid climate area of Nigeria.
- To review and delineate design preservation strategies for adobe traditional buildings in the warm humid climate regions of Nigeria and present original models accessible to people in restoring and preserving their vernacular buildings in the local context.

APPENDIX XII

INFORMATION AND DECLARATION PAGE

To take part in the survey, read carefully and thick the boxes below as appropriate

☑ I wish to confirm that I understand the information about the conduct of this study relating to the following guidelines

☑ That my personal information shall be kept confidential and anonymous

☑ That answers provided are mine and I am responsible for all the views and answers expressed in the survey

☑ I agree that the survey results shall be domiciled in a secured data location of University of Nottingham in line with General Data Protection Regulation (GDPR).

☑ I solely permit that all data collected from myself be used for the purposes of analyses, production, development and execution of all academic presentations and mandates.

☑ I understand my participation is voluntary by choice and I must be committed till the end.

☑ I am over (18) years of age.

☑ I agree to participate in this survey.
