Optimization of Building Envelopes using Indigenous Materials to achieve Thermal Comfort and Affordable Housing in Abuja, Nigeria

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Abstract

Purpose: This paper aims to demonstrate the optimization of an existing residential building in a Tropical climate using indigenous materials as an alternative to conventional building envelopes to achieve thermal comfort and affordable housing.

Design/methodology/approach: This study mainly adopted a quantitative research methodology through a comprehensive simulation study on a selected prototype building. The Energy plus simulation tool in DesignBuilder was used to predict the average monthly and annual thermal comfort of a typical residential building in the study area. Also, a cost analysis of the final optimization interventions was conducted to estimate the construction cost savings.

Findings: The comparative analysis of simulation results for the base-case and optimized models indicates potential advantages in replacing conventional building envelope materials with indigenous materials. The base-case simulation results showed that the annual operative temperature is more than the adaptive thermal comfort set points in tropical climates by 8.26%. This often leads to interventions using mechanical cooling systems, thus triggering overconsumption of Energy and increasing CO2 emissions. The building envelope materials for floor, walls, and roof were replaced with low U-values indigenous materials until considerable results in terms of thermal comfort and overall building construction cost were achieved. The final simulation results showed that using indigenous materials for the ground floor, external walls, and roof could substantially reduce the annual operative temperature by 8%, thereby increasing the predicted three months of thermal comfort in the base case to nine months annually. Likewise, there was a 32.31%, 35.78%, and 41.81% reduction in the annual CO2 emissions, cooling loads, and construction costs respectively.

Originality/value: The knowledge of indigenous materials as an alternative to conventional materials for sustainable buildings is not new. However, most of the available research is focused on achieving affordable housing. There is a dearth of research showing the extent that these indigenous materials can be used to improve indoor thermal comfort in developing countries such as Nigeria with tropical climates.

Keywords: Case study, Simulation, Thermal Comfort, Building Envelopes, Indigenous Materials, Affordable Housing, Nigeria.

Paper type: Research paper

1.0 Introduction

1.1 Background to the study

Over the last decades, a lot of research has been conducted to explore the possible solutions to the accompanying threats of climate change, such as global warming, experienced worldwide. Much attention has been focused on developing countries. Such countries are highly vulnerable to climate change due to the poor adaptable measures available to manage its adverse effects (Olanipekun et al., 2018, Udie et al., 2018). In the last 100 years, the earth's average temperature has increased by 0.4˚C to 0.8˚C (Idowu, et al., 2011). This hot, scorching weather typically experienced in many developing countries has resulted in buildings retaining a lot of heat, making building occupants uncomfortable to live in their homes (Federal Ministry of Power, Works, and Housing, FMPWH, 2016). The most common attempt at moderating and catering for the high indoor temperature, amongst others, is through the use of mechanical and electrical ventilation, such as air conditioning systems and electric fans, for cooling (Tatenda, 2012).

However, many residential buildings in developing countries usually have no provisions for mechanical air-cooling systems, perhaps due to financial constraints to purchase, install, and maintain such systems, thereby making such buildings quite uncomfortable to live in (Alicia and Oliver, 2010). According to Akande (2010) and Hanan (2014), more than 70 percent of the built environment experts believe that poor building designs often lead to over-dependence on mechanical ventilation systems in a bid to achieve indoor thermal comfort. Therefore, to mitigate this issue, the incorporation of passive design strategies in building design was recommended in Sustainable Build (2013). Iwaro and Mwasha (2013) describe a passive design strategy as the only appropriate and cost-effective approach in achieving energy-efficient buildings. Apparently, from most recent literature, energy-efficient buildings can be achieved by simply considering the building orientation, building shapes and positions, site microclimate conditions, and most importantly, selecting the building envelope material, which determines the heat gains and losses in the building.

1.2 Statement of Problem

In the country of Nigeria, it is apparent that there is still a huge gap between the annual electrical power demand and supply. A higher percentage (90%) of the country's population still lives in buildings without proper electricity supply (National Council on Power, NACOP, 2016). Meanwhile, FMPWH (2016) stated that residential buildings alone account for over 50% of the country's total energy consumption. More than half of this is spent on electrical and mechanical cooling systems such as electric fans and air conditioning units; hence, there is a need to encourage self-sufficient building designs with a specific focus on thermal comfort and electrical power savings (Lawal and Ojo, 2011).

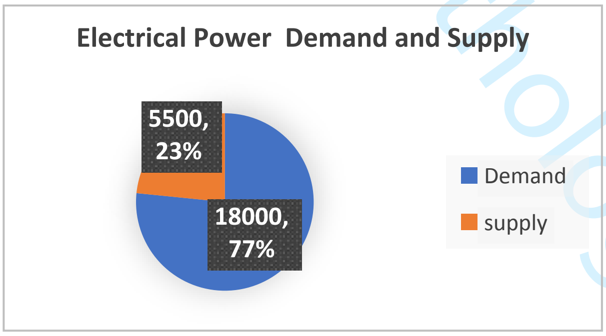

Figure 1: Electrical Power Demand and Supply Chat in Nigeria

Source: Adapted from NACOP (2016)

1.3 Significance of the Study

The energy demand in buildings contributes mostly to greenhouse gas emissions in the built environment (Tatenda, 2012). This study focuses on residential buildings since residential buildings in Nigeria have the highest percentage of energy demand and consumption compared to other sectors, most especially industry, and transport amongst others (Figure 2). NACOP (2016) attributed such a high energy consumption difference to people spending more hours in their homes, especially on weekends. However, Tatenda (2012) explains that the increased consumption results from built environment experts, especially the architects, not giving rapt attention to the optimization of building envelopes. Residential building occupants, thus, experience discomfort due to the hot ambient temperature from the accumulation of solar heat gains throughout the day caused by these envelopes (Iwaro and Mwasha, 2013). Therefore, this study is consistent with the UN Sustainable Development Goal 11' *Sustainable Cities' and Communities* and Goal 13' *Climate Action',* respectively.

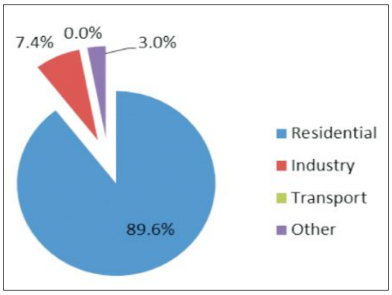

Figure 2: Percentage of Total Energy Consumption by Sectors in Nigeria

Source: FMPWH (2016)

1.4 Aim of Paper

This paper aims to demonstrate the optimization of an existing residential building by using indigenous materials as the alternative for building envelopes, thereby achieving low-energy and affordable housing in Tropical climate areas such as Abuja, Nigeria, and other places with similar climates.

2.0 Literature Review

2.1 Critical Overview of Sustainable Design in the Tropical Climate

Sustainable design is defined as a design strategy to promote the quality of buildings' outdoor and indoor environment by minimizing the negative effects of climate change using passive design strategies (Iwaro and Mwasha, 2013). The way a building is designed and constructed has significant effects on the natural environment. Its result could be directional such as buildings position and pavements on the natural vegetation areas (Cairns Regional Council, 2011). It could also be indirectly such as the processes of sourcing of building materials, i.e., from manufacturing to the transportation of materials to the construction site and via the use of energy sources for electricity supply when the building is in operation, thereby giving rise to greenhouse gas emissions (Asitha, 2007). Lawal and Ojo (2011) agree that the high rate of Energy consumed during building construction and building use contributes immensely to the continuous rise in carbon footprint; hence, there is a need for proper building design with detailed specifications.

2.2 Passive Design Strategies for Buildings in the Tropical Climate

In sustainable design, passive design strategies have a lot of advantages. Passive design strategies are generally accepted energy efficiency design methods in the built environment. It helps to harness natural environmental forces on buildings, reducing household energy consumption, especially for mechanical cooling needed to achieve indoor thermal comfort (Reardon and Clarke, 2013). Passive cooling of buildings in the tropical climate can be encouraged through the following measures:

i. **Cross Ventilation:** Naturally, a cooled internal environment can be achieved by capturing the cooling breezes and utilizing natural air flows from the cross-ventilated room.

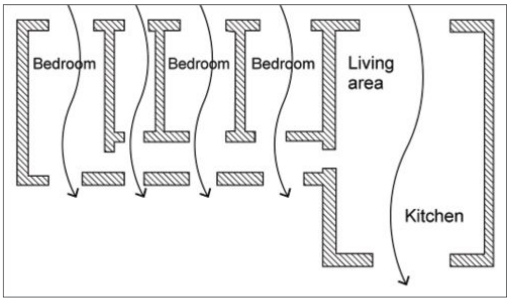

Figure 3: Typical cross-ventilation by cooling breezes

Source: Reardon (2015)

ii. **Orientation**: This refers to the building's positioning on-site to take advantage of the regional climatic features such as prevailing southwest wind and sun path, which helps to achieve natural cooling within the building.

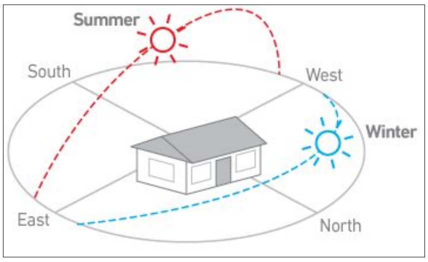

Figure 4: Typical building with longer facades facing north and south directions

Source: Sustainability Victoria (2015)

iii. **Thermal mass:** The appropriate incorporation of high-density and high-heat capacity materials such as bricks, concrete, and tiles into buildings tend to significantly save cooling or heating bills, unlike lightweight materials such as timber with low thermal mass (Figure 5). The material density level and the time lag hinder heat transfer through different envelopes such as cavity brick, brick veneer, and lightweight walling. It can be deduced that the thermal mass level is directly proportional to the time lag, meaning that when the thermal mass of any material is high, then the time for heat to pass through it will be longer. However, low thermal mass is considered more appropriate for tropical climates. Should high thermal mass construction materials be used in the tropics, adequate shading should be provided to reduce heat gain (Ochedi, et al., 2016).

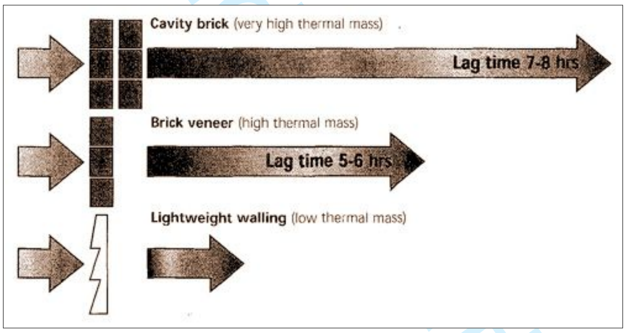

Figure 5: Typical building envelope types and their lag time

Source: Malaysia Clay Brick (2011)

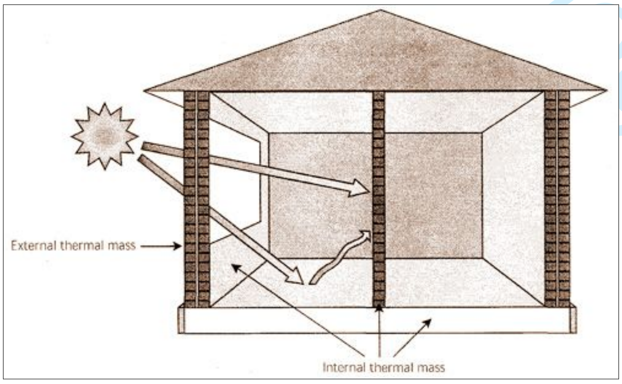

Figure 6: Typical building envelope thermal mass.

Source: Malaysia Clay Brick (2011)

iv. **Insulation:** The introduction of insulation into the building serves as a barrier to heat flow through the building envelope, thereby keeping the building warm in winter and cool during summer. It also serves as soundproofing and weatherproofing. Therefore, for economic reasons, it is good to install insulation during construction.

2.3. Elements of Building envelope

A typical building envelope is made up of the following components:

i. **Walls:** Walls are the major components of any building. Sarigga (2009) states that building walls' significance is often narrowed within the scope of achieving structural stability, functionality, and aesthetics. Walls are, notwithstanding, one of the primary means of achieving desirable thermal comfort within the building. The specified and used building wall materials, finishes, and thickness determine the occupants' heating and cooling needs. According to Reardon and Clarke (2013), walls in tropical climates require air cavities and appropriate thermal insulation to reduce heat gain inside the building. The basic elements of the wall system are Insulating Element(s), Air barrier system(s), Exterior cladding (synthetic or natural), Structural element(s), Drainage plane(s), and Vapour retarder(s).

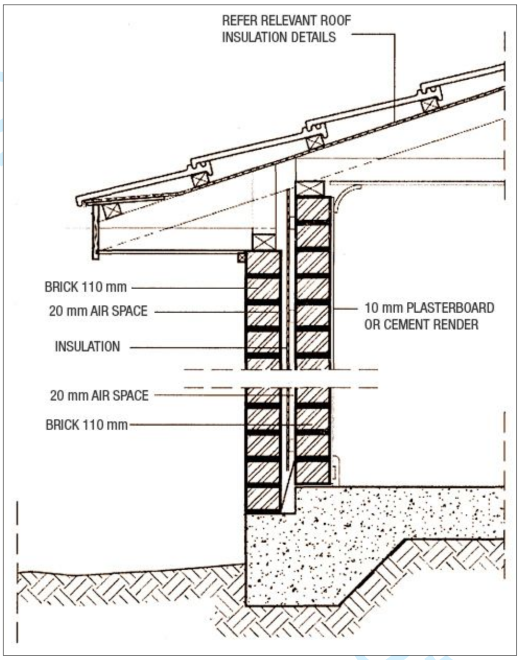

Figure 7: Typical building envelopes (Double Brick Cavity Wall, thermal floor, and Roof)

Source: Reardon and Clarke, 2013

ii. **Windows and Shading Elements:** Windows and shading elements such as blinds, drapery, and window-hood are essential parts of the building envelope. They provide visual and physical connections between the building interiors and the external environment. The exterior window openings allow natural air circulation, daylighting, and heat gain inside the provided spaces. However, it is recommended that exterior windows are well-sized, detailed, and positioned along the prevailing wind direction to maximize natural daylighting and ventilation (Mahmood, 2016).

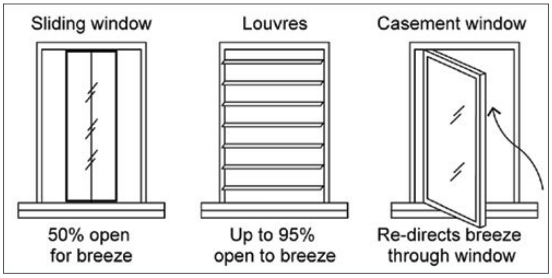

Figure 8: A typical breeze collection through window designs

Source: Reardon and Clarke (2013)

To achieve adequate daylighting and ventilation in the tropical climate. The window fenestrations must be between 15% and 20% of the total internal floor area (Reardon and Clarke, 2013). Rapt attention must also be given to shading devices and glazing systems known to be the essential components of a window in passive cooling design (Sergey, 2015). In Tropical countries like Nigeria, solar altitude should be considered in building designs. The North-South facing envelope elements can be easily shaded with horizontal and overhangs shading (Figure 9). The East-West facades are the most challenging as it requires a workable combination of both vertical and horizontal shadings due to the very low sun angle that is almost perpendicular to the facades (Sustainability Victoria, 2015).

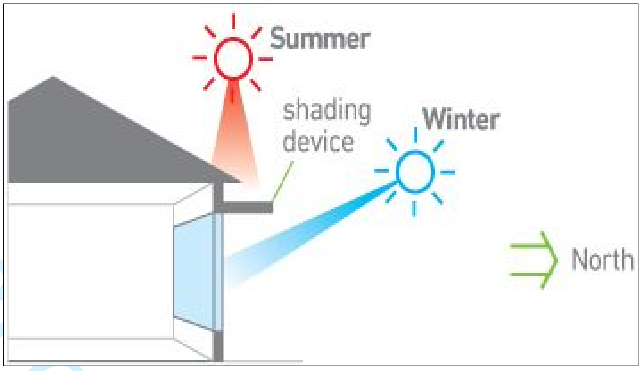

Figure 9: Typical North facing window and shading design for summer and winter

Source: Sustainability Victoria (2015)

iii. Roof: Sarigga (2009) described the roof as one of the critical structural members of any building. It has direct contact with the external environment, such as sunlight in the daytime. The major roof function is to protect against heat gain in buildings, especially during the hottest period of the day. The appropriate application of insulation with roof materials determines the occupant's thermal comfort and energy savings. However, DecorBold (2016) stated that to maximize the roof insulation and ensure efficiency, the factors of emissivity, mass, and reflective air space must be considered in buildings' roof designs (Figure 10).

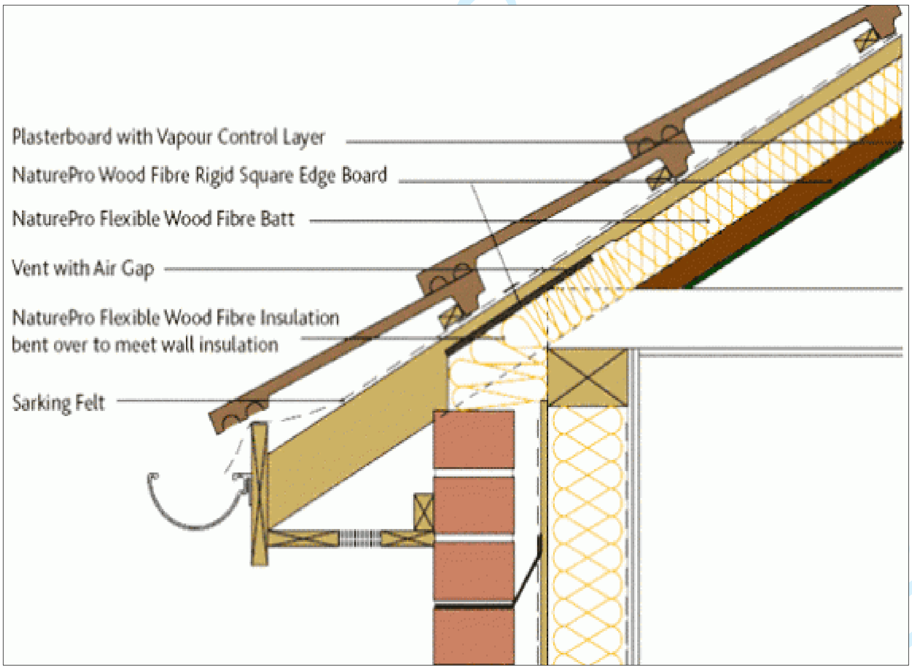

Figure 10: Typical Insulated Roof Details
Source: DecorBold, 2016

iv. Floor

The floor is the most ideal and economical place to receive earth connection and heavy materials for supplementary thermal maintenance (Reardon, 2015). The thermal mass can delay heat transfer via the building envelope, especially the ground floor, by almost 12 hours.

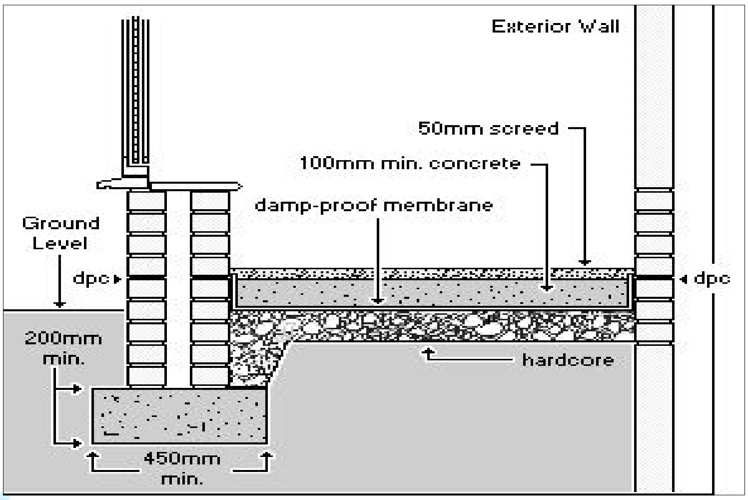

Figure 11: Typical thermal mass floor details
Source: Conservatory-Base, 2010

2.4. Building Envelopes and the External Environment

According to Jiyoung et al. (2016), the building envelope's environmental issues are enormous when considering the rate of depletion of natural resources, massive energy consumption, loss of species and habitat, low building performance, risks of health, and occupant's productivity, amongst others.

Iwaro and Mwasha (2013) and Jiyoung et al. (2016) argued that for a successful fight against environmental hazards on buildings to be achieved, there must be a clear understanding of the three parts of the building, i.e., the exterior environment, interior environment, and the building envelope. Among the aforementioned, the building envelope is seen to be less considered in many developing countries. Meanwhile, they are the major determinant of energy demands for heating and cooling within the building. They are either directly or indirectly in contact with the external environment depending on the building's architectural design (United Nations Environment Programme (UNEP), 2016).

Lawal and Ojo (2011) and UNEP (2016) acknowledge that the external heating loads could be generated from unwanted air infiltration, window solar heat gains, and heat losses through the building envelopes while the internal heating loads could be generated from occupant activities, working equipment, and electric lighting systems (Figure 12).

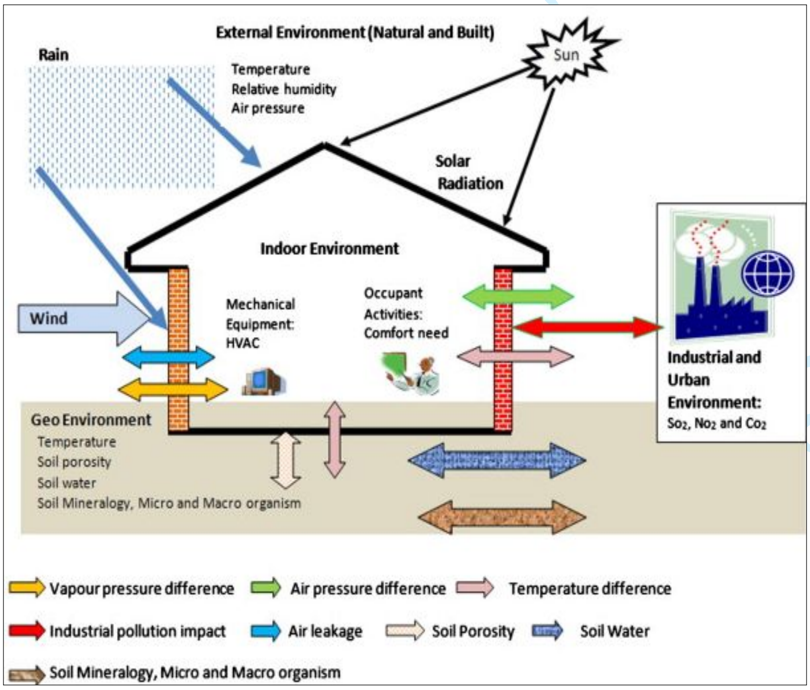

Figure 12: Environmental loads on building envelope

Source: Iwaro and Mwasha, 2013

2.5. Optimisation of the Building Envelope

Generally, the building envelope protects the building occupants and interior components against any form of external elements and weather conditions (UNEP, 2016). Also, to a more considerable extent, they determine the inflow of wind, heat loss, and gain into the building spaces (Latha, Darshana, and Venugopal, 2015). Kalua (2016) states that the heat transfer by convection, conduction, and radiation is mainly via the building envelope components such as floors, external walls, and roof. According to Carbon Trust (2012), it is crucial to develop effective means of reducing carbon emissions through the building envelope. The building envelope optimization can trickle down the heating and cooling load requirements, reduce ventilation bills, and most importantly, increase the thermal comfort of building occupants (Akande, 2010, Latha et al., 2015).

2.6. Benefits of Building Envelope Optimisation

The major benefits of building envelope optimization include (Hanan, 2014, Kalua, 2016, and Ascione, et al., 2016):

i. It creates a comfortable working environment with reduced solar glare, draughts, noise, and overheating; it also enhances the building occupants' output and self-esteem.
ii. It brings about a considerable drop in the building capital expenditure through a more efficient, well ventilated and insulated envelope with little or no heating and cooling load required.
iii. A well-insulated and ventilated envelope adds more value and attractiveness to the building, making it a good investment.

2.7. Sustainable Building Materials for Tropical Climates

According to Haase and Amato (2006), many developing countries are now aware of climate change outcomes such as global warming. They have started incorporating constructive ideas into the built environment for sustainable development, especially by using indigenous materials for building construction (UNEP, 2016). Iwuagwu and Iwuagwu (2015) stated that several researchers give adequate attention and preferences to indigenous materials over conventional materials both at the design and material specification stages. They are considered sustainable since they have little or no environmental impacts, low construction costs, and low Energy running costs in buildings.

2.7.1 Available Conventional Materials and the alternative Indigenous Materials in Nigeria.

Most developing countries in Africa, such as Nigeria, are swimming in the abundance of natural resources enough to meet their building material needs yet dependent on conventional building materials and technologies that have kept the overall construction costs expensive (Iwuagwu and Iwuagwu, 2015). From Table 1 and Figure 12, it can be deduced that the total available conventional building materials for substructure are fairly more than the indigenous building materials while the available indigenous materials for superstructure is relatively more than the conventional materials. This justifies the need to patronize the use of indigenous materials for building construction in Nigeria.

Table 1: List of Available Conventional Materials and the alternative Indigenous Materials in Nigeria.

Serial No	Building Components	Available Conventional Materials	Alternative Indigenous Materials
A	**SUBSTRUCTURE**		
1	Foundation	1. Steel section 2. Cement – Sandcrete Blocks 3. High tensile steel 4. Mild steel and **5.** Flat steel sheets	1. Stonescrete block unit 2. Stones and rocks
B	**SUPERSTRUCTURE**		
1	Floor	1. Steel reinforcement and structural steel 2. Concrete 3. Ceramic Tiles	1. Stones and rocks 2. Timber 3. Bamboo floor and foist

2	Structural Frames and Walls	1. Plywood 2. Steel beams and column 3. Fibreglass 4. Hardboard 5. Particle Board 6. Steel reinforcement 7. Cement sandcrete blocks	1. Adobe 2. Clay bricks 3. Coconut lumber 4. Straw bales 5. Compressed earth blocks 6. Fired/unfired clay bricks 7. Timber 8. Bamboo walls and trusses 9. Sheep wool 10. Stones and rocks
23	Roofing	1. Steel nails structural 2. Fibreglass 3. Aluminium sheets 4. Steel reinforcement 5. Cement concrete roof 6. Steel section 7. Galvanized zinc sheets	1. Asbestos sheet 2. Thatch 3. Straw 4. Zinc sheet 5. Bamboo roof tiles 6. Roof clay tiles.

Source: Adapted from Oloruntoba and Ayodele (2013) and Amal and Halil (2017)

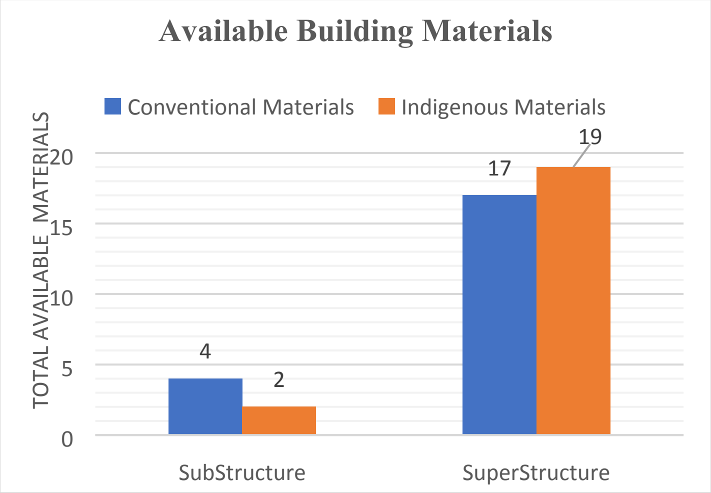

Figure 13: Available Conventional Building Materials and the alternative Indigenous Materials in Nigeria
Source: Adapted from Oloruntoba and Ayodele (2013)

2.7.2. Prospects of Indigenous Materials Patronage

Atolagbe and Fadamiro (2014) and Iwuagwu and Iwuagwu (2015) recognize five advantages in specifying indigenous materials over conventional materials as follows:

i. **Cultural sustainability:** The indigenous materials such as thatches, laterite bricks, mud bricks, timber, bamboo, etc., in respect to their forms, usage, and techniques of their processing, are attributed to the families and the whole community cultural way of life.

ii. **Economic and Affordability Sustainability:** There is a huge tendency to boost the Gross Domestic Profit (GDP) of such countries that embrace the use of indigenous materials regarding financial expenditure, labour, and social prospects. Also, the overall construction cost reduces, thereby paving the way for affordable housing.

iii. **Climatic and Comfort Sustainability:** In tropical climate regions like Nigeria, the careful selection and use of indigenous materials are climate-responsive and help achieve users' thermal comfort within the building.

iv. **Social sustainability:** The utilization of indigenous materials enriches the social lifestyle of the community dwellers in terms of good communication, deeper family ties, welfare, unity, harmony, love, and so on. It is also good to note that transferring ideas during the assemblage of materials enhances intellectual wellbeing.

v. **Ecological Sustainability:** The techniques involved in the production, recycling, waste disposal, regeneration, and reuse of construction waste of indigenous materials is considered to be very cheap and not harmful to the environment.

Oloruntoba and Ayodele (2013) stated that the cost of purchasing building materials is between 60 to 70 percent of the total construction cost, hence the need to encourage the use of indigenous materials in the Nigerian building industry.

3.0 Context Review

3.1. *Geography, climate, and demography of study area*

3.1.1 Geographical Location

Abuja lies between latitudes 8°25' and 9°25' North and longitudes 6°45' and 7°39' east of the Nigeria map with an elevation of about 840m (2760 ft.) above sea-level (Akinniyi and Olanrewaju, 2015). It was strategically carved out from the centre of Nigeria's map. It is just to the North of the confluence of both rivers Niger and Benue. The Abuja land area is about 8,250 sq. km, which is almost three times bigger than that of Lagos state, the former Nigeria federal state capital. It is also defined by two distinct and famous rock formations called 'the Zuma Rock' where Abuja emanated and Aso Rock located towards the eastern part of the city. Abuja metropolitan public layout appreciates its features. The features are the expressway, Abuja City, and their connectivity to the satellite areas such as Mpape, Kubwa, Nyanya, Bwari, and Lugbe, amongst others. Lugbe was captured as the most appropriate for this research case study due to its unique location, ease of accessibility, closeness to the International Airport of Abuja and the Abuja central area.

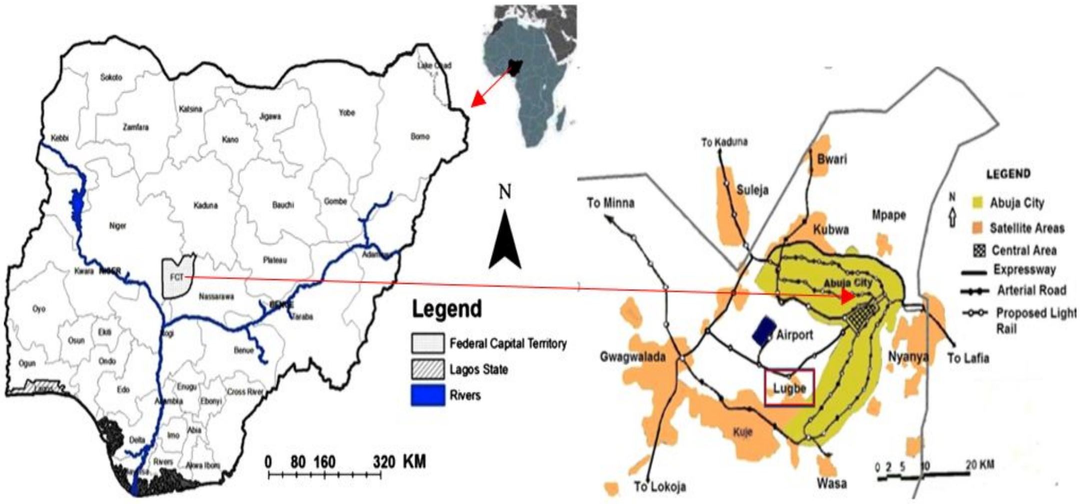

Figure 14: Nigeria Map Blown from Africa Map showing Abuja Metropolitan Public

Source: Adapted from Abubakar (2014)

3.1.2. Climate Data

According to Batagarawa (2013), Abuja experiences three weather conditions annually, including a dry season between November to March, a warm, humid, wet season between April to October. Also, there is a brief interlude of harmattan in between the aforementioned weather conditions. Abuja city's predominant climate conditions, such as the average annual temperature for the daytime, are about 28°C while it drops to 21°C at night (Figure 15). These weather conditions are considered appropriate to represent typical weather conditions in Tropical climate; hence the selection of Abuja, Nigeria, for this research. Also, the annual average daylight hours are 12hrs while the average precipitation is 1221mm. According to Meteoblue (2017), the wind rose for Abuja indicates how many hours per year, the wind blows from the indicated direction. For instance, the wind blows from the South-West (SW) to North-West (NE) direction. The wind rose study was used to select a site and a housing type. This helps to examine its effects on the study area. The building's annual operative temperature will determine further interventions for retrofitting and new construction methods for future building designs. The expected major sustainable design preliminaries to be considered is integrating natural cross-ventilation such as the South / West prevailing wind (Figure 16).

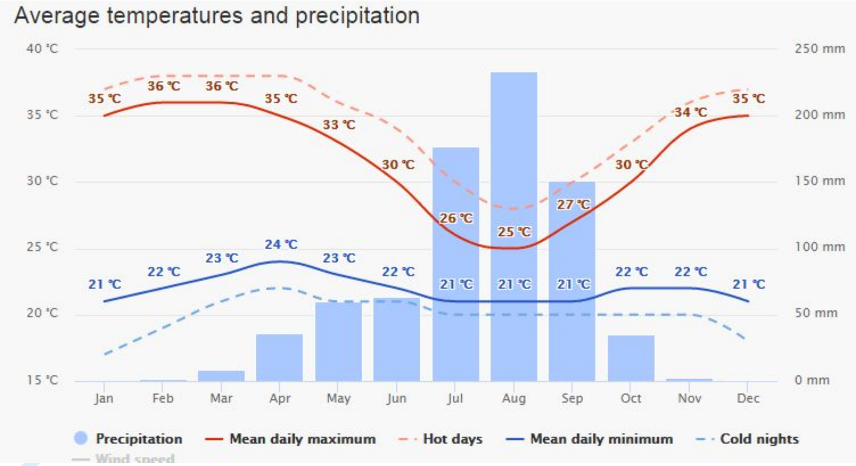

Figure 15: Average temperature and precipitation for Abuja

Source: Meteoblue (2017)

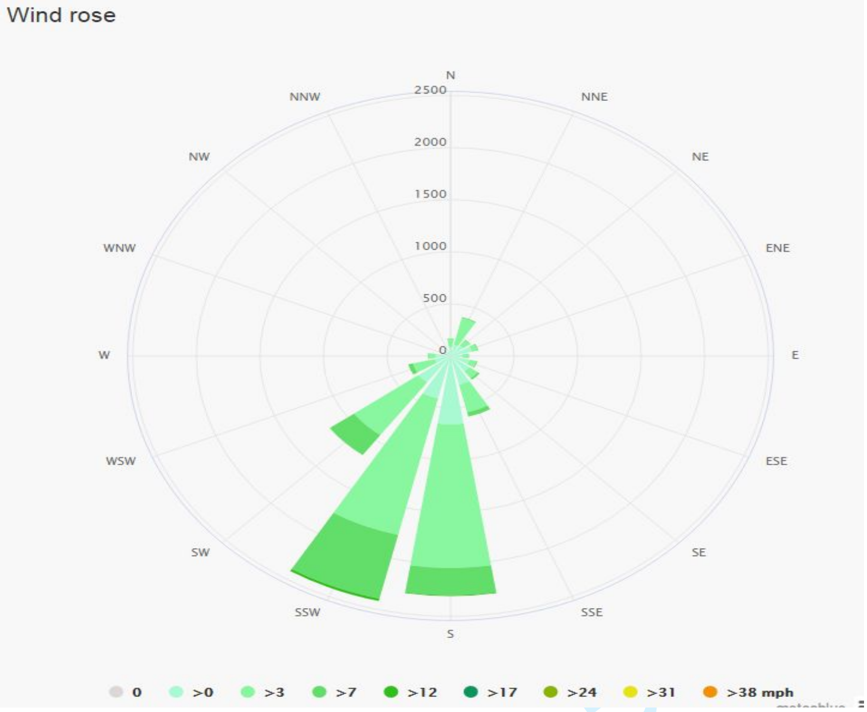

Figure 16: Wind rose diagram for Abuja
Source: Meteoblue (2017)

3.2 Historical Overview of Abuja Housing Development

According to Akinniyi and Olanrewaju (2015), adequate housing supply is one of the major criteria used to measure the standard of living in any country as it serves as a pointer to determining both their social and economic values. In Nigeria, the National Bureau of Statistics (NBS, 2015) stated that over the years, in most urban centres, such as Port Harcourt, Lagos, Kano, and Abuja there have been huge challenges in providing adequate housing for the ever-increasing population even at the hub of the housing boom. For instance, in Nigerian cities, the estimated cost of a house has escalated by about 400-500%, while cities in India and South Africa only increased by approximately 285% and 210%, respectively (Figure 17). Alao (2009), Fadairo and Olotuah (2013) posited that the Nigerian cities are the most expensive amongst other cities when compared to other developing countries with similar climates. Abubakar (2014) acknowledges a severe challenge of the housing shortage in Nigeria even though there is no tracking or documented data on its demand and supply. The reason for this housing challenge was partly traced to the federal government's inability to adequately provide accommodation for the massively deployed employees to Abuja from Lagos in the early 1980s (Akinniyi and Olanrewaju, 2015).

In the 1980s and 1990s, the federal government constructed 22,000 housing apartments in Gwarinpa Phase III in an attempt to reduce the overwhelming housing deficit. This scheme was intended to house the junior cadre employees, also referred to as low-income earners but were later occupied and owned by the senior public employees known as Middle or High-income earners through monetization exercises organized by the federal government (Ukoha and Beamish, 1997). The private developers' involvement in producing affordable mass housing in Abuja proved abortive as it came out opposing its main aim for affordable housing. Therefore, it was challenging for the city's low-income earners to subscribe and own a roof over their families. Olotuah (2015) highlighted that these challenges are over 20% interest on available housing mortgage, collateral encumbrance, developers' inability to timely secure land through the government, over 47% of the Abuja households earn far low compared to the city's cost of living.

The clamouring force for affordable housing amongst the low-income earners has been recently played down due to a lack of active and favourable policies, thereby allowing the private housing developers to hike the prices of the buildings (NBS, 2015). Abubakar and Doan (2010) and Myers (2011) advocated for the adoption of new policies in the interest of the low-income earners, thereby making it possible for them to own a house in the cities effortlessly. The advocacy includes; Increment of residential occupier density through the amendment of some zoning regulations, the provision of an affordable and flexible mortgage system, the Encouragement of Government and private developers, massive use of local technology and building materials. However, the above general overview of the Abuja city housing development from inception is instrumental to this research work. It helps identify the problems associated with affordable housing delivery and possible solutions, such as indigenous materials.

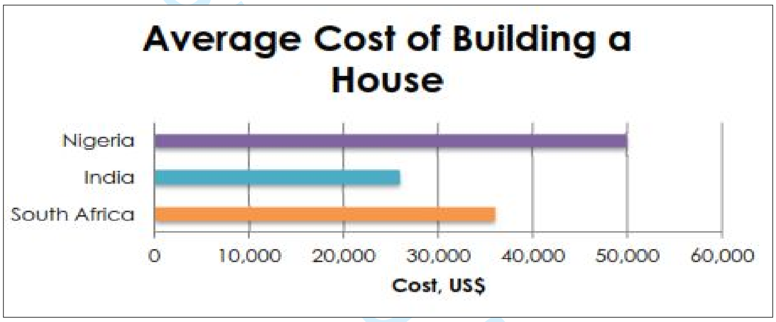

Figure 17: Average Cost of Building a House in Nigeria, India, and South Africa

Source: NBS (2015)

4.0. Methodology

4.1. Introduction

This study was executed using both qualitative and quantitative (mixed) analytical methods. The qualitative method involved carrying out a critical literature and context review using existing materials such as journal articles, textbooks, articles, and secondary data. This method helped to gain in-depth insight into sustainable design strategies for Tropical climates and to identify associated relevant research gaps. The quantitative method primarily involves a dynamic simulation study using the EnergyPlus simulation tool in DesignBuilder (Olaniyan, 2012). This simulation tool helps to create an artificial environment where raw climatic data from the area under study was generated and preloaded. EnergyPlus gives the freedom to generate relevant information that permits a system-subsystem active behaviour of the building model under controlled conditions (Nedhal and Sharifah, 2011). This method helps to predict the current and future conditions of buildings; such as determining if the average annual indoor thermal comfort falls within the acceptable range for tropical regions. The computer modeling techniques have been widely promoted in the current literature as a useful, accurate, efficient, and reliable tool for building optimization (Olaniyan, 2012). They save time and money compared with a range of available quantitative research methods (Onyenokporo and Ochedi, 2019). In this study, a simulation study using the EnergyPlus simulation tool in DesignBuilder was adopted to test a selected building prototype that represents the dominant residential building for an average low- and middle-income earners.

Figure 18 describes how this research was carried out from research motivation to conclusion and recommendations. The motivation for this study arises from the need to promote energy-efficient and affordable residential buildings using indigenous materials. A critical literature and context review were conducted to formulate the research questions. To achieve the research, aim and objectives were drawn from the research questions, a base-case model (building under study) was developed using the DesignBuilder tool. The climatic data were preloaded and the as-built conventional building envelopes were selected before carrying out the model simulations. To improve on the base-case model, the external materials such as walls, roof and floor were replaced simultaneously with indigenous materials. Several analyses were conducted to determine if the research aim and objectives were met before concluding with recommendations for further studies.

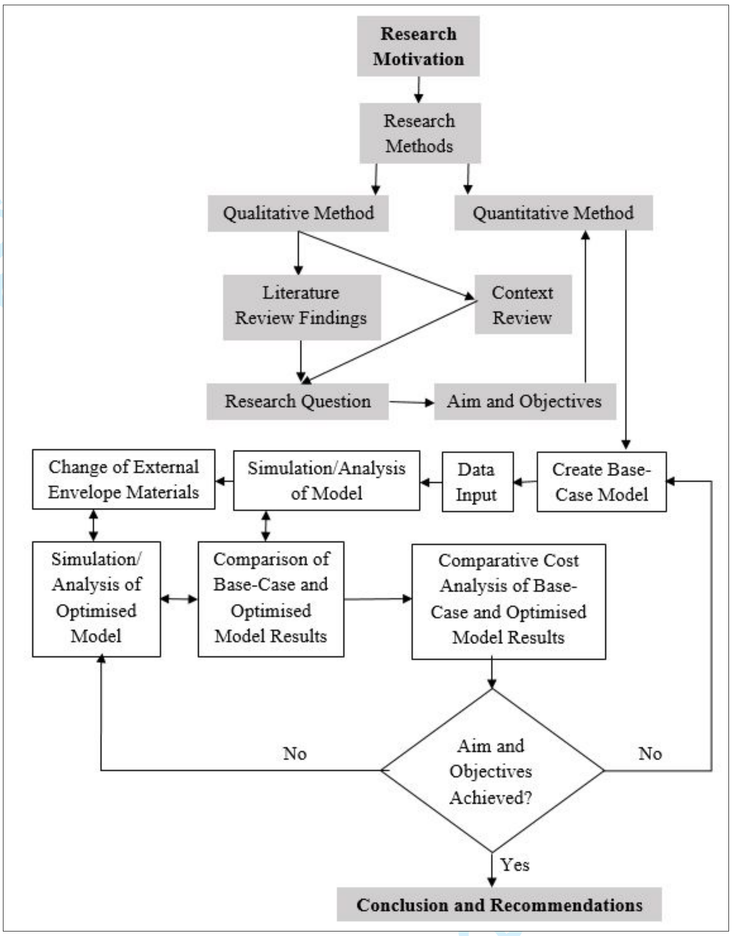

Figure 18: Research Design Algorithm

Source: ~~Olumide Jegede (2017) a~~Adapted from CIBSE (2020) Quality flow chart

5.0 Research Findings and Discussion

5.1 Case Study Building

The evaluation of the energy performance of a building in any location requires building and site-specific information (Onyenokporo and Ochedi, 2019). The selected site layout covers about 185 hectares of land. Its development process is comprised of six stages during this research. The housing prototype under study falls within stage two and phase three (Figure 19). The whole site comprises different housing prototypes such as a two-bedroom bungalow (in red hatch), three-bedroom bungalow (in black hatch), four-bedroom maisonette (in the blue hatch), and five-bedroom fully detached duplex not captured in the site call-out plan. It can be deduced from the site that the three-bedroom bungalows have the highest volume on the site layout and will be the focus of study in this paper. All three-bedroom bungalows' longest elevations face the North/South (N/S) while the shortest sides face East/West (E/W) directions, respectively. The highlighted building in the red box was chosen to represent other buildings with the same orientation on site. The building is surrounded by similar buildings in the North, South, and East directions. The building illustration drawings (Figure 20) showed a single-family fully detached bungalow of three bedrooms, all en-suite with ante-room, main living lounge, visitor toilet, box room, dining, kitchen, and store. The building is about a 195 squares metres floor area sitting on a 485 square metres plot of land. The built-up area is approximately 40% of the total plot area.

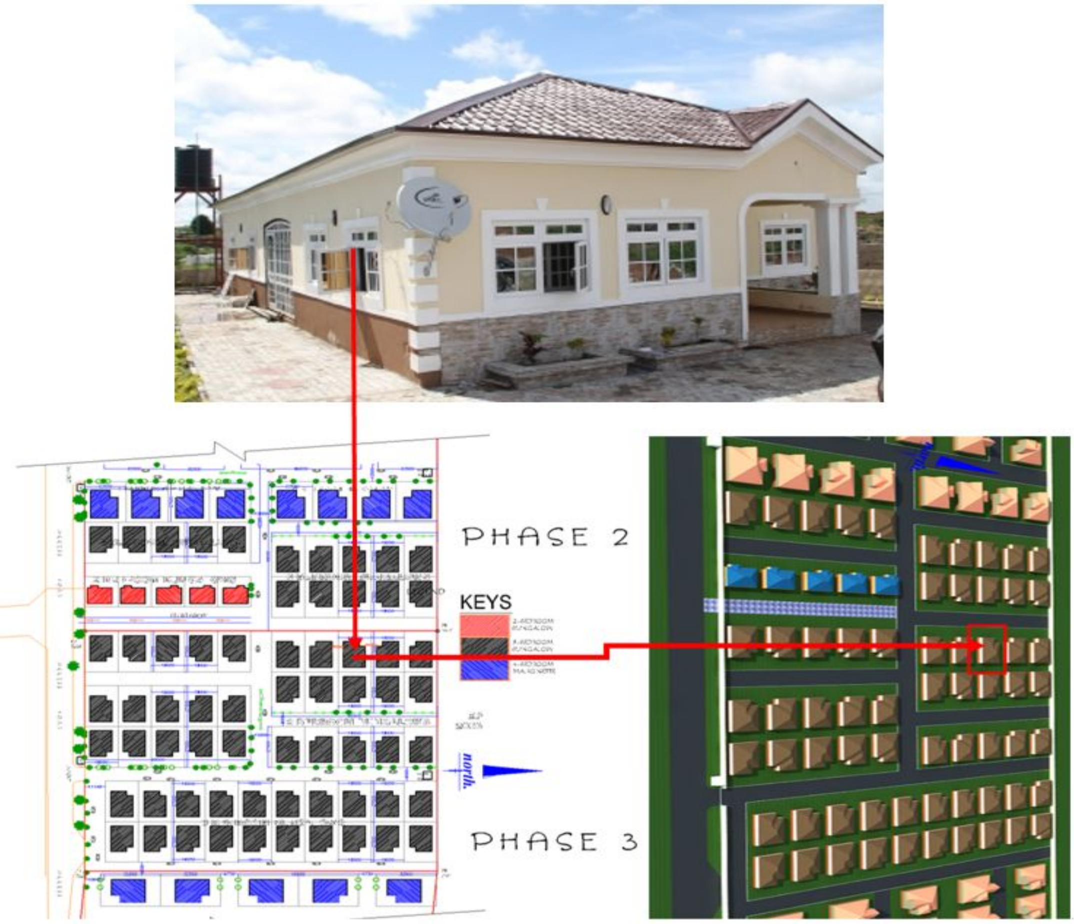

Figure 19: Photograph and Layout showing case study building

~~Source: Olumide Jegede (2017)~~

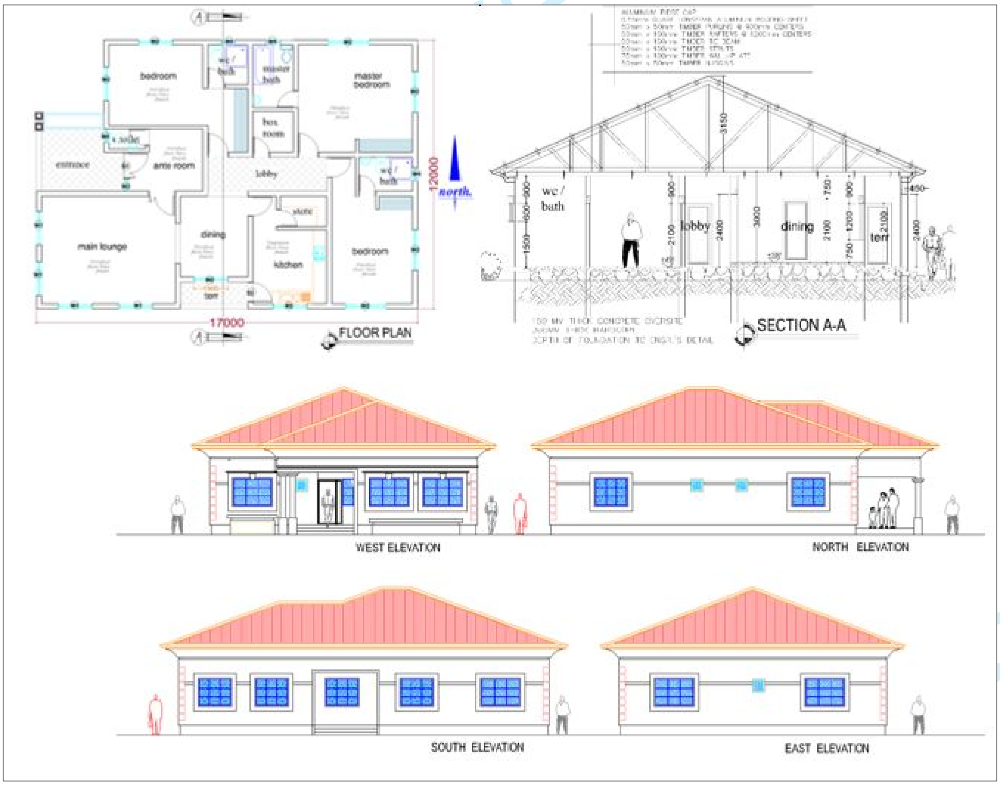

Figure 20: Floor plan, Section and Elevations of case study

~~Source: Olumide Jegede (2017)~~

Table 2: Building components with corresponding U-values

Case study	Building Envelope	Description	U-Value (W/m²K)
3Bedroom Bungalow	Ground Floor	150 mm Oversite Concrete. A thick damp-proof membrane on 450mm well ramped Laterite.	2.412
	External walls	30mm Hollow Sandcrete blocks with 13mm plastering on both sides.	2.683
	Roof	5mm thick longspan Aluminium Roof covering nailed on well-seasoned timber with *450mm* overhang fascia concrete.	0.775

~~Source: Olumide Jegede (2017)~~

5.1.1. Natural Daylighting and Sun Path Analysis

Analysis of figure 21 and table 3 shows that the natural daylighting of the building under study is marked as FAIL meaning it did not meet 80% of the area for adequate daylight. Also, marked as FAIL for not meeting the uniformity ratio >= 0.3, min DF = 0.8%, and BREEAM (Building Research Establishment Environmental Assessment Method) health wellbeing Credit HEA01 benchmarks. These results show that the building will require artificial lighting to complement the inadequate natural daylighting. This could be a result of inadequate and inappropriate positioning of windows which, additionally, will add to the energy load of the building. To PASS the benchmarks, the windows must be strategically positioned, efficiently designed, and manufactured using adequate materials. This must be done carefully to avoid excessive solar heat gains into the building and increment in overall construction cost. The sun path analyses were carried out to examine the sun's movement around the building under-study, its shadow effect, and the impact of solar radiation. The sun rises from the east and sets in the West. For emphasis, the two predominant weather conditions in the context area were analysed. At 12:00noon, the sun angle is almost overhead during the dry season, while it is slightly tilted during the rainy season (Figure 22). The building roof is directly exposed to solar radiation and did not provide shading to some of the windows in the early hours of the day when the sun is just rising and towards the evening when the sun is about to settle.

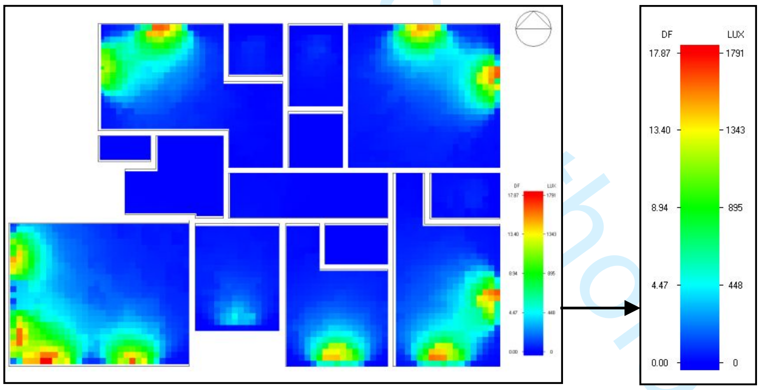

Figure 21: Daylighting Map

Source: DesignBuilder (2017)

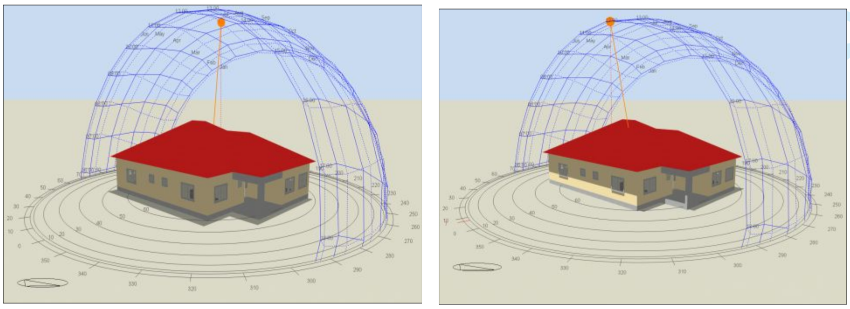

Figure 22: Sun Angle in March 21st (Dry Season) and July 21st (Raining Season) at 12:00Noon

Source: DesignBuilder (2017)

Table 3: Daylighting study Overall Benchmark

Benchmark	Results
80% of the area adequately daylight	Fail
Uniformity Ratio >= 0.3, min DF = 0.8%	Fail
BREEAM Health Wellbeing Credit HEA01 Status	Fail

Source: DesignBuilder (2017)

5.1.2 Simulation results for Base-Case Model

To determine the existing building envelope's thermal performance, appropriate weather data simulation for the study context was used. The simulation was first carried out using natural ventilation, without heating /cooling. The first simulation results showed that the annual operative temperature of the base-case model is about 30.52ºC. This is considered uncomfortable when compared to the average thermal comfort range of between 25°C and 28°C in Tropical climate regions (Table 4).

Table 4: Average Thermal Comfort Range and Thermal Sensation for Tropical Climate

Average Thermal Comfort	*Thermal Sensation*
25°C ≤ 27°C	Very Comfortable
27°C ≤ t ≤ 28°C	Comfortable
28°C ≤ t ≤ 29°C	Comfortable to Slightly Uncomfortable
29°C ≤ t ≤ 30°C	Slightly Uncomfortable
≥ 30°C	Uncomfortable

Source: Soebarto and Handjarinto (1998) adapted from ASHRAE 55-1992

Table 5: Monthly Operative Temperatures with highlighted months within the comfort zone.

	Jan (ºC)	Feb (ºC)	Mar (ºC)	Apr (ºC)	May (ºC)	Jun (ºC)	Jul (ºC)	Aug (ºC)	Sep (ºC)	Oct (ºC)	Nov (ºC)	Dec (ºC)
Operative Temperature	30.90	32.84	32.19	32.16	31.23	29.76	28.84	28.13	28.49	29.06	30.88	30.01
Outside dry-bulb temperature	27.21	29.04	30.38	28.59	27.36	25.93	24.93	24.32	24.83	25.32	27.06	26.08

5.2. Optimized Model Intervention Developments and Simulation Analysis

The optimization interventions were simultaneously carried out on the building envelopes such as the Ground floor, External wall and roof covering to achieve a reasonable reduction in the external heat gains which determines the average monthly and annual thermal comfort temperatures. The following is the order of optimization processes utilized in this study (Table 8*)*.

Optimized Model 1: The introduction of a well-compacted hardcore of 300mm depth into the base-case model ground floor brought about a significant reduction of 50.66% in its U-value from 2.412W/m²k to 1.190W/m²k. Also, the existing external walls made of 230mm hollow sandcrete block was replaced with cavity bricks of the same thickness thereby reducing its U-values by 41.15% significantly from 2.683W/m²k to 1.579W/m²k. However, the existing roof covering material (longspan aluminium) with 450mm overhang fascia concrete remains untouched to ascertain the thermal energy reduction from the major changes made in the floor and external walls. The optimized model 1 simulation result shows that the building annual operative temperature dropped by about 3.64% from 30.52ºC to 29.41℃ (Table 5). This is considered uncomfortable when compared to the average thermal comfort range of between 25°C and 28°C, hence the need for further optimization (Table 4).

Optimized Model 2: The roof overhang was considerably increased from 450mm to 600mm with its material changed from a fascia concrete to a wooden fascia board. These were done in a bid to reduce the amount of solar heat gain through the external window openings. The third simulation results showed a noticeable 10.69% drop in annual heat gain through the external window openings from 8644.98 kWh to 7720.50kWh. Also, there was a significant reduction of 6.72% in the average annual operative temperature from 30.52ºC to 28.47ºC. Hence, considering the average monthly operative temperatures, the months within the considerable thermal comfort zone increased from three to eight months annually (Table 6). Although, these eight months can still be classified as comfortable to slightly uncomfortable to Table 4.

Optimized Model 3: As acknowledged in the literature review, roof insulation is another way of reducing solar heat ingress (Figure 10). A 200mm thickness of reed thatch (indigenous material) was introduced by selection along the roof rafter which dropped the as-built roof U-value by 63.23%, as well as a 25.92% reduction in annual heat gain. This further reduced the average annual operative temperature by 7.47%. These upward improvements are evident in the average monthly operative temperatures. Table (7) shows that mechanical cooling systems are only needed between February and April annually.

Optimized Model 4: To further improve on the optimized 3 model. The roof covering made of Longspan aluminium was replaced with an indigenous Clay tile. It is important to note that the Longspan aluminium roof covering is also produced locally but less patronized than the imported ones. The simulation results have shown a reduction in 63.87% U-value and 7.57% average annual operative temperature.

Table 6: Monthly Operative Temperatures with highlighted months within the comfort zone.

	Jan (℃)	Feb (℃)	Mar (℃)	Apr (℃)	May (℃)	Jun (℃)	Jul (℃)	Aug (℃)	Sep (℃)	Oct (℃)	Nov (℃)	Dec (℃)
Operative Temperature	28.88	30.62	32.10	30.29	29.13	27.71	26.75	26.12	26.56	27.00	28.71	27.94
Outside dry-bulb temperature	27.21	29.04	30.38	28.59	27.36	25.93	24.93	24.32	24.83	25.32	27.06	26.08

Table 7: Monthly Operative Temperatures with highlighted months within the comfort zone.

	Jan (℃)	Feb (℃)	Mar (℃)	Apr (℃)	May (℃)	Jun (℃)	Jul (℃)	Aug (℃)	Sep (℃)	Oct (℃)	Nov (℃)	Dec (℃)
Operative Temperature	28.57	30.36	31.91	30.11	28.94	27.51	26.56	25.93	26.38	26.80	28.43	27.63
Outside dry-bulb temperature	27.21	29.04	30.38	28.59	27.36	25.93	24.93	24.32	24.83	25.32	27.06	26.08

Table 8: Optimized Model Intervention stages with Percentage Reductions Relative to Base Case

Models	**Building Envelope**			**Annual Solar Heat Gains**		**Annual operative temperature**	
	Building Component	***U-Value (W/m²K)***	***% Reduction relative to Base-case***	***(kWh)***	***% Reduction relative to Base-case***	***(℃)***	***% Reduction relative to Base-case***
		Interventions					
Base-Case	*Ground Floor*	2.412	-	*8644.98*	-	*30.52*	
	Wall	2.683	-	-	-	-	
	Roof	0.775	-	-	-	-	
Optimized 1	*Ground Floor*	*1.190*	*50.66*	*8113.03*	*6.15*	*29.41*	*3.64*
	Wall	*1.579*	*41.15*				
	Roof	0.775	-				
Optimized 2	*Ground Floor*	-	-	*7720.50*	*10.69*	*28.47*	*6.72*
	Wall	-	-				
	Roof	*Change of Overhang from 450mm to 600mm. Material changed from concrete fascia to wooden fascia board while roof covering not changed.*					
Optimized	*Ground Floor*			*6404.47*	*25.92*	*28.24*	*7.47*

3	*Wall*						
	Roof	*Insulated with reed thatched of 200mm thickness*					
		0.285	*63.23*				
Optimized 4	*Ground Floor*	-	-	*6403.12*	*25.93*	*28.21*	*7.57*
	Wall	-	-				
	Roof	*Change of roof covering to Clay tiles*					
		0.280	*63.87*				

~~Source: Olumide Jegede (2017)~~

5.3 Comparative Cost Analysis

This section covers comparative cost analysis using the optimized models 3 and 4 as they exhibited better performance than models 1 and 2. The comparative cost analysis is crucial in this research and the end product of the optimized model aims to pave the way for affordable housing delivery in Nigeria. This analysis considered the building envelope materials for the floor, wall, and roof of the selected building in the study area. It addressed the existing building using conventional materials (Base-case) and the last two optimized models with desirable results. This aims to determine the capital costs of the outstanding interventions regarding annual operative temperature and cooling loads concurrently. Figure 23 below was extracted from the prepared bill of quantity (BOQ) for analysis. The results show that there were 41.81% and 26.00% reductions in the capital cost of construction for Optimized model 3 and 4 compared to the base-case model at the time of this research. Therefore, the BOQ has proven that the massive use of indigenous materials reduces the cost of construction materials in both optimized models (Table 9).

Table 9: Comparative cost analysis of both the base-case model and optimized models

Scenarios	**Measures**	**Quantities**	**Total Cost (₦)**	**% Reductions relative to Base-case**
Existing External Conventional Building Materials **(Base-case model)**	**Substructure**: External foundation wall: 225mm, sandcrete blocks and oversite concrete: 150mm thickness	$29m^3$	1,018,000.00	
	External walls: 225mm hollow sandcrete blocks	$150m^2$	630,000.00	
	Roof covering: Longspan Aluminium made in China, Concrete fascia	$195m^2$	3,040,000.00	
		Total	**4,688,000.00**	
Proposed External Indigenous Building Materials **(Optimized model 3)**	**Substructure**: External foundation wall: 225mm, sandcrete blocks and oversite concrete: 150mm thickness	$29m^3$	1,018,000.00	**41.81%**
	External walls: Cavity Bricks	$150m^2$	525,000.00	
	Roof covering: Longspan Aluminium made in Nigeria with a wooden fascia of 600mm projection	$195m^2$	1,184,900.00	
		Total	**2,727,000.00**	
Proposed External Indigenous Building Materials **(Optimized model 4)**	**Substructure**: External foundation wall: 225mm, sandcrete blocks and oversite concrete: 150mm thickness	$29m^3$	1,018,000.00	**26.00%**
	External walls: Cavity Bricks	$150m^2$	525,000.00	
	Roof covering: Clay Tiles made in Nigeria with a wooden fascia of 600mm projection	$195m^2$	1,925,900.00	
		Total	**3,468,900.00**	

~~Source: Sebolatan Oluwafemi Ipaye (*MNIQS, RQS*, 2017)~~

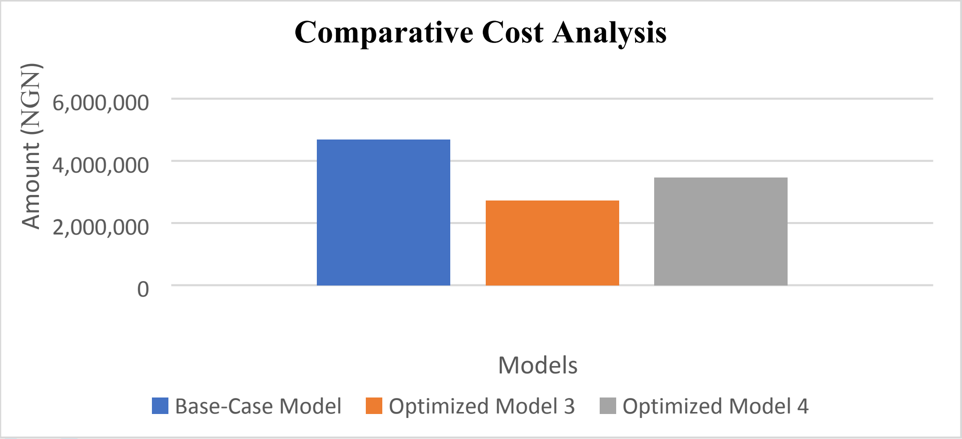

Figure 23: Comparative Cost Analysis between Base-Case Model and Optimized Models

5.4 Cooling Loads and CO_2 Emission Comparative Analysis

The evaluation of cooling loads was deemed necessary since thermal comfort formed part of this research's purpose. This comparison is between the base-case model and the optimized model 3. Optimized model 3 is considered to have the best performance in the simulation studies with a significant 35.78% reduction in the annual cooling loads and with a considerable reduction in the annual CO_2 emissions by 32.31% (Figure 24). The months of February, March, and April remain the hottest months and this is mostly during the peak of the day (Figure 25). The optimized model 4 has no significant drop in both the annual solar heat gains and average thermal comforts.

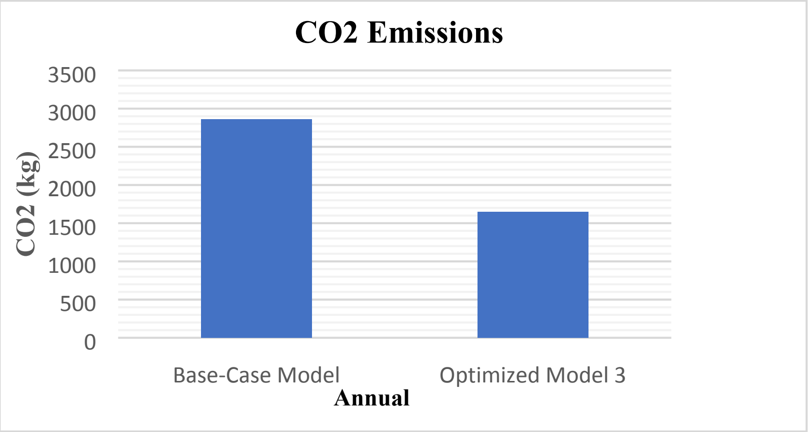

Figure 24: Annual CO_2 Emission comparison between Base-Case Model and Optimized Model 3

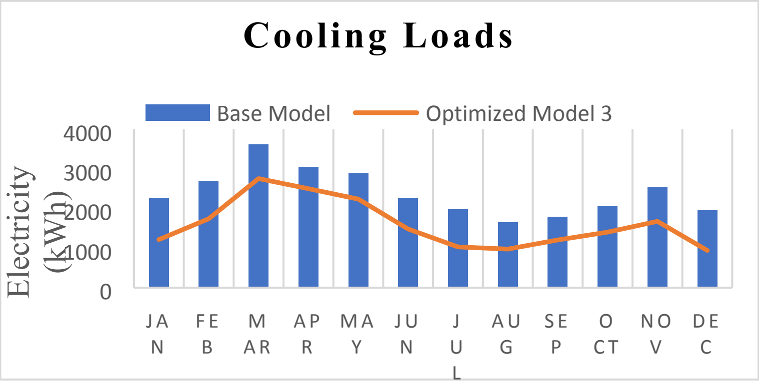

Figure 25: Monthly cooling loads comparison between Base-Case Model and Optimized Model 3

5.5 Improved Building Envelopes and their Interventions

Figure 26 represents a 3D illustration of the final green building using indigenous materials; figure 27 illustrates the guidelines for constructing these buildings in Abuja, Nigeria. The substantial reductions in U-values of optimized model 3 for the ground floor, external walls, and roof were considered suitable for green building in hot and humid climates (Crawford, 2018).

Figure 26: 3D illustration of the final green building using indigenous materials in building construction.

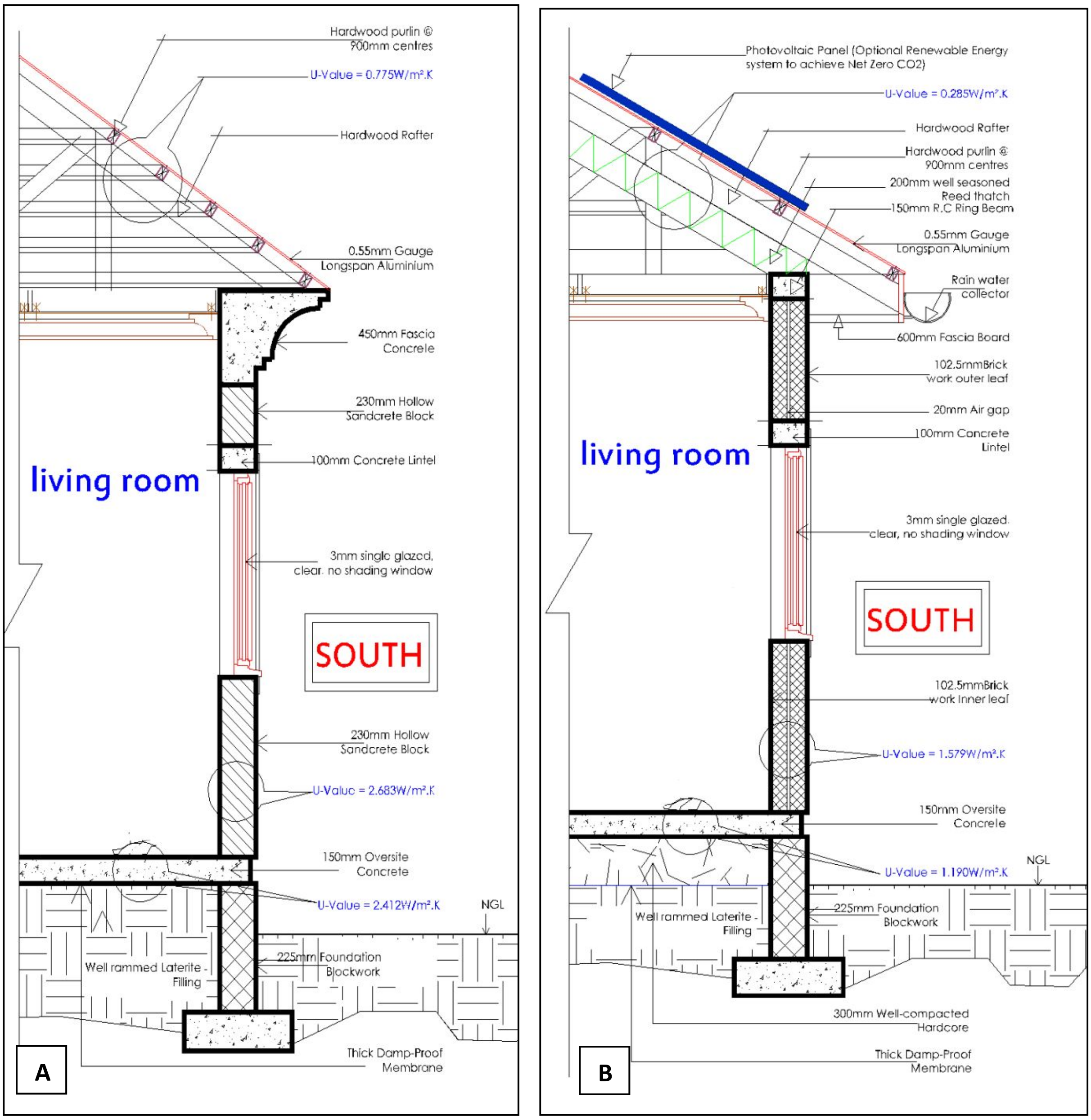

Figure 27: Sectional views showing the As-Built Construction Method (A) and Proposed optimized Construction Guideline (B)

~~Source: Olumide Jegede (2017)~~

6. 0 Conclusion and Recommendations

6.1 Main findings and outcomes

The literature and context review conducted in this study recognized the importance of building envelopes optimization using indigenous materials amongst other passive design strategies. In developing countries with Tropical climes, this is key to achieving indoor thermal comfort and downsizing energy consumption. Several simulations were carried out on the building under study (Base-case model) using the EnergyPlus simulation tool in DesignBuilder. This helped to predict the average annual thermal comfort gaps while a bill of quantities was prepared to ascertain these interventions' cost implications. The Base-case model simulation result showed that the annual operative temperature is considered way above the average thermal comfort range by 8.26%. This is expected to trigger overconsumption of energy and an increase in CO_2 emissions annually while trying to achieve indoor thermal comfort using mechanical cooling systems. However, the final simulation results for the optimized models proved that using indigenous materials for the ground floor, external walls, and roof could bring about a significant reduction of about 8% in operative temperature, thereby increasing the predicted three months of thermal comfort in the base-case model to nine months annually. There were also 32.31%, 35.78%, and 41.81% reductions in the annual CO_2 emissions, cooling loads, and construction costs respectively.

6.2 Recommendations

Further investigation is recommended by monitoring the hourly temperature of a retrofitted or a newly constructed residential building using the optimized construction guidelines in countries with tropical climates. This would help in evaluating the post-occupancy thermal comfort, materials acceptance, and the easiest/suitable construction technique for implementation.

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