JOURNAL OF DESIGN FOR RESILIENCE
IN ARCHITECTURE & PLANNING

Research Article
Online: www.drarch.org
Volume 4, Issue 3, (354-371), 2023
DOI: 10.47818/DRArch.2023.v4i3102

Climate resilience and energy performance of future buildings in Nigeria based on RCP 4.5 and 8.5 scenarios

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Abstract

The predicted rise in global temperature by the Intergovernmental Panel on Climate Change IPCC appeals for a review of the methods and materials used for building construction for reduced emissions and comfort in buildings. Buildings account for the most carbon emissions in the globe. This study presents the impact of temperature change across the 36 state capitals in Nigeria, and the Federal Capital Territory, FCT, based on Representative Concentration Pathways, RCPs 4.5 for 2020 and 8.5 for 2090. A simple studio apartment with optimised alternatives for retrofits and new builds was simulated using EnergyPlus for both climate scenarios to determine the strategies for improving the energy performance of future buildings. The result of the study shows a significant increase in mean monthly outdoor temperature of about 5°c across the states, with potential heat stress affecting buildings in future climates. Moreover, about one-third of the locations experience a shift in climatic zones to hotter ones. The impact of this climate drift will be more severe in the Northcentral and Southwest regions of the country. The design strategies recommended to mitigate the effects of a changing climate focused on building envelope insulation, thermal mass, and solar shading. The performance of the optimised models under future scenarios accounts for up to 25% and 73% savings in cooling energy for retrofits and new builds, respectively. To protect existing buildings from the impact of future climates, developers must make massive investments in solar shading of buildings. In contrast, a combination of envelope insulation and solar shading strategies proves effective for new builds.

Keywords: building optimisation, climate scenarios, energy performance, future buildings, representative concentration pathways

1. Introduction

Like its global counterparts, the Nigerian climate is marked by the intrinsic attributes of variability and unpredictability. It is likely to experience unprecedented shifts in temperature levels, rainfall and storms throughout the 21st century (Sayne, 2011). Following climate projections, there will be changes in rainfall patterns with an increase in temperature in the coming decades. The Nigerian Meteorological Agency NiMET warns that the average temperature in cities in Nigeria is likely to increase, which may lead to thermal discomfort (Agabi, 2023; Falaju, 2023). As outdoor temperature increases, the energy performance of buildings will be affected. As stated by (Ramos Ruiz & Olloqui del Olmo, 2022), buildings' energy efficiency is regarded as a critical factor in the move toward a low-carbon economy. Buildings in Nigeria, like other parts of the world, are vulnerable to climate change impact. In the European Union, for example, most regulations to mitigate climate impacts are geared towards fewer consumptions with increased energy efficiency

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Article history: Received 09 May 2023, Accepted 28 November 2023, Published 17 December 2023

(Ramos Ruiz & Olloqui del Olmo, 2022). Precisely, a changing climate leads to increased energy demand for cooling, reduced indoor comfort because of increased outdoor temperatures, and damage to building materials and infrastructure due to extreme weather occurrences such as tropical storms, hurricanes and floods. As temperatures continue to rise, buildings in Nigeria will need increased cooling to keep a comfortable indoor temperature, which can increase energy demand and carbon emissions. Consequently, the demand for energy for cooling can lead to multiple power cuts and collapse on the electricity grid due to strain from system loads (Fabbri et al., 2020).

There are efforts by the Nigerian government through the energy transition programme towards shifting to a low-emission economy to align with the European Union's net-zero target. These government endeavours, perceived as an ambitious target, are greeted with several challenges, including poverty and overpopulation (Abubakar, 2022). Additionally, (Kristl et al., 2020) emphasised that one of the challenges to climate change adaptation in the building sector is the need for more building policies and legislation governing buildings. A study conducted by (Allu, 2014) also opines that the lack of design guides and carbon emissions data in residential buildings in Nigeria is linked with the evidence of the negative impacts of climate change experienced. Likewise, the depletion of natural resources and the lack of re-use in the construction industry are also some of the challenges threatening the future of humanity as far as climate change is concerned (Ahmed et al., 2021). The implications of this temperature rise have far-reaching consequences in the built environment and demand urgent interventions from key players in the industry, including the end users, whose lifestyles need to change for a better quality of life (Kristl et al., 2020). Most of the existing buildings today and currently designed ones will be rendered obsolete in terms of energy efficiency in the future (Escandón et al., 2019), except if a conscious attempt is made to consider their adaptability during their entire service lives (Kristl et al., 2020). Considering the climate crisis in building design development will guarantee the development of an environmentally friendly and resilient building stock (Díaz-López et al., 2021). As purported by (Mutasim Baba & Ge, 2018), buildings designed based on historical weather data will operate differently under changing future climates; it is, therefore, imperative to design buildings adaptable to climate change.

This study shows heat stress is a significant challenge for future buildings, influencing their energy efficiency, occupants' comfort and global warming impact. Effective building envelope insulation and solar shading of buildings are found as crucial elements in reducing energy consumption for cooling. Retrofitting existing buildings with solar shading devices and integrating insulation in the building envelope for new builds can help improve indoor thermal comfort and reduce reliance on mechanical cooling systems.

1.1. Aim and Objectives

1.1.1. Aim

This research aims to assess and enhance the energy performance of new and existing buildings in Nigeria under varying climate scenarios to achieve energy efficiency and reduced emissions in the future.

1.1.2. Objectives

The following objectives have been outlined to improve the Global Warming Impacts, GWI of new and retrofitted buildings in the future.

a. To investigate, using a case building, the correlation between outdoor temperatures in different states of Nigeria and their impact on the energy performance of buildings under RCP 4.5 and 8.5 climate scenarios.
b. To identify specific components of the case building envelope that require modification or alteration to enhance energy efficiency for future constructions in Nigeria.

c. To propose strategies and recommendations for improving the energy efficiency of new and existing buildings in Nigeria, considering the projected climate scenarios.

1.2. Research Questions

a. How do changes in outdoor temperatures in the various Nigerian States affect the energy performance of buildings under different climate scenarios?
b. Which elements of the building envelope need to be adjusted or changed to optimise the energy efficiency of buildings under changing climate conditions?
c. What strategies can be suggested to improve energy efficiency and reduce emissions in both new and existing buildings in Nigeria, considering future climates?

2. Literature Review

Climate change already affects every region globally, with the most significant effects due to anthropogenic activities (IPCC, 2021). Human-induced emissions by developed nations are primarily responsible for the global increases in temperature, while developing countries are at the backdrop of these changes (Akpodiogaga-a & Odjugo, 2010). While no nation will be absolutely spared of the consequences of a changing climate, the impact of global warming will affect the poorest people, particularly those in Africa (Akpodiogaga-a & Odjugo, 2010; Huq et al., 2006; Nyong & Niang-Diop, 2006). The impacts of a changing climate are no longer a subject of debate but a call for solution-based actions (Allu, 2014). The escalating threat of this change has prompted the need for sustainable building practices and urgent consideration of building efficiency, construction methods and materials worldwide. As more buildings are erected to meet the growing population's demand, there will be dramatic heat stress and higher energy demand, particularly for cooling (Dodoo, 2020; Laue et al., 2022; Mahmoud & Ragab, 2021). According to the Intergovernmental Panel for Climate Change IPCC, Urban sprawl intensifies human-induced warming locally. With further urbanisation, the possibility of extreme heat waves is likely to be experienced. Nigeria, despite its middle-income status, has an excessive poverty rate. It is classified as one of the ten most vulnerable countries to the dangers of climate change (WBG, 2019). More worrisome, the country’s population amidst the poverty level is expected to double its current number by 2055 (Macrotrends, 2022), resulting in unprecedented warming in urbanised areas. Buildings significantly contribute to global carbon emissions, so understanding climate change's impact on future building performance becomes crucial. With buildings at the centre of systems, a changing climate will alter buildings’ energy demand and load factor (Jenkins et al., 2015).

2.1. Greenhouse Gas Emissions & Climate Projections

Like many other countries, buildings make up a significant source of carbon emissions In Nigeria. They are considered long-term investments and key players during climate change adaptation actions (Chmutina, 2013). According to (IUCN, 2022), the greenhouse gas (GHG) emission in Nigeria is about 126.9 million tonnes, with the energy sector amounting to 60% of the overall emissions. Accordingly, in 1999, Nigeria’s GHG emission per capita was 0.33 tonnes of CO_2 emissions per capita, below the global average of 7 tonnes. This figure was close to double in 2021 (Figure 1). Further studies show that the country’s emission is primarily based on the burning of fossil fuels or cement production (Hannah Ritchie et al., 2020; Ogundipe et al., 2020; Orewere et al., 2022). Although Nigeria's carbon emission levels are lesser than industrialised nations like China and the USA (Figure 2), its impact, if not well managed, will offer the most significant environmental threats (Czechowski, 2020). China and the USA are industrialised nations with significantly higher emission figures compared to Nigeria. However, while both China and the USA have active policies and actions in place to control their environmental impacts, the same cannot be said for Nigeria, which has relatively low carbon emissions. Consequently, the potential impact of carbon emissions is likely to be more detrimental in Nigeria.

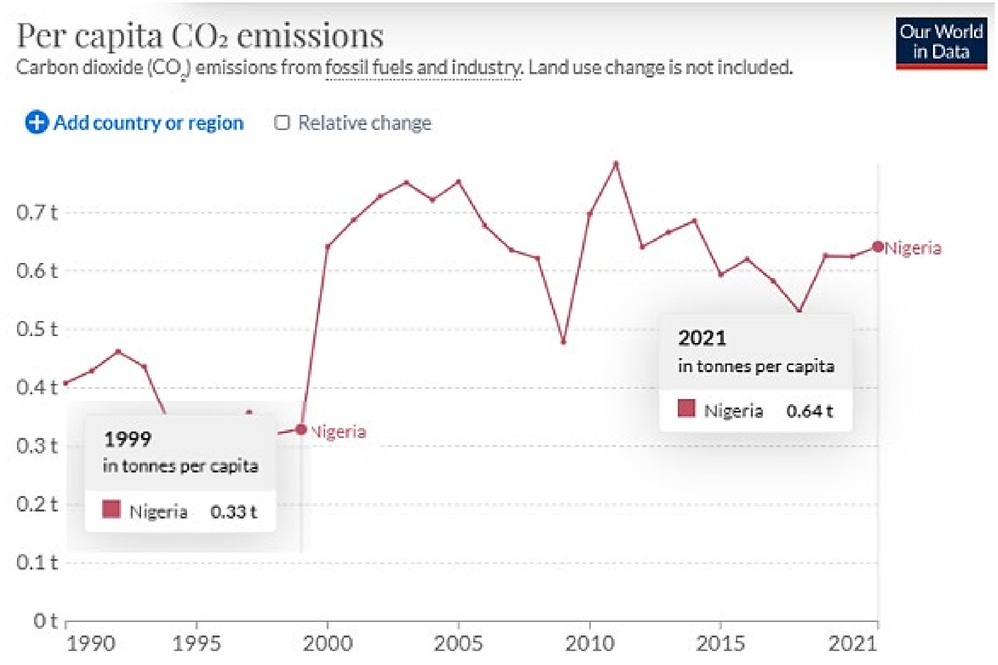

Figure 1 Nigeria's Per Capita Carbon Emissions in 1999 and 2021 (Hannah Ritchie et al., 2020)

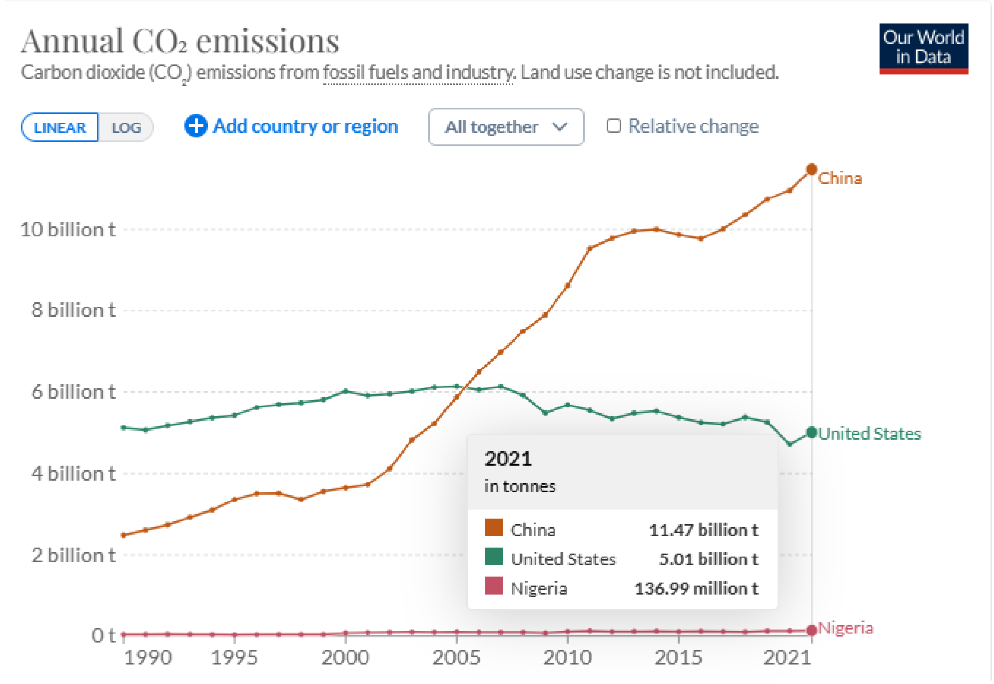

Figure 2 Annual share of Global Carbon emissions. (Hannah Ritchie et al., 2020)

Climate projections indicate that overheating and consistently high temperatures will be prevalent in the future across Africa (Laue et al., 2022); It is essential that while retrofitting existing housing stock remains crucial for buildings to adapt to future climate, the focus for developing countries should be geared towards strategies and policy development (Kristl et al., 2020). One of the concerns for professionals in the built environment, especially architects, is the consideration of the building's energy efficiency, emissions and occupant's comfort in the preliminary stages of building designs. Emissions in buildings primarily emanate from the consumption of electricity generated from fossil fuels. It is estimated that by 2050, GHG emissions will have to be reduced by

50% to avoid the worst-case impact of climate change (UNEP, 2009). With climate change affecting the energy demand for cooling, the performance of future buildings in Nigeria, compared to existing ones, is likely to widen. Understanding the drivers of this gap and implementing targeted strategies is crucial for achieving energy-efficient and sustainable buildings. This section delves into the impacts of projected climate changes on buildings in different climates and explores the design strategies employed to reduce the energy performance gaps in future buildings.

Different studies were conducted using varying climate projections to determine the effects of changing climate on buildings' performances. These investigations encompass several building uses, forms and locations. For example, (Kim et al., 2021) explored the carbon emissions and cooling energy consumption of an office prototype building in the Midwest and Northeast of the US, using RCP 8.5 climate scenario for 2050 and 2080. The investigation suggests that cooling energy consumption will significantly affect GHG emissions while these emissions by electricity consumption will increase in future scenarios. Similarly, an electricity consumption of about 18% increase was observed in a study by (Summa et al., 2020) on a residential net-zero building in Rome, using RCPs 4.5 and 8.5 climate scenarios in 2050. As asserted earlier, no country is spared of the increasing temperature, as overheating hours are also predicted in cold climates under future scenarios. In fact, (Khourchid et al., 2022) suggest that the most significant increase in cooling demand will occur in temperate and cold climates. He further posited that the Cooling demand in the 21st century (2040-2080) will increase by 33%, 89%, 288% and 376% in tropical, dry, cold and temperate climates, respectively, while towards the end of the century, (2080-2100), the energy demand will increase to 55%, 302%, 734% and 1020% for tropical, dry, cold and temperate climates respectively. By implication, the tropics will experience the least demand for cooling energy. Regardless of the building typology, form and location, the effects of a changing climate remain significant. This is further supported by studies carried out by authors for different climates, including heritage buildings in Italy (Huerto-Cardenas et al., 2021), container houses in the subtropical region of China (Suo et al., 2023), and Hellenic non-residential building stock in Greece (Droutsa et al., 2021).

In tropical climates, although limited, similar investigations were conducted to determine the impact of rising temperatures on thermal comfort and carbon emissions in tropical buildings. According to research by (Mourshed, 2012) conducted in Dhaka, the capital of Bangladesh, the impact of increased temperature will amount to a surge in demand for energy for comfort cooling. More so, this stress in energy demand, he noted, will be catastrophic to the deficient energy supply of the country. As a result of overheating and the increased occurrence of hot spells, the design of energy-efficient and low-carbon buildings will be a severe challenge in this climate. Furthermore, there is an expected increase in air temperature of about 3.3^{o}c for 2050 for tropical regions, according to (Callejas et al., 2021) for an investigation conducted in Brazil. If the current trend continues, climate models predict it will be warmer by up to 2^{o}c, with a low precipitation rate due to excess evaporation in Sub-Saharan Africa (Nyong & Niang-Diop, 2006). These investigations, particularly in Africa, show a 2^{o}c increase in temperature every 20 years.

2.2. Strategies for Reduced Energy Consumption in Buildings

Several authors share similar views on strategies for reducing the energy demand of buildings. For example, (Khourchid et al., 2022; Mobolade & Pourvahidi, 2020) suggest the use of thermal insulation and solar shading for cooling energy reduction and thermal mass (earth-sheltered walls) for cooling in tropical regions (Callejas et al., 2021). Harnessing the thermal mass in building design can help moderate indoor temperature fluctuations, reducing cooling energy requirements. Although thermal mass as a strategy for energy reduction is adequate, more is needed to completely negate the demand for cooling under future climates. Also, the reliance on passive ventilation means, and shading of external windows as a strategy to reduce overheating and discomfort levels in buildings was emphasised by (Dodoo, 2020) for a modern multi-storey building in Sweden and by (Huerto-Cardenas et al., 2021) for an investigation on heritage buildings. Additionally, (Fabbri et al., 2020) suggest that strategies for new designs and renovations and retrofits will be centred on ventilation, thermal insulation and reflectance. The study predicts a considerable risk of multiple grid collapses and blackouts because of a surge in cooling energy demand.

Building form also shows potential for improving the energy performance of buildings. As investigated by (Ahmadian et al., 2022), for future climate scenarios in London, deep plan court and tunnel court buildings with a lower number of storeys are advantageous as regards building energy reduction in the future. In a tropical climate like Nigeria, the use of a courtyard is one of the sustainable ways of improving a building's energy performance whilst ensuring the indoor thermal comfort of occupants (Modi et al., 2022; Nwalusi & Okeke, 2021), provided there are openings to the courtyard and outdoor environment. Likewise, a study conducted by (Callejas et al., 2021) shows the significance of orientation in reducing the energy demand, with a significant reduction of up to 38% achieved under future climate scenarios in the tropics. There is no one-fit-all strategy for optimising the energy performance of a building, as the location and building type will naturally dictate the best approach to overcome heat stress in buildings. Moreover, buildings should not be perceived as permanently sealed entities but as dynamic tools that are constantly in touch with the outside world physically and psychologically. Most strategies for energy demand focus on the building envelope and system, but effective landscaping of the environment using greeneries and water bodies is a good mitigation technique for reducing thermal forces that affect buildings (Croce, 2020).

The climate change act of Nigeria obligates public and private entities to promote a low-carbon economy and sustainable livelihood (IUCN, 2022). Though it is possible to achieve the energy needs of a country while reducing the carbon emissions rate by integrating renewable or green technologies (Nnaji et al., 2013), the greenhouse gas emission trends for different climate scenarios will always follow the same pattern (Kim et al., 2021). According to (Videras Rodríguez et al., 2020), when these strategies are implemented during the design stage, energy saving of up to 14% is expected. To future-proof buildings for the impacts of a changing climate, understanding how buildings will perform in the future and developing climate-sensitive policies and techniques to mitigate climate risks is essential (Yassaghi & Hoque, 2019).

3. Methods and Materials

This research employs a mixed-methods approach, combining experimental data collection and literature review. Weather data was collected using Meteonorm climate data generator for current and future climate scenarios, using RCPs 4.5 and 8.5 across 37 locations in Nigeria, Including Abuja. According to (Droutsa et al., 2021; José et al., 2017), while RCP 4.5 is an assumed imposition of conservative emissions and mitigation policies on buildings and the environment, RCP 8.5 is the highest greenhouse gas emissions with continuing current practices, where little effort is made to reduce emissions. A simplified non-existing test building was drafted in AutoCAD and modelled in DesignBuilder for energy performance analysis. Energy simulations were conducted to assess cooling demand and energy load variations under different building parameters and climate scenarios. The energy performance data was analysed using Excel to quantify differences between climate scenarios and case building models. The results are presented using tables and figures in the succeeding section.

3.1. Weather Data

Weather data generated for this study include Global horizontal radiation (Gh), Diffuse radiation (Dh), Direct normal radiation (Bn), Air temperature (Ta), Dewpoint Temperature (Td) and Wind speed (FF). The data generated using Meteonorm is based on ground data, analysis, and satellite data, with typical years in minutes and hourly resolution based on stochastic generation (Remund et al., 2020).

According to Figure 3 below, the primary data source for Meteonorm includes IPCC scenarios, Global Energy Balance Archive, GEBA of ETHZ, Geostat data and Meteorological stations and ERA5/T.

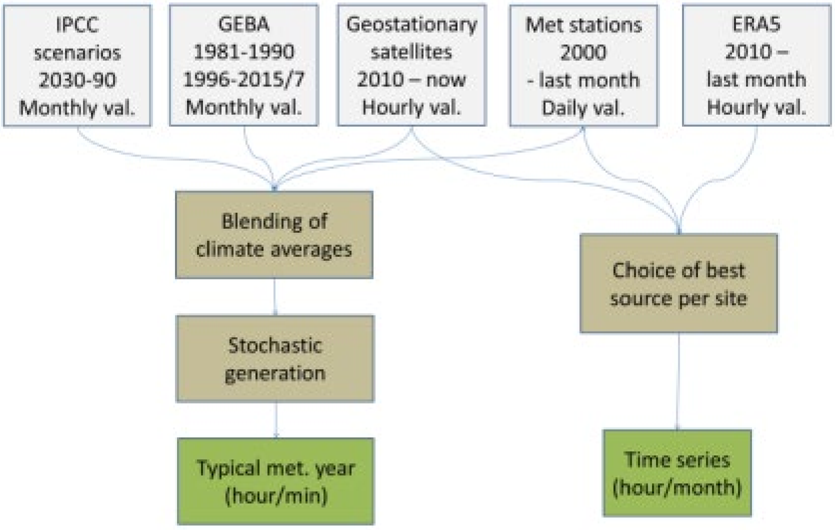

Figure 3 Data Sources and Pathways of Data Selection and Generation in Meteonorm Source: (Remund et al., 2020)

3.2. Test Building

A simple studio apartment (Figure 4) was designed to test the energy performance of buildings across various locations. The apartment consists of a livingroom to the west, a bedroom and toilet facilities to the east, a kitchenette to the north, and the building's entrance to the south. The building fabric comprises contemporary building materials applicable to Nigeria's construction sector. Specifically, the walls are made of 225mm non-insulated hollow Sandcrete blocks with 30mm cement-sand plaster on both the interior and exterior surfaces. The roofing comprises aluminium roofing sheets nailed to timber struts, and the windows feature single-pane glass.

Figure 4 Sketchup Model (Left) and AutoCAD Floor Plan (Right) of Case Building

Three simulations were conducted using the same case building but with different building fabrics and using different climate scenarios, as summarised below;

STAGE 1 (As-Built): The case building, as shown in Figure 4 above, was modelled in DesignBuilder, and the cooling and total energy loads per conditioned building area were collected for the locations using RCP 4.5 for 2020 and RCP 8.5 for 2090. Experimental data collected at this stage informs the energy performance of existing buildings in the future if current building construction trends are sustained.

STAGE 2 (Retrofitted): The case building (as-built) was fitted with shading devices to primarily shade the external walls. In contrast, the exterior windows, except for the north facing ones, were fitted with shading devices with vertical and horizontal fins, as shown in Figure 5 below. Initially modelled as a single pane (u-value = 6.121 w/m²-k) in stage 1, the window glazing was replaced with triple-glazed low-emissivity panes (u-value = 0.786 w/m²-k). Data collected at this stage informs the energy performance of existing buildings when retrofitted to adapt to future climates.

Figure 5 Optimised Model with Shading Devices

STAGE 3 (New Building): This stage focused on remodelling the case building with enhanced building fabrics. The initial wall, which had a thickness of 285mm (u-value = 2.55 W/m²-K) and lacked insulation, was increased in thickness by implementing a cavity wall. This new wall consists of a 200mm layer of brick and plaster on the exterior and a 180mm layer on the interior, separated by a 200mm polyurethane insulating foam, as illustrated in Figure 6c below. The optimised wall has a u-value of 0.128 w/m²-k. Materials for the initial roof (u-value = 2.658 w/m²-k) were also replaced with an added insulation layer (u-value = 0.778 w/m²-k) while glazing and shading for walls, as shown in stage 2 above, were maintained. Energy loads collected for simulations at this stage inform the performance of new buildings under future climate scenarios.

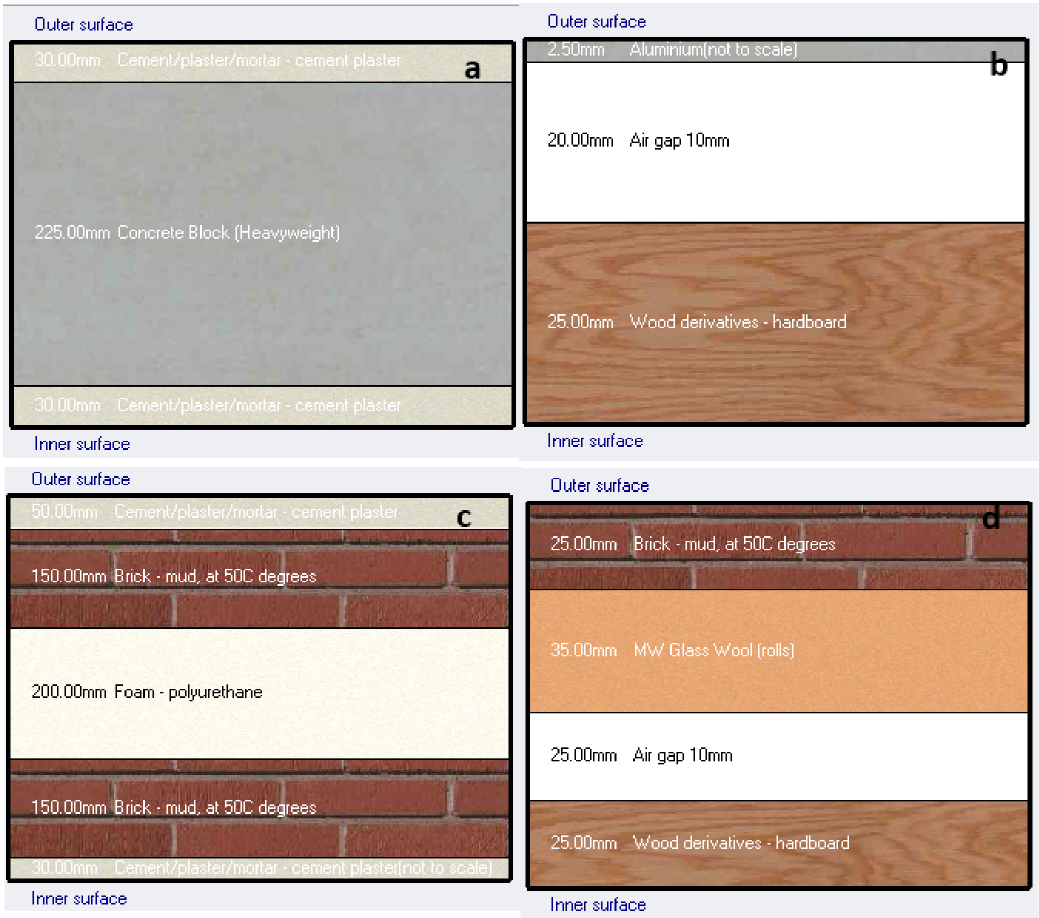

Figure 6 Cross Section of Materials: Wall (a), Roof (b), Optimised Wall (c), Optimised Roof (d)

4. Results and Findings

4.1. Outdoor Temperature Variations

As global temperatures increase, the changes in regional mean temperature, precipitation, and soil moisture get larger (IPCC, 2021). The grouping of climate data presented in this section is based on the climate classification purported by (Mobolade & Pourvahidi, 2020) for the bioclimatic approach for climate classification of Nigeria, ASHRAE climate classification and geopolitical classification of the state capitals in Nigeria (Chineke & Idinoba, 2011). As seen in Figures 7-11 below, climate change impacts differ with location and climate scenarios. The impact of climate on buildings will require localised interventions for the best energy efficiency (Allu, 2014).

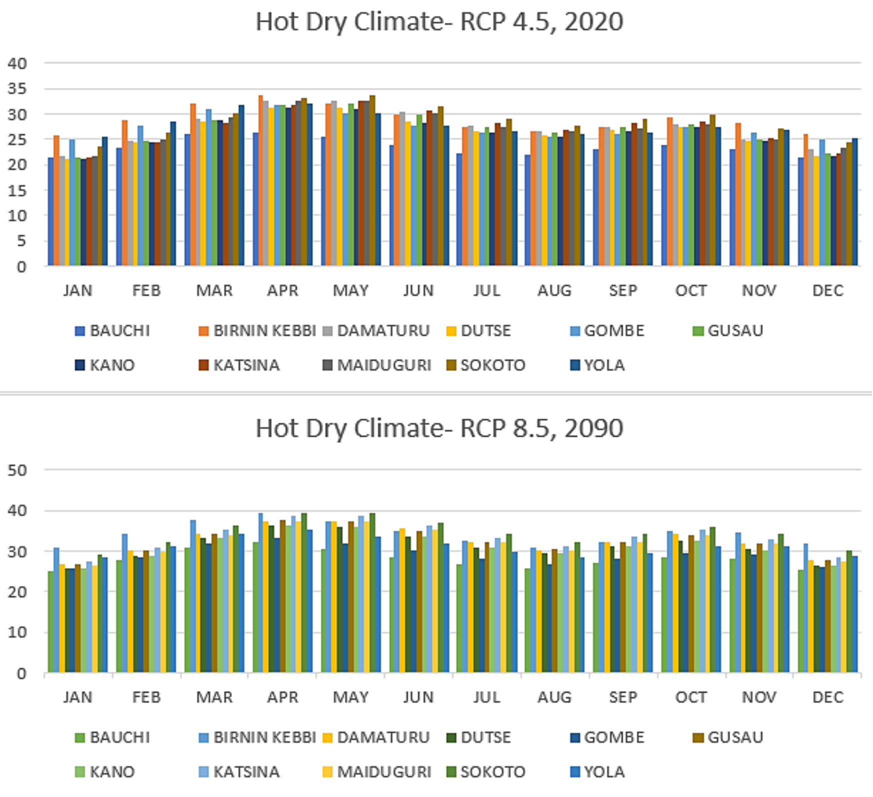

Figure 7 Temperature Variations for Locations with Hot Dry Climate

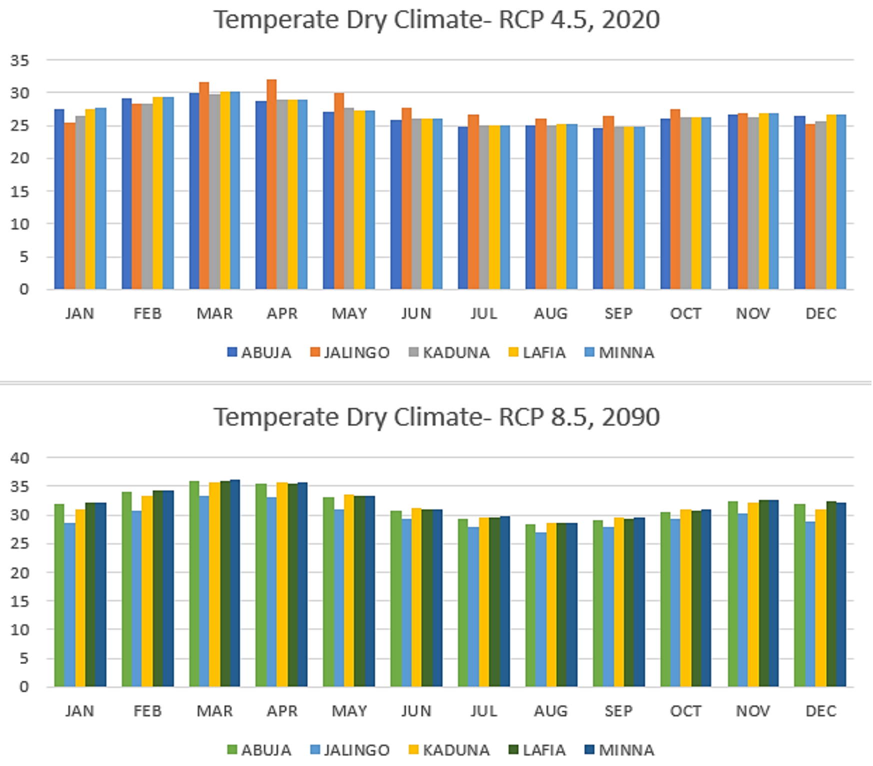

Figure 8 Temperature Variations for Locations with Temperate Dry Climate

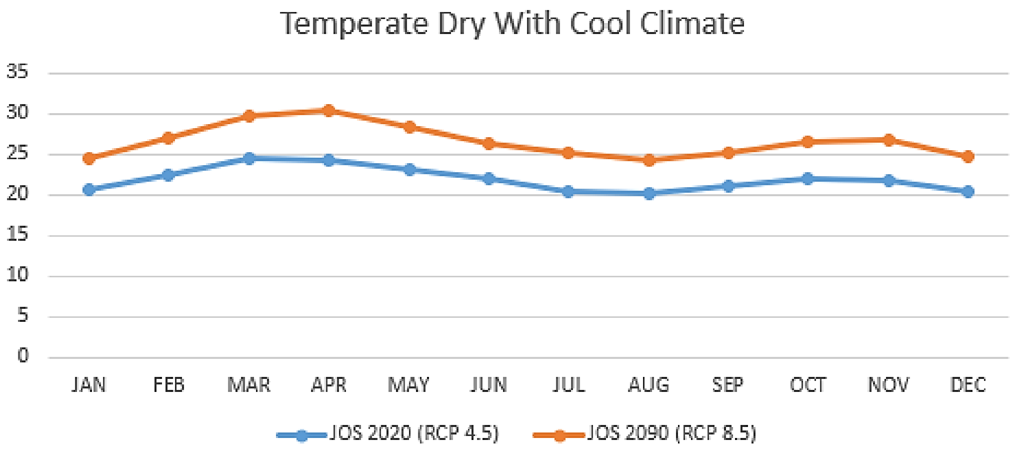

Figure 9 Temperature Variations for Location with Temperate Dry with Cool Climate

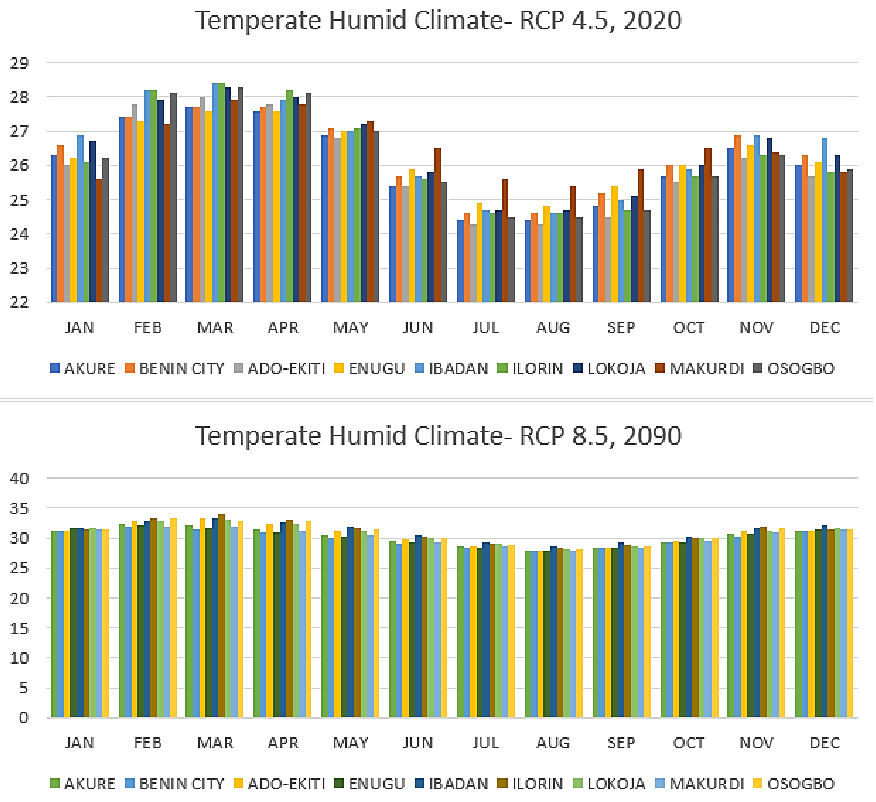

Figure 10 Temperature Variations for Locations with Temperate Humid Climate

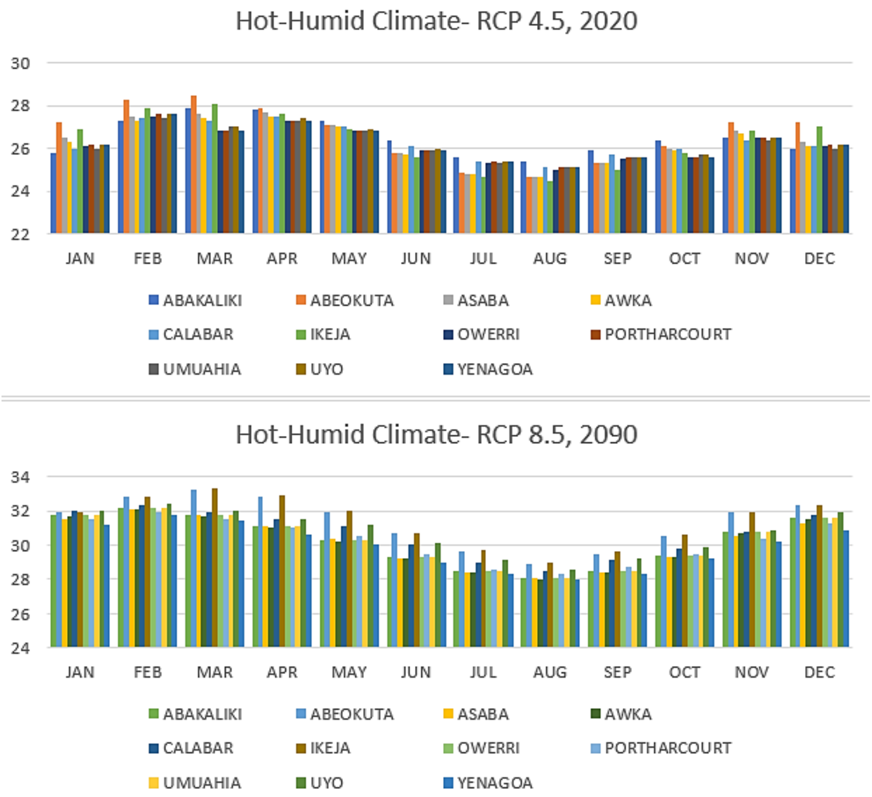

Figure 11 Temperature Variations for Locations with Hot-Humid Climate

4.2. Energy Performance Gap

Table 1 Energy Performance Table for Case Building across Locations and Different Climate Scenarios

S/No	Location	Cooling Load 2020	Cooling Load 2090	% Increase	Energy Load 2020	Energy Load 2090	% Increase
1	JOS	72.06	323.6	349	317.65	569.2	79
2	BAUCHI	135.84	343.74	153	381.52	589.42	54
3	KADUNA	215.09	413.53	92	460.64	659.08	43
4	DUTSE	267.41	364.57	36	513.05	610.21	19
5	KANO	267.4	363.03	36	513.01	608.64	19
6	DAMATURU	288.06	383.05	33	533.17	628.71	18
7	MAIDUGURI	291.69	380.37	30	537.31	625.99	17
8	KATSINA	299.92	383.46	28	545.53	629.07	15
9	YOLA	321.66	406.21	26	567.35	651.9	15
10	GOMBE	294.83	371.11	26	540.5	616.78	14
11	SOKOTO	340.43	401.59	18	586.09	647.23	10
12	GUSAU	322.64	377.23	17	568.24	622.83	10
13	PORTHARCOURT	379.31	439.56	16	624.88	685.12	10
14	BIRNIN KEBBI	359.12	415.46	16	604.77	661.11	9
15	BENIN CITY	375.63	431.51	15	621.25	677.13	9
16	MINNA	369.44	424.35	15	614.99	669.9	9
17	ADO-EKITI	371.83	426.14	15	617.49	671.81	9
18	YENAGOA	380.94	433.78	14	626.53	679.37	8
19	CALABAR	386.63	440.01	14	632.18	685.66	8
20	UYO	388.34	440.78	14	633.87	686.31	8
21	JALINGO	353.86	400.57	13	599.54	646.25	8
22	ABUJA	374.76	423.57	13	620.31	669.12	8
23	UMUAHIA	386.76	436.68	13	632.29	682.21	8
24	AWKA	385.06	434.67	13	630.8	680.2	8
25	OWERRI	386.47	435.93	13	632.03	681.48	8
26	ENUGU	387.05	435.47	13	632.58	681	8
27	ABAKALIKI	389.55	436.43	12	635.08	681.96	7
28	AKURE	383.52	429.64	12	629.18	675.31	7
29	ASABA	389.41	434.32	12	634.98	679.89	7
30	ILORIN	383.27	426.37	11	628.96	672.06	7
31	MAKURDI	391.91	433.26	11	637.45	678.8	6

32	IKEJA	398.03	436.28	10	643.74	681.99	6
33	IBADAN	394.68	432.02	9	640.39	677.73	6
34	LOKOJA	394.2	431.44	9	639.74	676.98	6
35	ABEOKUTA	397.92	433.83	9	643.63	679.54	6
36	LAFIA	392.62	427.89	9	638.19	673.45	6
37	OSOGBO	399.08	426.65	7	634.8	672.37	6

Table 2 Energy Performance Table for Retrofitted and New Buildings in 2090

S/No	**Location**	**Test Building (Retrofitted) 2090**				**Test Building (New Building Envelope) 2090**			
		Cooling load	**% Decrease**	**Energy Load**	**% Decrease**	**Cooling Load**	**% Decrease**	**Energy Load**	**% Decrease**
1	JOS	243.13	25	488.72	14	86.96	73	343.1	40
2	BAUCHI	265.8	23	511.48	13	117.16	66	373.42	37
3	KADUNA	328.74	21	574.3	13	173.84	58	429.92	35
4	DUTSE	287.77	21	533.41	13	147.46	60	403.66	34
5	KANO	286.01	21	531.62	13	147.5	59	403.66	34
6	DAMATURU	302.95	21	548.61	13	156.7	59	412.91	34
7	MAIDUGURI	300.08	21	545.7	13	156.29	59	412.46	34
8	KATSINA	307.14	20	552.75	12	160.53	58	416.68	34
9	YOLA	317.38	22	563.06	14	167.31	59	423.57	35
10	GOMBE	288.85	22	534.52	13	140.12	62	396.35	36
11	SOKOTO	324.07	19	569.7	12	170.11	58	426.3	34
12	GUSAU	299.62	21	545.22	12	155.98	59	412.12	34
13	PORTHARCOURT	334.41	24	579.97	15	191.56	56	447.66	35
14	BIRNIN KEBBI	336.03	19	581.68	12	182.5	56	438.71	34
15	BENIN CITY	335.26	22	580.88	14	188.14	56	444.31	34
16	MINNA	336.53	21	582.08	13	182.34	57	438.41	35
17	ADO-EKITI	333.98	22	579.65	14	179.22	58	435.44	35
18	YENAGOA	333.57	23	579.17	15	185.39	57	441.52	35
19	CALABAR	334.79	24	580.34	15	194.24	56	450.32	34
20	UYO	335.31	24	580.84	15	195.71	56	451.75	34
21	JALINGO	313.17	22	558.86	14	158.73	60	414.99	36
22	ABUJA	334.87	21	580.41	13	177.81	58	433.88	35
23	UMUAHIA	334.58	23	580.1	15	191.44	56	447.48	34
24	AWKA	335.32	23	580.85	15	191.92	56	447.98	34
25	OWERRI	334.48	23	580.04	15	191.66	56	447.75	34
26	ENUGU	335.97	23	581.5	15	193.08	56	449.13	34
27	ABAKALIKI	336.18	23	581.71	15	195.08	55	451.13	34
28	AKURE	335.32	22	580.98	14	187.8	56	444.03	34
29	ASABA	335.98	23	581.55	14	192.73	56	448.83	34
30	ILORIN	336	21	581.69	13	184.64	57	440.9	34
31	MAKURDI	337.24	22	582.78	14	194.37	55	450.44	34
32	IKEJA	336.89	23	582.6	15	198.72	54	455.01	33
33	IBADAN	336.89	22	582.61	14	192.66	55	448.96	34
34	LOKOJA	337.34	22	582.88	14	191.76	56	447.82	34
35	ABEOKUTA	336.72	22	582.43	14	196.51	55	452.8	33
36	LAFIA	336.5	21	582.07	14	183.39	57	439.48	35
37	OSOGBO	334.69	22	580.41	14	183.06	57	439.36	35

5. Discussion

Despite its location, Nigeria's climate, though generally classified as warm and humid, presents composite climates for different cities (Ajibola, 2001). Based on climate projections and experiments, there would be a shift in ASHRAE climatic classifications of ten locations in the country, which is 27% of the country. The locations include the following capitals; Akure, Bauchi, Ekiti, Ibadan, Ilorin, Jos, Lafia, Lokoja, Osogbo and the Federal Capital Territory FCT, Abuja. These locations, except for Bauchi, would shift from ASHRAE climate zone 1A (very hot and humid) to 1B (very hot and dry), while that of Bauchi will shift from 2B (hot-dry) to 1B (very hot and dry) in 2090. The result (Figures 7-11) shows a relative increase in outdoor temperature of about 5^{o}c across the country under RCP 8.5 in 2090. Increased temperature levels characterise RCP 8.5, according to (José et al., 2017). The changes in climate classifications in some locations follow assertions by (Díaz-López et al., 2021), who opined that climate categories for building locations will likely change in the future, with several cities tending toward warmer classifications.

5.1. Performance of Existing Building

In line with reviewed literature on building performance in future climates, the results of the stage 1 experiment show that existing buildings will consume more energy in the future. Compared to contemporary times, the cooling load in 2090 will increase by 7%-349%, while the overall energy load will also increase by 6%-79%, depending on the location (Table 1). Based on the case building, the most affected states with increased energy consumption are Jos, Bauchi and Kaduna, having cooling load increases of 349%, 153% and 92%, and energy load increases of 79%, 54% and 43%, respectively. Although Bauchi is in a hot-dry climate (Figure 7), it currently experiences temperatures of about 21^{o}c during the cold months of December and January. On the other hand, the city of Jos, situated in a cold climate (Figure 9), is the most affected by a changing climate contributing to the highest increase in energy consumption in the future.

While Climate change affects cooling demand in all climatic zones, its impact differs according to the distinct climatic zones (Khourchid et al., 2022). In this study, the least affected location on cooling load for the building is in Osogbo, with a 7% increase in 2090. In contrast, the locations with the least total energy load in the future are Makurdi, Ikeja, Ibadan, Lokoja, Abeokuta, Lafia and Osogbo, with only a 6% increase. All these state capitals are in the humid region (temperate humid and hot humid) of the country (Figure 10 and Figure 11) except for Lafia, situated in the country's dry climate (Figure 8). Additionally, most of these states with the least energy consumption for future climate scenarios are in the country's Southwest and Southeast geographical zones. It is further deduced that based on current construction practice in Nigeria, where building insulation is underplayed (Alegbe, 2022), an increase in energy consumption, especially for cooling, will affect buildings domiciled in the Northwest and North eastern part of the country. According to (Díaz-López et al., 2021), existing buildings do not match the reality of the current and changing climate, as most buildings are designed and constructed according to obsolete climatic classifications and with no consideration for future climate reality. Hence, climatic design for a sustainable future needs to be a focus during the building design stage because, in a changing climate, buildings considered near-zero energy buildings may lose their viscosity in a short time (Summa et al., 2020).

5.2. Performance of Retrofitted Building

When the case building was optimised by providing shading to walls and windows, the cooling load was reduced to 19-25% (Table 2). These improvements in the building fabric are ideal for building retrofits. The reduction in the performance gap between the various locations signifies an improvement in the building performance compared to the non-optimised case building model. Most of the buildings in the Southwest and Southeast regions recorded decreased in energy consumption. The highest decrease in cooling energy with the optimised building also occurred in Jos, the coldest region in the country. The least savings, on the other hand, occurred in Sokoto and Birnin-Kebbi, two states in the Northwest geo-political zones and hot-dry climate (Figure 7) of Nigeria. On the overall energy performance, there is a 12-15% decrease across all locations compared to the case building under the future climate scenario. This implies the importance of shading exposed wall surfaces and windows to prevent solar gains. According to (Dodoo, 2020), external window shading can reduce overheating and discomfort levels in buildings. The most significant savings in energy occurs in the building sited in Portharcourt, Yenagoa, Calabar, Uyo, Umuahia, Awka, Owerri, Enugu, Abakaliki and Ikeja. These locations form a more significant part of the South South and Southeast zones.

5.3. Performance of New Building- Enhanced Building Envelope

The greatest savings in the energy performance of existing buildings in future climates occur when the building envelope of the case building is completely refurbished. The major refurbishment was in the roof and walls by adding insulation and increasing the thickness and materials of the external wall (Figure 6). This refurbishment is in addition to the changes made at stage 2 of the building simulation experiments (see test building in the methods & materials section). These modifications not only contribute to better energy performance, but the greenhouse gas emissions of future buildings are also reduced. As corroborated by (Conroy et al., 2021), contrary to current practices, building envelope assemblies with greater insulation levels to meet future low-energy use requirements will result in reduced greenhouse gas (GHG) emissions due to lower thermal energy requirements. However, it is essential to emphasise that the amount of GHG emissions for a building will depend on the climate scenario for the future (Kim et al., 2021).

The stage 3 investigation shows that the greatest savings in cooling energy for the building occurred in the country's coldest parts: Jos and Bauchi (Table 2, new building envelope). This is compared to the 349%, and 153% increase predicted in 2090 for the case building performance in these locations before any modification (Table 1). A lot of energy consumption and emissions can be reduced in the most affected locations using adequate mitigation techniques. Furthermore, the greatest energy savings of the new building model occurs in the North (Northwest and Northeast), with up to 73% savings in cooling energy and up to 40% reduction in overall energy load. In comparison, the most minor energy savings occurs in the Southwest region, with up to 33% in energy consumption reduction. While there are variations between savings in cooling energy and total energy loads in these locations, the optimised models for retrofits and new builds show improved energy performance for buildings in the South than those in the North. This is because of the predicted energy demand for cooling in the Northern states in future climate scenarios and savings recorded for buildings in the South. However, energy savings for buildings with the new envelope in future climate is comparable across all locations, with a 7% difference between the highest and least savings.

According to (UNEP, 2009), the building sector has the most potential for delivering significant GHG emissions; it is only possible to meet emission reduction targets by supporting building energy efficiency. Sadly, most developers do not consider climate-sensitive design a viable option, especially concerning external shading (Karol & Lai, 2014) and building envelope insulation in the tropics. Most architects and contractors replicate the same designs in different climate zones. In the past decades, the challenge with buildings was to improve indoor thermal comfort through increased fabric insulation; however, in the future, the major challenge will bother on how to reduce overheating risks to ensure acceptable comfort conditions (Fabbri et al., 2020) and reduced GHG emissions. To ensure the existing building stock adapts to changing climate, designers will centre strategies for new designs and renovations on air exchange, fabric insulation and optimisation of reflective surfaces (Fabbri et al., 2020).

6. Conclusion

In an era of changing environmental conditions, buildings in Nigeria must adapt, needing modifications to the existing housing stock. Retrofitting and optimising structures for energy efficiency become crucial as climate scenarios evolve. Most buildings are designed with outdated climate data, lacking future energy efficiency considerations. This oversight not only threatens indoor comfort with rising global temperatures but also increases global emissions through excess energy consumption. The lack of consideration for future energy efficiency in building construction is concerning, with implications beyond comfort, leading to heightened energy consumption and elevated global emissions.

This study underscores the urgency of proactive design strategies prioritising building envelope enhancements, thermal mass insulation, and solar shading to bolster energy performance under evolving climates. The utilisation of Meteonorm weather files and EnergyPlus simulations laid the foundation for a three-stage assessment of prototype building energy performance across 37 locations in Nigeria. These stages illuminate a trajectory for existing, retrofitted and new buildings, fostering an informed approach to future climate scenarios.

A summary of the study findings is as follows.

1. By 2090, significant temperature changes are projected, notably affecting the Northcentral and Southwest zones, potentially leading to a climate classification shift.

2. In 2090, outdoor temperatures are projected to increase by up to 5°C nationwide compared to 2020.
3. Simulations show that rising outdoor temperatures will strain building energy loads, particularly cooling systems. While overall energy consumption may surge by up to 79% in the future, cooling energy needs may rise between 7% and 349%, depending on the location, necessitating increased focus on future cooling demands.
4. Optimised glazed surfaces and enhanced insulation within building envelopes consistently reduce energy requirements.
5. Future buildings can achieve up to 40% energy savings in new constructions through solar shading and thermal mass optimisation. Investing in solar shading is crucial to shield buildings from heat stress.
6. Emissions by electricity consumption increase in future scenarios due to rising temperatures. Implementing green technology for electricity generation can reduce future GHG emissions, though it will affect construction costs.

The evident outcomes from optimised building models, as demonstrated through EnergyPlus simulations, emphasise the significant potential for achieving energy savings. Embracing these building optimisation strategies could position Nigeria to develop energy-efficient, climate-resilient buildings that actively contribute to global initiatives in climate change mitigation. However, it is crucial to recognise that regulatory policies, urban environments, and buildings have been identified as pivotal areas requiring comprehensive attention to address adaptability challenges effectively. While natural science approaches have played a role in combating climate change, there is a notable lack of emphasis on the importance of involvement by development policy-makers or practitioners within the climate change community. Immediate actions directed at adapting buildings to future climates may be perceived as costly, it is not to be compared to the long-term cost associated with delayed implementation.

The implementation of design strategies aimed at enhancing building efficiency in a changing climate could face hindrance due to a potential rise in capital costs in tropical climates. As such, governments of developing countries, like Nigeria, must grasp the extent of vulnerability and augment adaptive measures in the built environment, which constitutes a significant contributor to greenhouse gas emissions. This stresses the need for proactive measures and policy interventions to ensure sustainable and resilient building practices amid evolving climates.

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Resume

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