Vol. 21 (1). 2024, ISSN 15965538, pp 25 - 36

Journal of Civil and Environmental Systems Engineering

Department of Civil Engineering, University of Benin, Nigeria

Journal homepage: https://j-cese.com/

Simulation and Comparative Evaluation of the Potential of a Green Building for Mitigating Carbon dioxide (CO_2) Emissions in Nigeria

S. Egbiki[1*] and S.1. Akosubo[2]

[1,2]Department of Civil Engineering, Faculty of Engineering, Nigerian Maritime University, Okerenkoko, Delta State, Nigeria

Corresponding Author email:egbiki4u@yahoo.com

Abstract

Greenhouse gases emissions especially carbon dioxide (CO_2) is majorly responsible for global warming and climate change effects. This paper simulates and investigates the potential of a green building in mitigating CO_2 emissions in Nigeria. EDGE (Excellence in Design for Greater Efficiencies) software was used to model the green building, which is a shopping mall located in Abuja, the capital city of Nigeria. To understand the dynamic variability and performances of the green building under different microclimatic conditions, 14 locations were used. The 14 locations which are Benin-City, Calabar, Port Harcourt, Lagos, Enugu, Lokoja, Abuja, Jos, Maiduguri, Sokoto, Kano, Kaduna, Abeokuta, and Ibadan are the available locations in the EDGE Software and span across the three major biomes of Nigeria. The results show that the green building was able to reduce CO_2 emissions by more than 50% in all the locations except in Jos which is 48.8%. While Benin City shows more potential in saving CO_2 emissions (55.5%) the low value in Jos could be attributed to its cold climate. The percentage range in the performance of the green building in reducing CO_2 emission in the 14 locations is within 6.8%. This important knowledge provides useful information for developers who might intend to replicate similar green buildings in different locations within the Nigeria's biomes. This knowledge is also critical for adopting green buildings in Nigeria for the reduction of CO_2 emissions and demonstrating proof of concept at the national and local scales where actions are needed to implement relevant green building policies in line with Nigeria's long term-low emission development strategy (LT-LEDS).

***Keywords**: Green Building, Mitigation, CO2 Emissions, Temperature, Policy*

1.0 INTRODUCTION

Climate change is one of the greatest environmental challenges of our time. Exacerbated by the COVID-19 pandemic, the entire world is acknowledging the urgency of a climate-smart roadmap to support a green and resilient recovery by reaching the goals set by the Paris Agreement in 2015. The Paris Agreement of 2015 by the United Nation Climate Change Conference of the Parties (COP21) mandated every country through their Nationally Determined Contributions (NDCs) to reduce global temperature to 1.5^0C by 2050, half the carbon dioxide (CO_2) emissions by 2030 and finally achieve net zero carbon by 2050. The COP26 of 2021 held in Glasgow and the COP27 of 2022 held in Egypt discussed expensively every country's commitment to reduce global CO_2 emissions in order to mitigate the effects of climate change. From COP27, though Africa contributed a small proportion of global CO_2 emissions, the consequences of climate change are badly felt in Africa. Climate change effects such as global warming, excessive flooding, rise in sea levels, heatwaves, air pollutions, pandemics, poor agricultural harvests, fire outbreaks, water scarcity, wars and even untimely death are majorly felt in Africa (UN Climate News, 2020; Elisha et al., 2017 and Ebele and Emodi, 2016).

To respond to the climate challenges, Nigerian President, Muhammadu Buhari at COP26 in Glasgow, announced that Nigeria will cut its carbon emissions and reach net-zero by 2060. On arriving from COP26, The President subsequently signed into law a new climate bill that creates five-year emission budgets, with a view to achieving net-zero greenhouse gas emissions between 2050 and 2070 (FGoN, 2021). To this end, the Federal Government of Nigeria decided to develop its long term-low emission developmentstrategy (LT-LEDS) as part of her onus to ensure a low-carbon future, with an initial focus on a Long-Term Vision to 2050 for the country. The vision provides a clear sense of direction to all stakeholders fora well-managed transition to a low-carbon economy that grows existing and new sectors, create new jobsand provide economic opportunities for the nation (FGoN, 2021). The vision states that: "*By 2050, Nigeriais a country of low-carbon, climate-resilient, high growth circular economy that reduces its current levelof emissions by 50%, moving towards having net-zero emissions across all sectors of its development in a gender-responsive manner"* (FGoN, 2021). It is hoped that this vision will promote sustainable development and guarantee a climate-proofed economic development through multi- stakeholder engagement, especially as Nigeria is also engaged in developing Medium-Term (2021-2025) and Long-Term (Agenda 2050) national development plans (FGoN, 2021).

However, with the Nigeria teeming population and rapid urbanization, the demand for housing is on the rise. Since fossil fuels are majorly used in the construction sector in Nigeria to produce energy, more greenhouse gas (GHG) emissions are expected because the building construction sector contributes about40% of the global Greenhouse Gas (GHG) emissions and 39% of global energy use (Lassio *et.al*, 2016). To reduce these GHGs emissions and align with the LT-LEDS, the building construction sector needs tobe given a priority attention. Despite the criticality of this sector, from the COP27, there is no serious commitments by Africa governments on how to reduce CO2 emissionsfrom the built environment. In Nigeria where rapid urbanization is rift, and the demand for housing on the rise, green buildings which are energy efficient buildings represent one of Nigeria's important intervention sectors to reduce its quota of global CO2 emissions (EDGE, 2022). The world green buildingcouncil (WGBC) has also affirmed thatgreen buildings can help reduce the buildings and construction sector's CO2 emissions (WGB Week, 2021). Many other researchers have confirmed that green buildingshave helped to mitigate climate change.Hong et al. (2014) studied the GHG emissions of a building case study in China. The results indicated thatthe electricity use, and materials production had the greatest impact to the On-site CO2 emissions. Seo etal. (2016) in Korea pointed out that the CO2 emissions from the material production phase accounted for 93.4% of the total CO2 emissions. Akbarnezhad and Xiao (2017) showed that using low embodied carbon material instead of conventional material achieved a 30%reduction in the building's total CO2 emissions.A university building complex of American University of Nigeria (AUN), Yola certified in September 2021 to an EDGE green building standard showed that the CO_2 emissions saved was 56.3% while the energy saving was 34% (EDGE Report, 2022). Another university hostel of AUN, Yola certified in September 2021 to an EDGE green building standard also showed a CO_2 saving of 38.6% and energy saving of 27% (EDGE Report, 2022).

Although much research has shown the effectiveness of green buildings as key climate change mitigation strategy by reducing CO_2 emissions, the effects of microclimatic, physiographic and design factors on its performances under different climatic conditions remain poorly studied and largely unexplored. This important knowledge gap is critical for adopting green building and demonstrating proof of concept at the national and local scales where actions are needed to implement relevant green building policies. The objective of this study is to simulate and investigate the performances of a green building under different microclimatic conditions within the major biomes of Nigeria using an EDGE (Excellence in Design for Greater Efficiencies) software. The major biomes of Nigeria which are Tropical Rainforest, Mangrove Swamps, Savannah are distinct in terms of their climatic, ecological, and physiographic regimes and therefore offer a good opportunity for investigating these factors on the performances of green buildings to provide empirical data in support of policy development and demonstration of proof of concept.

2.0 EDGE and other Green Buildings Technologies

Different green building bodies such as World Green Building Council (WGBC), Leadership in Energy and Environmental Design (LEED), WELL green building standard, Building Research Establishment Environmental Assessment Method (BREEAM), Energy Star and DGNB (German Sustainable Building Council) defined green buildings in different ways using relative and qualitative approaches in evaluating their performances by assigning values. They all use different names for green buildings such as energy efficient buildings, sustainable buildings, smart buildings, eco-friendly buildings, etc (Li. *et.al*, 2014; Dwaikat, 2018; Yas and Jaafer, 2020). To achieve a more quantitative and numerical approach, the International Finance Corporation, a member of the World bank group, developed EDGE (Excellence in Design for Greater Efficiencies) software.

EDGE is a green building software that has gain popularity globally. It uses three metrics in evaluating green building performances. They are energy efficiency, water efficiency and embodied energy in the building materials. EDGE has three levels of defining green buildings. Level 1 is called EDGE Certifiedwhich is achieved when a green building is able to save minimum 20% in energy use, 20% in water use and 20% in embodied energy in materials when compared with a local benchmark conventional building(EDGE, 2022). Level 2 is called EDGE Advanced which is achieved when a green building is able to saveminimum 40% in energy use, 20% in water use and 20% in embodied energy in materials when compared with a local benchmark conventional building (EDGE, 2022). Level 3 is called EDGE Zero Carbon which is achieved when a green building saves minimum 40% in energy use, 20% in water use and 20% in embodied energy in materials when compared with a local benchmark conventional building including 100% carbon offsets (EDGE, 2022). The carbon offset can be achieved either using 100% renewable energy or purchase of carbon

Vol. 21 (1). 2024, ISSN 15965538, pp 25 - 36

offsets (EDGE, 2022). The concept of green buildings is still very new in Nigeria. In 2020, EDGE was officially introduced into the Nigeria market for certifying buildings as green. Since then, many buildings have been certified. From January 2020 to June 2022, 214,530m^2 of floor space Area has been certified; 2,084tCO_2/year has been avoided; 144,274m^3/year of water has been saved and 8,572MWh/year of energy has been saved (EDGE Report, 2022). As many companies and real estate developers are keying into the certification process, it is envisioned that more CO_2 emissions will be saved by 2050 (EDGE Report, 2022).

3.0 METHODOLOGY

3.1 Study Area

The green building used in this study is a shopping mall called Jabi Lake Mall that was completed in 2015. It is situated in Jabi, Abuja and is shown in Figure 1. The building was certified in year 2022 as an EDGE green building by International Finance Corporation. The Mall is a 31,560m^2 development designed to be a one stop leisure, restaurant and retail destination. The site sits on 5 hectares of land. Thetwo-storey mall featured contemporary architecture and a lakeside boardwalk with views over the water.Cinemas, restaurants, cafes and a children's arcade.

Figure 1: Jabi Lake Mall

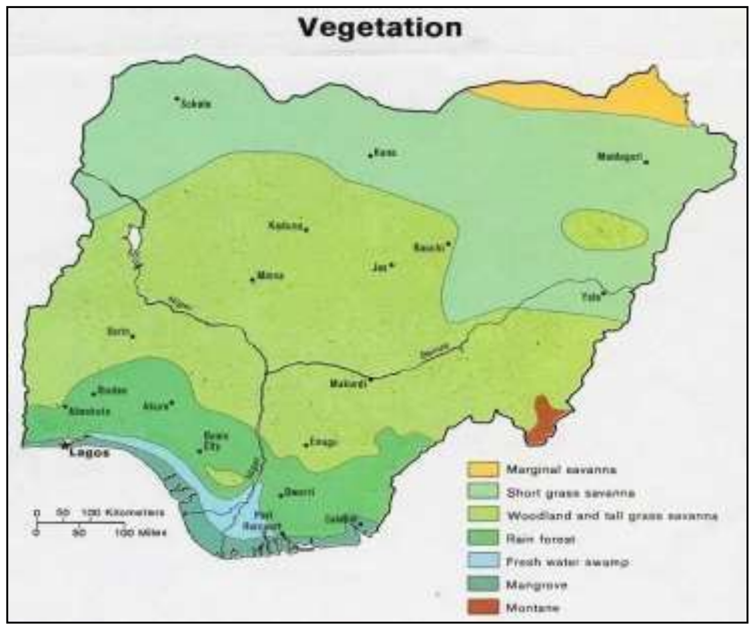

Figure 2: Map of Nigeria showing the biomes.
Source: https://nigerianscholars.com/tutorials/ ecology-overview/nigerian-biomes/

The 13 other locations used to understand the performances of the building under different climate conditions are Benin City, Calabar, Port Harcourt, Lagos, Enugu, Lokoja, Abuja, Jos, Maiduguri, Sokoto, Kano, Kaduna, Abeokuta, and Ibadan. These locations which are available in the EDGE software fall within the three major biomes of Nigeria. The major biomes of Nigeria which are Tropical Rainforest, Mangrove Swamps and Savannah differ in climatic conditions and therefore offers an opportunity to understand the variability of a green building under such conditions. Figure 2 show the 14 locations within their biomes.

Vol. 21 (1). 2024, ISSN 15965538, pp 25 - 36

3.2 Data Collections

The building design data were extracted from the architectural, mechanical, and electrical drawings of the building. The building was also physically inspected to take further data needed for the simulation. Tables1 - 4 show the design input data used for the building simulation. The hydrological and microclimatic data used in the simulations were obtained from the inbuilt data in the EDGE software. These data were obtained from Nigerian meteorological and hydrological agencies by International Finance Corporation to build the software. The average data used spans over a period of 25 years. Figures 3-8 show average temperatures, relative humidity, windspeed, rainfalls, elevations, latitudes of the 14 locations.

Table 1: Building Design Details

Building Design Details	**Value**
Gross internal Area (m2)	32,986
No of floor above grade	2
Floor to floor height (m)	6
Aggregate roof area (m2)	17,795
No of operating day	7
Hours of operation	12
Average footfall/day	3,367

Table 2: Building External Wall Dimensions

Building Dimensions	**Metre**
North	67
Northeast	27
East	420
Southeast	104
South	87
Southwest	15
West	309
Northeast	14

Table 3: Building Area Load Details

Area Load Breakdown

Components	**Area (m^2)**
Supermarket	4,833
Anchor store	5,016
Line store	15,151
Bathroom	248
Office	82
Mechanical & Electrical	1,854
Communal Corridors	5,786.82
Data Centre	15
External Lighting	29,295.60
Car park	10,762.50

Table 4: Building Energy and Water Details

Energy Details	**Value**
Window to Wall ratio (%)	7.6
Solar Reflective Index of Roof (%)	56
Solar Reflective Index of wall (%)	45
Insulation of roof (W/m^2. K)	0.8
Insulation of external wall (W/m^2. K)	0.46
Insulation of ground floor (W/m^2. K)	0.49
Insulation of glass (W/m^2. K)	5.73
Solar Heat Gain Coefficient of glass (%)	68
Visible Transmission (%)	70
Coefficient of performance of AC(W/W)	3
Efficacy of Internal Lighting (Lumen/Watt)	110.3
Efficacy of external lighting (Lumen/Watt)	112.3
Water Details	
Flow rate of Wash hand basin(litre/min)	2.35
Flow rate of washing closet (litre/flush)	3.93
Flow rate of urinal (litre/flush)	4.33
Flow rate of Kitchen sink (litre/min)	7.73

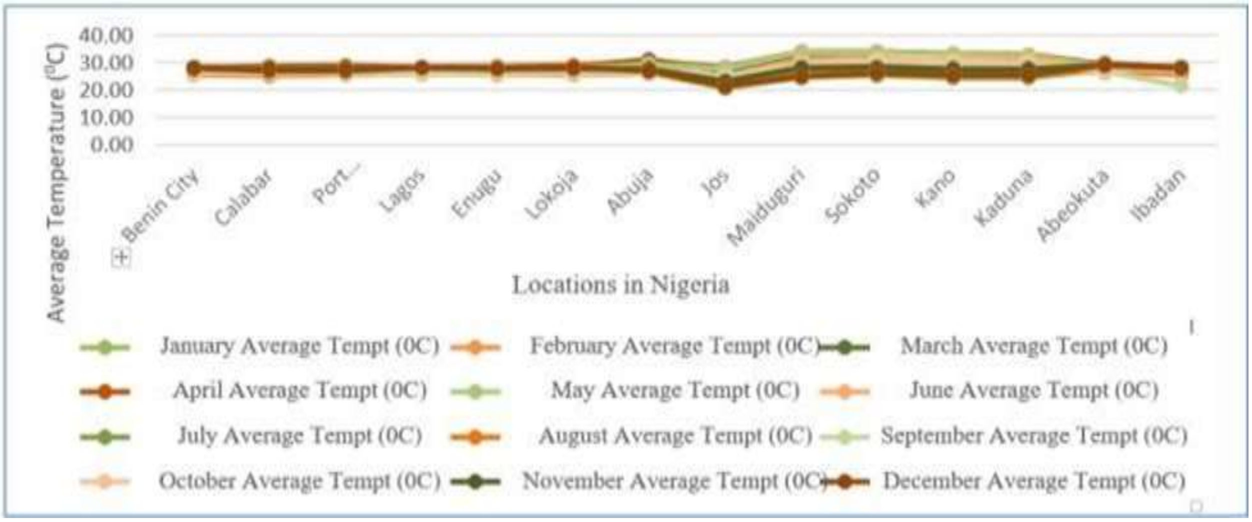

Figure 3: Average Temperatures in the 14 locations

Figure 4: Relative Humidity in the 14 locations

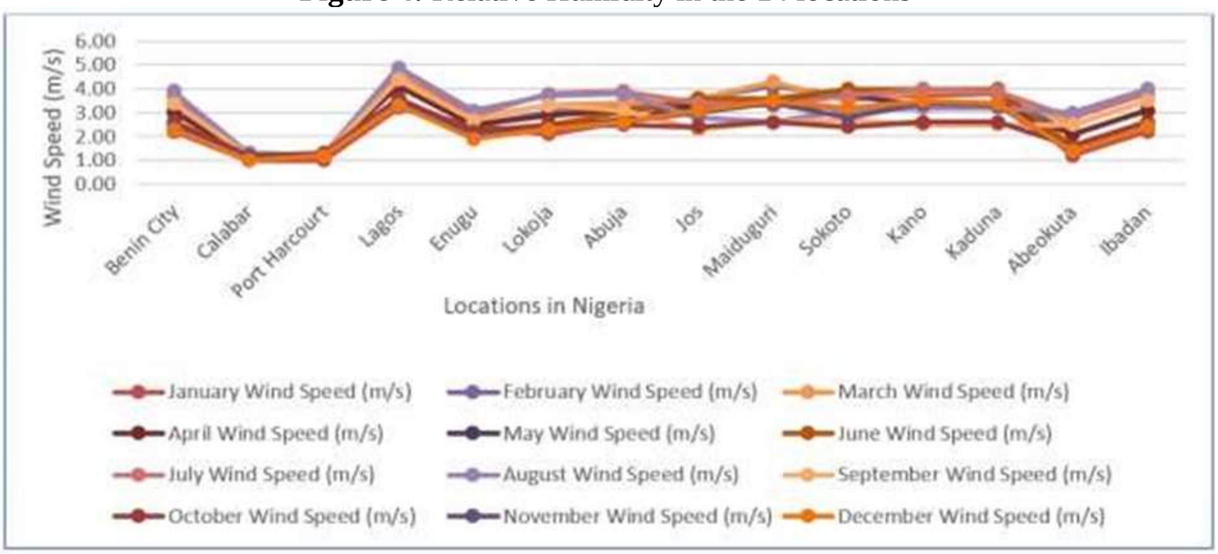

Figure 5: Wind Speeds in the 14 locations

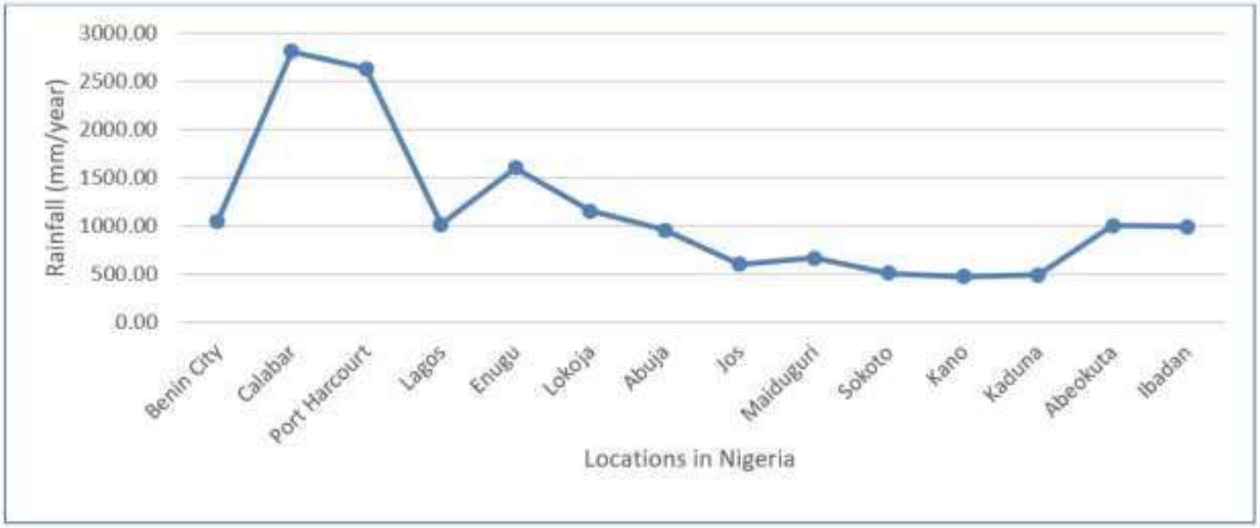

Figure 6: Average Rainfalls in the 14 locations

Figure 7: Elevations in the 14 locations

Figure 8: Latitudes in the 14 locations

3.3 Building Simulation with EDGE

The building design data coupled with the hydrological and microclimatic data were used as input datafor the building simulation in the EDGE software. Firstly, the building was simulated using Abuja as a location where the building was built. Having fulfilled the EDGE standard certification by achieving32.21% in energy, 36.31% in water, and 99.69% in embodied energy in materials), the building was replicated in 13 other locations to understand how the operational CO_2 emissions will be varied. Figures9 and 10 show the monthly operational CO_2 emissions and the annual operational CO_2 emissions savingsin Abuja location respectively. According to EDGE certification, when a building is more than five years of its construction, the embodied energy in the building materials is considered negligible and the materials will be considered as reuse. In this study, the building was constructed in 2015 and all thebuilding materials were considered as reused.

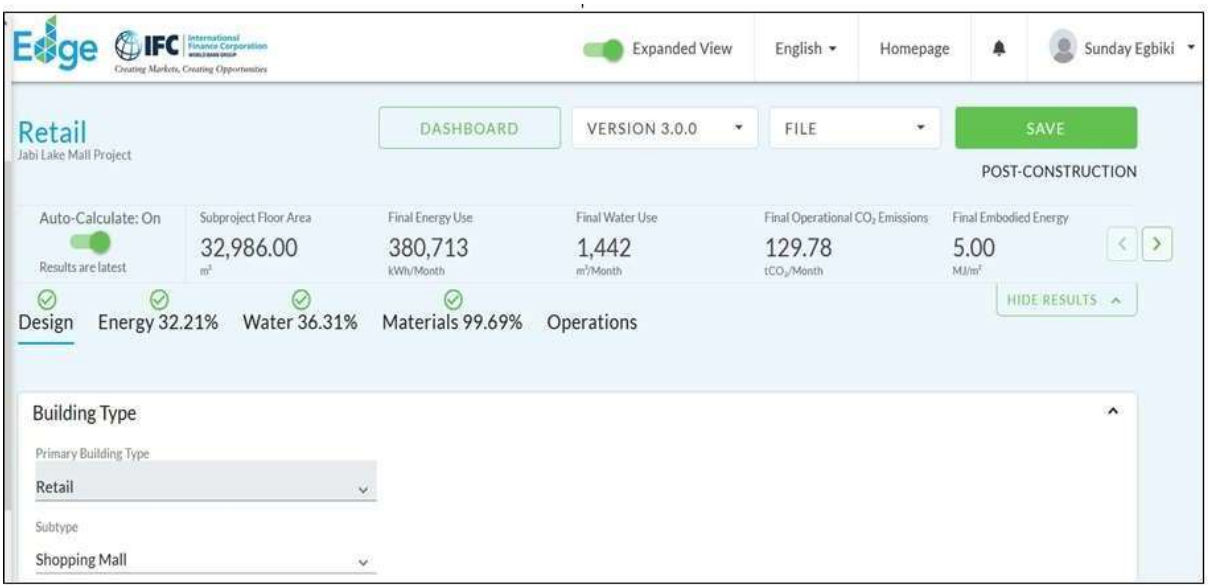

Figure 9: Simulation of the building operational CO_2 Emissions in Abuja location

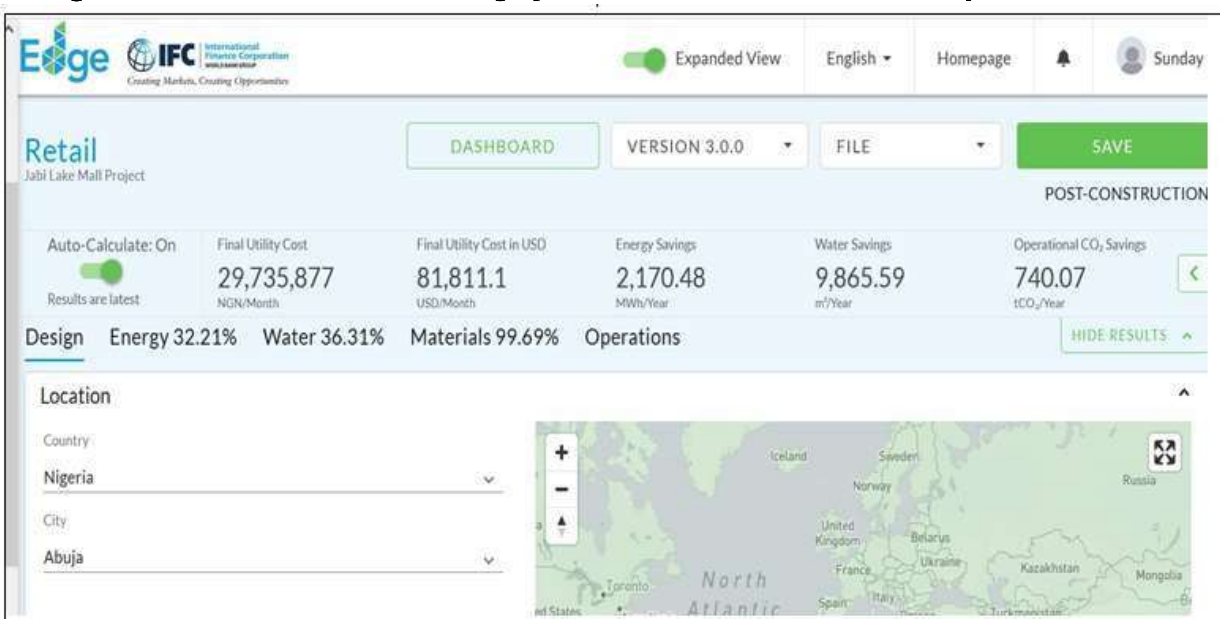

Figure 10: Simulation of the building operational CO_2 Emissions Savings in Abuja location

4.0 RESULTS AND DISCUSSION

The results of the simulations from the 14 locations are presented in Table 5 and Figures 11-12. Table5 shows the annual operational CO2 emissions, annual operational CO2 emissions savings and the percentages of the annual operational CO2 emissions savings. Figure 11 shows the variations of the annual operational CO2 emissions and operational CO2 emissions savings from the 14 locations andFigure 12 shows the variations of the percentages of the annual operational CO2 emissions savings from the 14 locations.

Table 5: Operational CO2 Emission and Operational CO2 Emissions Savings in the 14 Locations

Locations	Operational CO2 Emission (tCO2/Year)	Operational CO2 Emission Saved (tCO2/Year)	% OperationalCO2 Emission Saved (tCO2/Year)
Benin-City	1622.16	722.26	55.5
Calabar	1598.88	720.31	54.9
Port Harcourt	1592.16	722.45	54.6
Lagos	1616.16	721.39	55.4
Enugu	1684.44	752.63	55.3
Lokoja	1684.68	752.27	55.3
Abuja	1557.36	740.07	52.5
Jos	1188.12	608.02	48.8
Maiduguri	1692.48	821.03	51.5
Sokoto	1693.2	822.39	51.4
Kano	1624.56	788.63	51.5
Kaduna	1596.72	771.49	51.7
Abeokuta	1640.4	744.36	54.6
Ibadan	1679.52	754.01	55.1

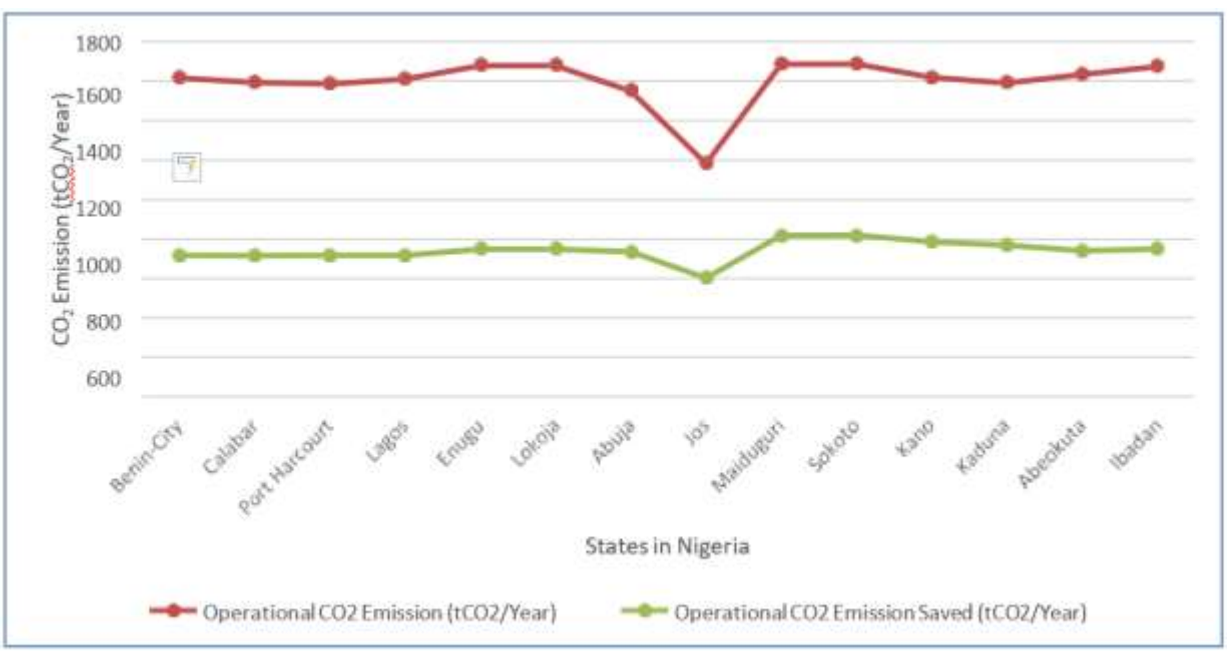

Figure 11: Operational CO2 Emission and Operational CO2 Emissions Savings in the 14 Locations

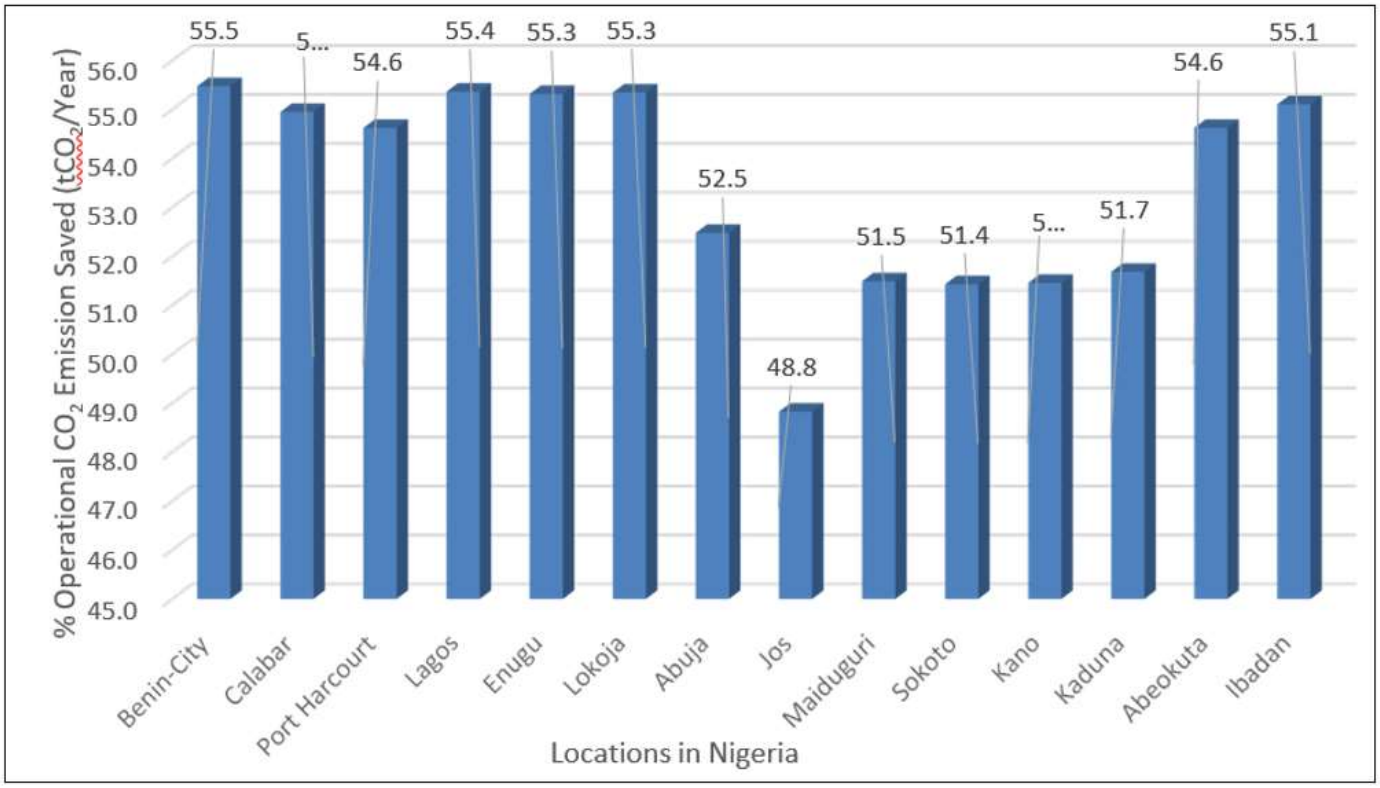

Figure 12: Percentage Operational CO_2 Emissions Savings in the 14 Locations

For the annual CO_2 emissions from the 14 locations, Sokoto emits the highest with a value of 1693.2tCO_2/year while Jos emits the lowest with a value of 118.12tCO_2/year. This gives a range valueof 505.08tCO_2/year. For the annual CO_2 emissions savings from the 14 locations, Sokoto also saves thehighest with a value of 822.39tCO_2/year while Jos saves the lowest with a value of 608tCO_2/year. Thisgives a range value of 214.39tCO_2/year. For the percentage annual CO_2 emissions savings from the 14locations, Benin City saves the highest with a value of 55.5% while Jos saves the lowest with a value of 48.8%. This gives arange value 6.8%. This result indicates that the percentage annual CO_2 emissionssavings from the 14 locations are more than 50% except in Jos where the percentage is 48.8%. Also, locations with similar biomesexhibit similar behaviours in terms of annual operation CO_2 emissions, operational CO_2 savings and percentage operational CO_2 savings. These values are in alignment with the values obtained from a certification carried out in American University of Nigeria where 56.3% and 38.6% were saved in the CO_2 emissions from the certified educational and hostel buildingsrespectively (EDGE Report, 2022). Also, the result from Akbarnezhad and Xiao (2017) where 30% wassaved in the CO_2 emissions has validate the resultsobtained from this study.

5.0 CONCLUSION

This study confirms that green buildings have the potential of reducing CO_2 emissions from the built environment. In the case of this study, it was able to reduce CO_2 emissions by more than 50% on average from all the locations used. It has also indicated that under different climatic conditions withinthe biomes ofNigeria, the percentage variance in the performance of a green building in reducing CO_2emission is within 6.8%. This important knowledge provides useful information for developers who might intend to replicate similar green buildings in different locations within the Nigeria's biomes. Thestudy also provides useful knowledge that is critical for adopting green buildings in Nigeria for the reduction of CO_2 emissions and demonstrating proof of concept at the national and local scales whereactions are needed to implement relevant green building policies in line with Nigeria's long term-lowemission development strategy (LT-LEDS).

Acknowledgement

The authors are grateful to DAAD for sponsoring this research study and Broll Facilities for releasingthe building design data used for this study.

Reference

Akbarnezhad A, Xiao J. (2017): Estimation and minimization of embodied carbon of buildings. AReview 2017;7:(1). doi: https://doi.org/10.3390/ buildings7010005

Ebele, N. E. and Emodi, N. V. (2016). Climate change and its impact in Nigerian economy. Journalof Scientific Research & Reports, 10(6), 1-13.

Dwaikat L.N and Ali K.N (2018): The economic benefits of a green Building-Evidence from Malaysia. Journal of Building Engineering. **2018**, 18, 448–453.

EDGE, (2022): EDGE Manual for Green Building Design Published by International Finance Corporation, 2022

EDGE Report, (2022): EDGE Statistic in Nigeria: A publication by International FinanceCorporation, 2022.

Elisha L., Sawa B.A and Ejeh L. (2017). Evidence of climate change and adaptation strategies among grain farmers in Sokoto State, Nigeria. IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT),11(3),1-7.

FGoN, (2021): 2050 Long-Term Vision for Nigeria (LTV-2050): Towards the Development of Nigeria's Long-Term Low Emissions Development Strategy (LT-LEDS), 2022

Hong J, Shen G, Feng Y, Lau W, Mao C. (2014): Greenhouse gas emissions during the construction phaseof a building: A case study in China. J Cleaner Prod 2014; 103:249–59.doi: https://doi.org/10.1016/j.jclepro.2014.11.023

Lassio J, Franca J, Santo K, Haddad A. (2016): Case study: LCA Methodology Applied to Material Management in a Brazilian Residential Construction Site. J Eng 2016. doi:https://doi.org/10.1155/2016/8513293.

Li Y., Yang L., He B., and Zhao D. (2014). Green building in China: Needs great promotion. Sustain.

Cities Soc. **2014**, 11, 1–6.

Seo, M, Kim, T, Hong, G and Kim, H. (2016): On-site measurements of CO_2 emissions during the construction phase of a building complex (2016) 10.3390/ en9080599

UN Climate News, 2020: https://unfccc.int/news/climate-change-is-an-increasing-threat-to-africa WGB

Week (2021): Report during the World Green Building Week held in London.

Yas Z. and Jaafer K. (2020): Factors influencing the spread of green building projects in the UAE. Journal of Building Engineering. **2020**, 27, 100894.