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Article

Design and performance analysis of a net-zero energy building in Owerri, Nigeria

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Abstract: Building cooling load depends on heat gains from the outside environment. Appropriate orientation and masonry materials play vital roles in the reduction of overall thermal loads buildings. A net-zero energy building performance has been analyzed in order to ascertain the optimum orientation and wall material properties, under the climatic conditions of Owerri, Nigeria. Standard cooling load estimation techniques were employed for the determination of the diurnal interior load variations in a building incorporating renewable energy as the major energy source, and compared with the situation in a conventionally powered building. The results show a 19.28% reduction in the building's cooling load when brick masonry was used for the wall construction. It was observed that a higher heat gain occurred when the building faced the East-West direction than when it was oriented in the North-South direction. Significant diurnal cooling loads variation as a result of radiation through the windows was also observed, with the east facing windows contributing significantly higher loads during the morning hours while the west facing windows contributed higher amounts in the evening. The economic analysis of the net-zero energy building showed an 11.63% reduction in energy cost compared to the conventional building, with a 7-year payback period for the use of Solar PV systems. Therefore, the concept of net-zero energy building will not only help in energy conservation, but also in cost savings, and the reduction of carbon footprint in the built environment.

Keywords: renewable integration; built environment; energy; net-zero; building; orientation; cooling load

1. Introduction

About 40% of greenhouse gas emissions and the world's energy consumption respectively, are attributed to buildings, and as a result of this energy being sourced mostly through fossil fuel, its negative impacts on the environment cannot be over emphasized. This negative impact will most likely become worse as more buildings continue to spring up as a result of the ever-increasing population [1,2]. As at 2016 in Nigeria, residential buildings already accounted for close to 50% of the nation's electricity consumption [3], and this has continued to rise with the increase in the population, and rise in rural-urban migration. Though energy crisis is a global phenomenon, Nigeria's inability to generate sufficient electricity, coupled with its increasing load demand (driven by increasing population and rural-urban migration), has further made the energy crisis in the country more critical. This has led to limited energy availability and access to the populace, which in turn has negatively affected the socio-economic development of the country. There is therefore, the need to ensure energy conservation and efficiency in buildings in order to reduce building energy demand.

To effectively design a net zero energy building, one of the important factors to consider is the passive techniques that when incorporated minimize the energy requirements for meeting the normal demands of the building, and ensure less greenhouse gas emission. Bio-climatic architecture, essentially based on climate considerations, with the aim of achieving physical comfort for the occupants of the building with minimum use of resources is promising for achieving net zero energy buildings. Some of these techniques include building orientation, building form, building materials, glazing, incorporation of renewable energy, etc. [3].

Building orientation takes into consideration the path of the sun when erecting the building to minimize exposing surfaces of the building to solar irradiation [4]. Morrissey et al. [5] pointed out that building orientation is the most important parameter when it comes to factors considered in passive solar design of buildings since it determines the amount of direct solar irradiation received by the building. The greatest energy saving obtained when a building was oriented 30°, 45° and 60° along its southern axis was when the longest walls faced 30° to the south, which is in line with the growing consensus that the best option is to orient buildings 20°–30° to the south [6,7]. In their study, Odunfa et al. [8] and Ochedi and Taki [9] all reported a reduction in solar gains when the longest side of the building faces the North-South direction.

Reduction of heat gain in buildings can be achieved through compact building forms (low surface-volume ratio) [3]. About 36% energy savings can be achieved with the appropriate building form and orientation [10].

With the help of low energy materials and efficient structural design, the energy demand of a building can be reduced. Akande et al. [11] is of the opinion that a reliable approach towards sustaining energy efficiency in residential buildings in Nigeria is to reduce the use of energy intensive materials such as glass and steel in the construction of buildings. Reflective materials and light colours have reduced heat gains by about 30% during peak sun periods [12]; and the use of brick masonry against concrete walls have resulted in significant energy reductions in buildings [8,13]. Windows significantly affect building energy performance [2,14–16]. They account for about 60% of the overall energy loss of buildings, resulting from conduction, convection and radiation [17]. This adds to building cooling and heating loads [14,18]. Therefore, optimum design and sizing of windows reduces the building energy consumption [19]. Proper window orientation reduces heat gains [16]. Rawat et al. [20] have studied the effect of window orientation in North East India, while Ahmed [14] also simulated the effects of window orientation on a building in Gaza Strip.

Renewable energy systems when integrated in a building meet the energy loads/demands of the building in an environmentally friendly manner. When renewable energy systems are used to meet the energy requirements of buildings, no GHGs are emitted. Usman [21] opined that choosing the right type and the right quantity of renewable energy for use in buildings is the most influential factor in actualizing a net-zero energy building. He reported that an output of 3484 kWh from a solar PV system was able to meet almost the total annual electricity load (3720.3 kWh) of a typical building. A study in Andalusia showed that about 78.89% of residential building energy demands can be satisfied with rooftop solar PV systems, while in the city of Al-Khobar, Saudi Arabia, a similar study showed that 19% of electricity demands of the villas and apartment buildings can be offset using rooftop solar PV systems [22]. Passive nocturnal radiation cooling can be utilized in the cooling of buildings thereby ensuring energy conservation and reduction in greenhouse gas emission [23–26]. This study therefore seeks to design and carry out a performance analysis of a net-zero energy building in Owerri, Nigeria. It undertakes a comprehensive analysis of a conceptual building envelope with respect to the cooling and heating loads, and the effects of building orientations as well as masonry materials on the energy performance of the building.

2. Methodology

The floor plan of the conceptual building model is shown in **Figure 1**. The apartment comprises different major zones including four bedrooms labeled BR1, BR2, BR3 and BR4, lounge, and kitchen. The specifications of the major zones are given in **Table 1**, while the envelop properties are shown in **Tables 2** and **3**. According to Trane [27], the principles of heat transfer play prime roles in achieving and maintain a comfortable indoor condition in buildings. This is applied in estimating the cooling and heating loads of the model building.

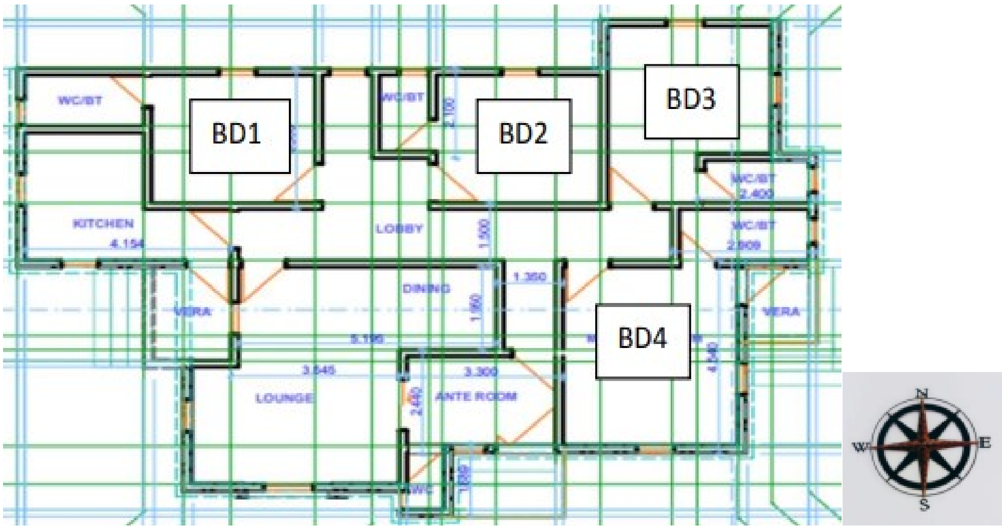

Figure 1. Floor plan of the designed building.

Table 1. The building specifications.

S/N	Zone	Dimension (m)	Area (m^2)	Volume (m^3)
1	BD 1	3.05 × 3.66 ×2.71	11.20	30.4
2	BD 2	3.66 × 3.66 × 2.71	13.40	36.3
3	BD 3	3.75 × 4.15 × 2.71	15.60	42.3
4	BD 4	3.75 × 4.15 × 2.71	15.60	42.3
5	Lounge	4.20 × 4.80 × 2.71	20.16	54.6
6	Kitchen	3.60 × 3.00 × 2.71	10.80	29.30

Table 2. Envelop properties.

S/N	Envelope part	Type	Insulation thickness (m)	U-value (W/m^{2}K)
1.	Walls	Brick Mansory	0.01	0.31
		Solid Cement Block	0.01	0.36
		Hollow Cement Block	0.01	0.37
2.	Roof			3.447

Table 3. Window properties.

S/N	Zone	Window type	Dimension (m)	Area (m^2)	U-value (W/m^{2}k)
1	BD1, BD2, BD3, BD4, Lounge, Kitchen	double leaf, 6.4mm uncoated single glazing type, with aluminum frame and thermal breaks	0.610 × 0.914	0.5575	5.43

In cooling load calculation, cooling loads are broadly classified into two, external loads and internal loads [8].

The external loads evaluated include heat gain from conduction through shaded walls, cooling loads arising from sunlit surfaces, radiation gain from the windows, loads arising from ventilation and air infiltration into the building.

Heat gain from conduction through surfaces (a shaded wall) is given as [27]:

$$Q_{cond} = U \times A \times \Delta T \tag{1}$$

U is the overall heat transfer coefficient of the wall expressed as:

$$U = \frac{1}{\mathrm{R1} + \mathrm{R2} + \mathrm{R3} + \mathrm{R4} + \mathrm{R5}} \tag{2}$$

where R1 is the outdoor air film resistance, R2 is the external cement plaster resistance, R3 is the block resistance, R4 is the inside cement plaster resistance, and R5 is the indoor air film resistance.

A is the net surface area of the wall expressed as:

$$A = (L_R H_R) - (L_w B_w) \tag{3}$$

ΔT is the dry bulb temperature difference across the surface.

The cooling loads resulting from direct sunlight on the walls, windows and roof, respectively (i.e., cooling load from sunlit surfaces) is given as [8,27,28]:

$$(Q_{cond}, SL)_{wa} = U_{wa} \times A_{wa} \times CLTD_{wa} \tag{4}$$

$$(Q_{cond}, SL)_{win} = U_{win} \times A_{win} \times CLTD_{win} \tag{5}$$

$$(Q_{cond}, SL)_{r} = U_{r} \times A_{r} \times CLTD_{r} \tag{6}$$

CLTD is the cooling load temperature difference which accounts for the heat added as a result of the sun shining on these exterior surfaces, and their capacity to store up heat [27].

The heat gain by radiation heat transfer through the windows is given as [27]

$$Q_{rad} = A_w \times SC \times SCL \tag{7}$$

where SC is the shading coefficient of the window, and SCL is the solar cooling factor [27].

Heat gain as a result of air infiltration into the room can be simplified as

$$Q_{infil} = \frac{\text{volume of space } \times \text{ air change rate per hour}}{3600}(1200\Delta\text{T} + 3010\Delta\text{W}) \tag{8}$$

where ΔT is the design outdoor dry-bulb temperature minus the desired indoor dry bulb temperature, and ΔW is the design outdoor humidity ratio minus the desired indoor humidity.

Heat gain as a result of ventilation can also be simplified as

$$Q_{vent} = Number\ of\ people \times (12.1\Delta T + 30.1\Delta W) \tag{9}$$

The occupants, light bulbs and appliances in the building make up the internal heat loads [27,28]. The total load emanating from the occupants is given as:

$$Q_{people} = Number\ of\ people\ ((SHGPP \times CLF) + LHGPP) \tag{10}$$

where SHGPP and LHGPP are the sensible and latent heat gain per person, while CLF is the cooling load factor which accounts for the capacity of the space to absorb and store heat released from the occupants.

The heat gained internally as a result of light bulbs is given as [27];

$$Q_{bulbs} = wattage_{bulbs} \times ballast\ factor \times CLF \tag{11}$$

The internal heat gain as a result of appliances is given as [27];

$$Q_{appliances} = Wattage_{app} \times Area \tag{12}$$

Therefore, the total heat gain can be given as:

$$Q_{total} = Q_{external} + Q_{internal} \tag{13}$$

Combining Eqs 1 to 11 results in the total heat gain in any the major zones of **Figure 1**. Hence, Q_{total} is expressed as:

$$\begin{aligned} Q_{total} = {} & ((\frac{1}{\text{R1} + \text{R2} + \text{R3} + \text{R4} + \text{R5}} + ((\text{L}_R\text{H}_R) - (\text{L}_W\text{B}_W)) \times \Delta\text{T})) + (\text{U} \times \text{A} \times \Delta\text{T})_{Roof} \\ & + (\text{U}_{wa} \times \text{A}_{wa} \times \text{CLTD}_{wa}) + (\text{U}_{win} \times \text{A}_{win} \times \text{CLTD}_{win}) + (\text{U}_r \times \text{A}_r \times \text{CLTD}_r) \\ & + (\text{A} \times \text{SC} \times \text{SCL}) + (\frac{\text{volume of space} \times \text{air change rate per hour}}{3600}(1200\Delta\text{T} + 3010\Delta\text{W})) \\ & + (\text{Number of people} \times \Delta\text{T} \times 33.76)) + (\text{Number of people}\ ((\text{SHGPP} \times \text{CLF}) + \text{LHGPP}) \\ & + (\text{wattage}_{bulbs} \times \text{Ballast Factor} \times \text{CLF}) + (\text{Wattage}_{app} \times \text{Area}) \end{aligned} \tag{14}$$

The appliances and their ratings, in the different zones of the building that served as load inputs into the analysis are listed for each zone in **Tables 4–8**.

Table 4. Appliances present in the lounge with their wattage.

S/N	Appliances	Wattage	Number	Total wattage
1	Ceiling fan	75	2	150
2	Television	100	1	100
3	Water dispenser	700	1	700
4	**Total**			**950**

Table 5. Appliances present in the bedrooms 1 and 2 with their wattage.

S/N	Appliances	Wattage	Number	Total wattage
1	Ceiling fan	75	1	75
	Total			**75**

Table 6. Appliances present in bedroom 3 with their wattage.

S/N	Appliances	Wattage	Number	Total wattage
1	Ceiling fan	75	1	75
2	Personal Computer	125	1	125
	Total			**200**

Table 7. Appliances present in bedroom 4 with their wattage.

S/N	Appliances	Wattage	Number	Total wattage
1	Ceiling fan	75	1	75
2	Personal computer	125	1	125
3	Television	100	1	100
	Total			**300**

Table 8. Appliances present in the kitchen with their wattage.

S/N	Appliances	Wattage	Number	Total wattage
1	Ceiling fan	75	1	75
2	Freezer	320	1	320
3	Microwave	900	1	900
	Total			**1295**

3. Results and discussion

As shown in **Figure 2** for the Lounge, the internal heat generation with a total cooling load of about 20 kW contributed the highest cooling load in the South-West (SW) orientation as well as the East-West orientation. The kitchen played a significant role in both orientations in increasing the cooling load, contributing about 14.5 kW each., followed by bedrooms 4 and 3, each contributing about 5kW in both orientations. It can be observed that the contributions from conduction, sunlit surfaces, radiation, and infiltration for the different zones and orientations are marginal, whereas that from ventilation is noticeable. Floor areas, number of exposed surfaces, appliances and direction all influenced the contributions made by the zones to the overall cooling load of the building. BD1 has the least cooling load, approximately 1.96 kW, while BD2 has a load of 2.1 kW. Though they have the same number of exposed walls facing the same direction (North), their floor areas are different. Also, in BD1 and BD2, the East-West orientation records a higher cooling load than the North-South orientation. Similarly, BD3 and BD4 have cooling loads of 4.4 kW and 6 kW, respectively, though with same floor areas and number of exposed walls. The variation occurred because the walls faced different directions. The energy intensive appliances in the kitchen influenced the topmost load contribution.

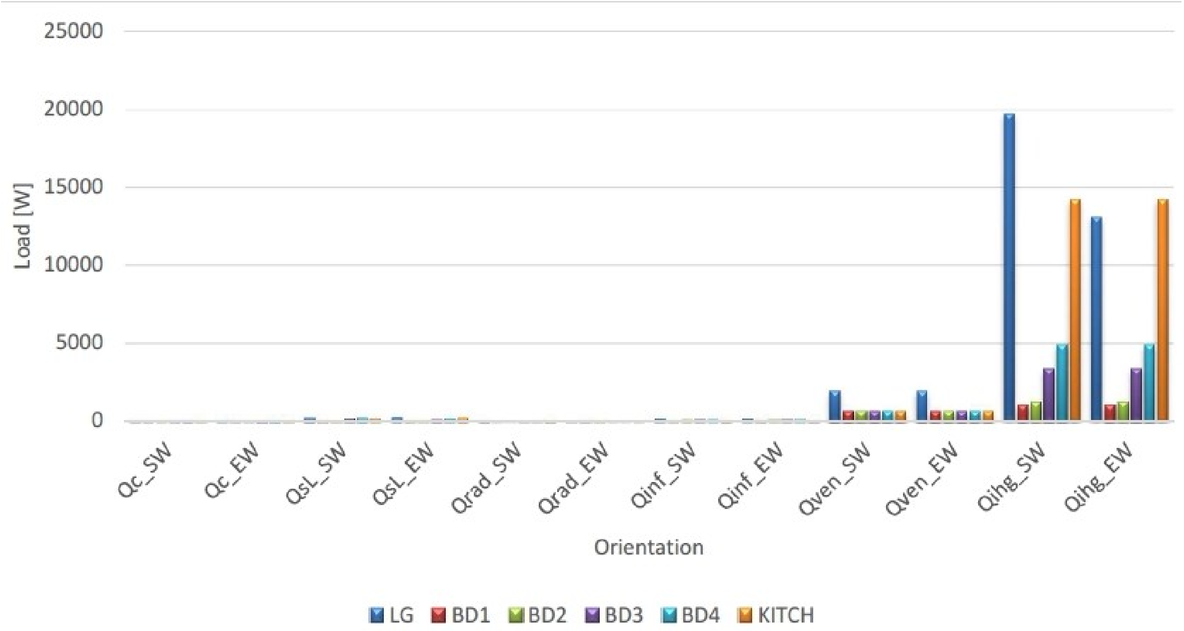

Figure 2. Building zonal loads for N-S and E-W orientations.

Figure 3 shows that the Lounge which has the highest floor area and with two exposed walls had the highest external cooling load of 4.8 kW. Also, the total external loads of the kitchen exceed those of BD1 and BD2 due to the simple reason that it has higher number of exposed walls. This consistent with the findings of Usman [21], that larger floor areas and exposed walls increase cooling load.

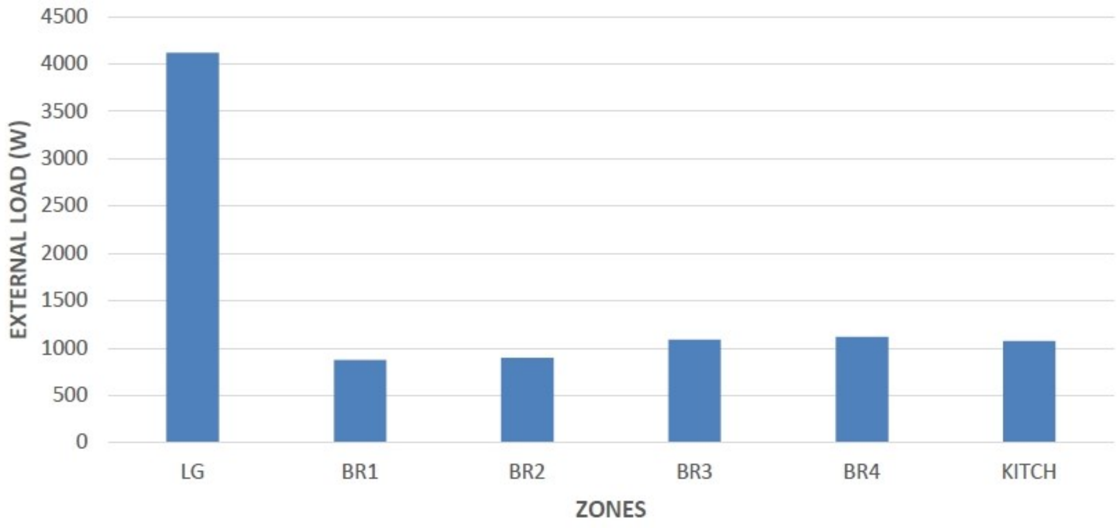

Figure 3. Total external loads of the zones.

Figure 4 shows time-dependent cooling loads arising from conduction through the walls, and radiation through the windows of the lounge facing different directions. The west facing wall contributed more to the cooling load in the early hours of the morning, but reduces as the sun rises, but then starts increasing from the evening hours and reaches its peak with 0.12 kW around 10:00 pm. This trend shows that the west facing wall absorbs a large amount of heat during the period when the sun is facing that direction (when the sun is setting), and gradually releases the absorbed heat into the room, hence increasing the cooling load. The south facing wall also followed a similar pattern, but contributed less than the west wall with a peak cooling load of 0.09 kW around 7:00 pm. The cooling loads as a result of radiation through the windows were seen to be higher in the west facing window than the south facing window. The cooling loads gradually increased as the day broke for both the west and south windows, but while it peaked at 0.03 kW around 12 noon for the south window, it continued to rise for the west window, and finally peaked at 0.06 kW by 5:00 pm before gradually decreasing.

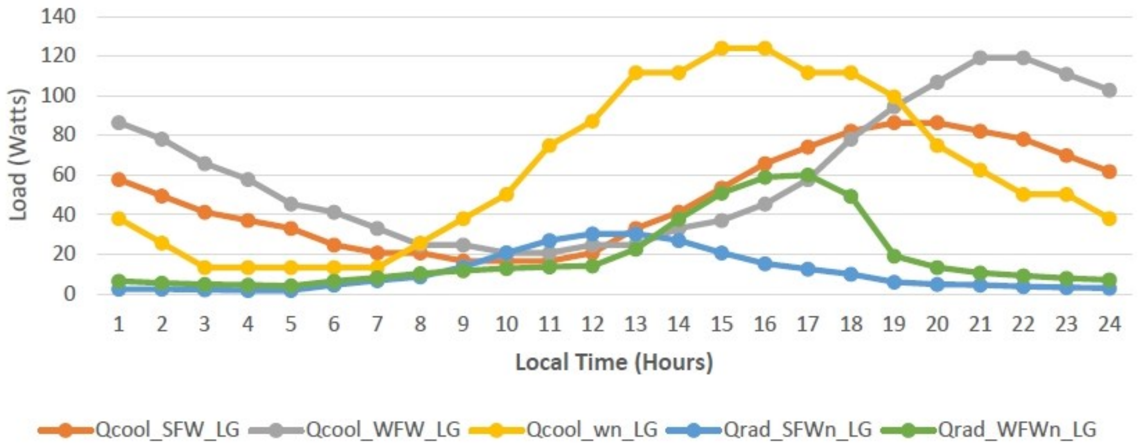

Figure 4. Orientation dependent cooling load of the lounge.

Figure 5 shows that for BD1 and BD2 with their only exposed walls facing the north, the cooling load contributed by the wall showed similar pattern as that of **Figure 4** but peaked at 0.05 kW between 9:00 and 10:00 pm. Though the radiation cooling load in **Figure 5** maintained the trend of **Figure 4**, it can be seen that it contributed far less cooling load than the lounge, reaching its peak of 0.013 kW around 12 noon, and sustained it with little variations till 6:00 pm, and thereafter decreased. This showed a great reduction in the cooling load through radiation when compared to the west facing window.

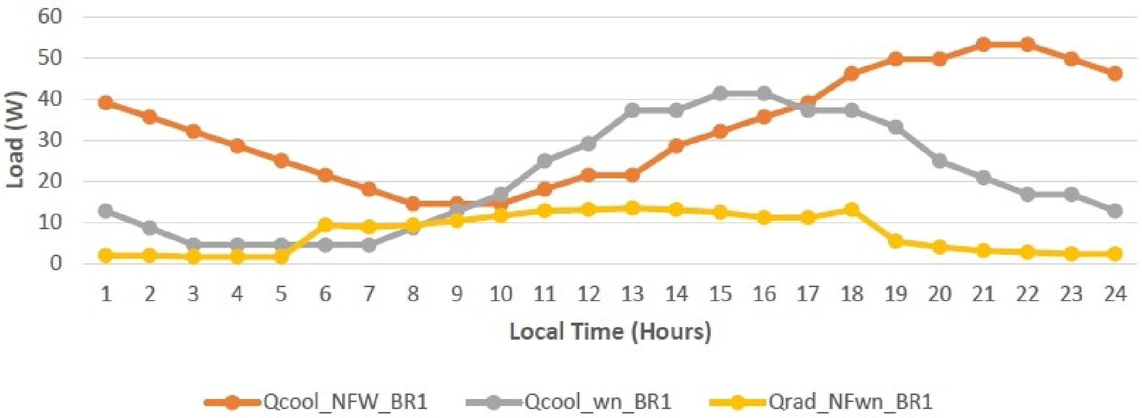

Figure 5. Orientation dependent cooling loads of BD1 and BD2.

The North facing wall and window of BD3 followed the same as that of BD1 and BD2, as can be seen in **Figure 6**. The wall area influences the cooling load in this zone significantly. The radiation cooling load was exactly the same, as the window areas remained the same. But unlike the west facing window of the lounge (**Figure 4**), it can be seen that radiation cooling load of the east facing window peaked in the morning hours of the day at 8:00 am attaining 0.057 kW. Around 3:00 pm, the east facing wall reached its peak with a cooling load of 0.096 kW, showing similar trend of absorbing heat when the sun is facing that direction (as the sun rises), and releasing it into the zone as the sun moves away from that direction.

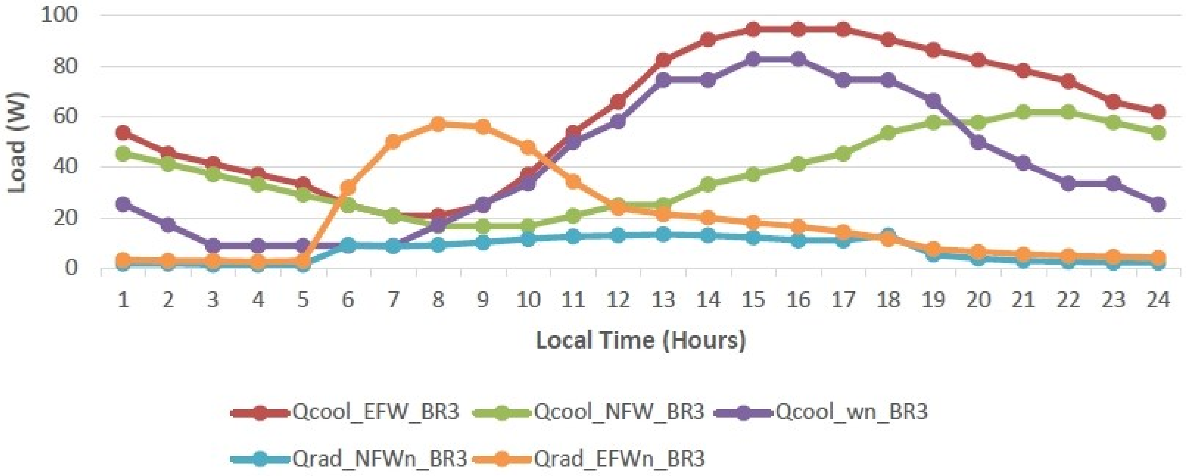

Figure 6. Orientation dependent cooling loads of BD3.

Figure 7 shows that the south facing walls and windows in BD4 followed the same pattern as the south facing wall and window of the lounge, while its east facing walls and window follows the east facing wall and window of BD3 respectively.

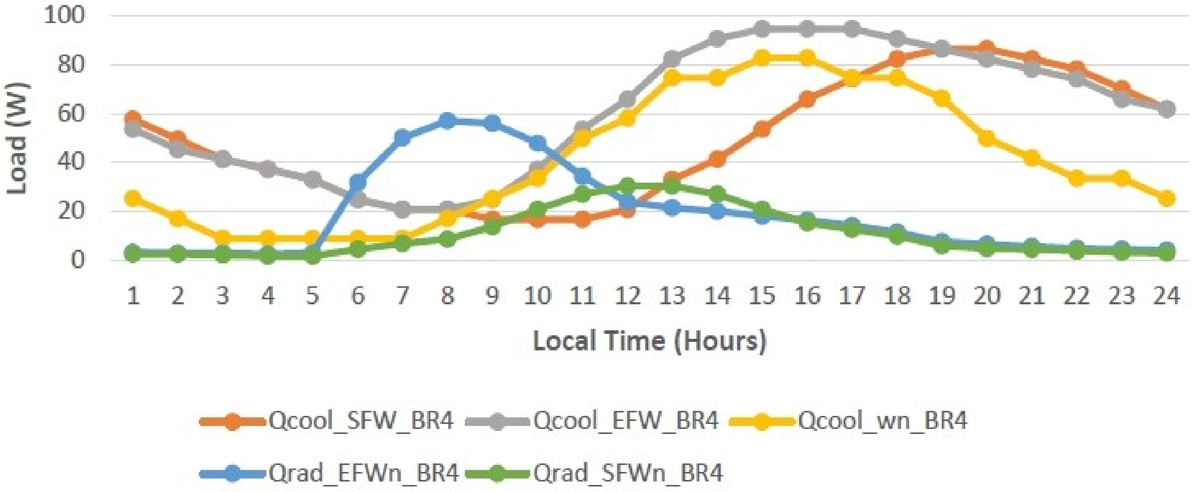

Figure 7. Orientation dependent cooling load of BD4.

It is clearly shown in **Figure 8** that the kitchen also maintained the same pattern as the lounge because their walls and windows faced the same direction. The only difference recorded is the amount of cooling load contributed through the walls, as a result of variations in wall areas.

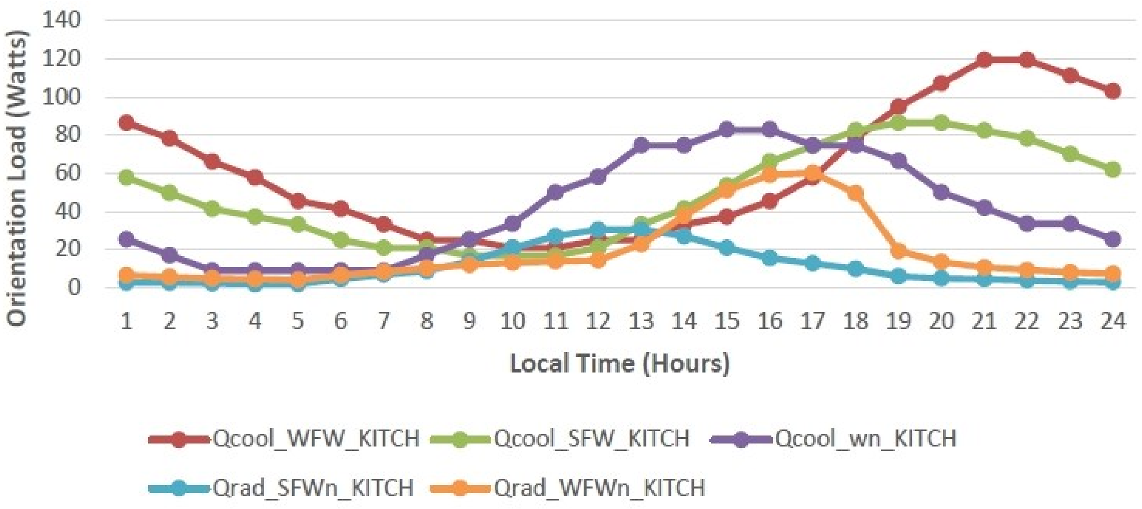

Figure 8. Orientation dependent cooling load of the Kitchen.

The result of the parametric analysis of the impact of window orientation on the energy performance of the building is shown in **Figure 9**. It compares the heat gained as a result of radiation through the windows of the building. It gives a clearer view of the contributions of the windows facing different directions to the total radiation heat gain. As can be seen, while the east facing windows contributed more significantly to the total cooling load in the morning hours, the west facing windows contributed more in the evening hours. The north facing windows contributed significantly less to the overall total heat gain throughout the day. Right orientation reduces heat gain into the building envelope, with the south-north orientation being the most optimum [8,9]. Therefore, the optimum orientation is one that reduces openings in the East and West directions during the day because the rising of the sun from the east and setting of same in the west make it difficult to prevent radiations from entering through these zones since they have low sun angles during these periods. The report of FMPWH [3], and findings of Ahmed [14], Soudbaksh et al. [17] and Djokovic et al. [19] all support the above observation.

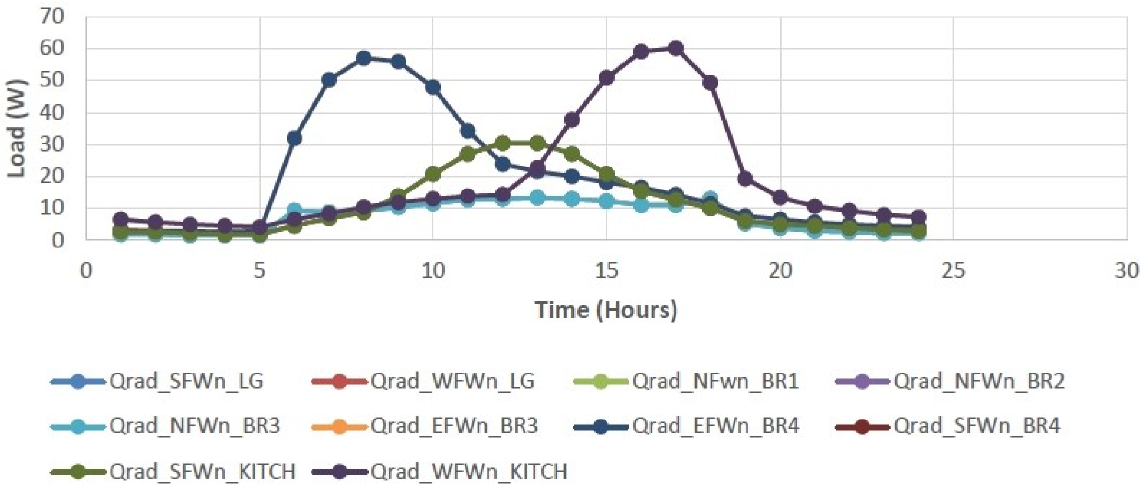

Figure 9. Comparative heat gain through radiation from all the windows.

Figure 10 shows the parametric effect of the U-values of masonry (wall) materials on the cooling loads of the different zones of the buildings in the south and west directions. It is observed that the brick masonry contributed a lower heat gain than its counterparts (the hollow and solid cement blocks), irrespective of the direction the wall is facing. This is in agreement with the work carried out by Ede et al. [13], who showed that brick walls contributed a lower heat gain compared to concrete walls. Odunfa et al. [8] also demonstrated that indeed the brick masonry when used as the wall materials reduces the cooling load compared to the regular blocks used in wall construction in Nigeria.

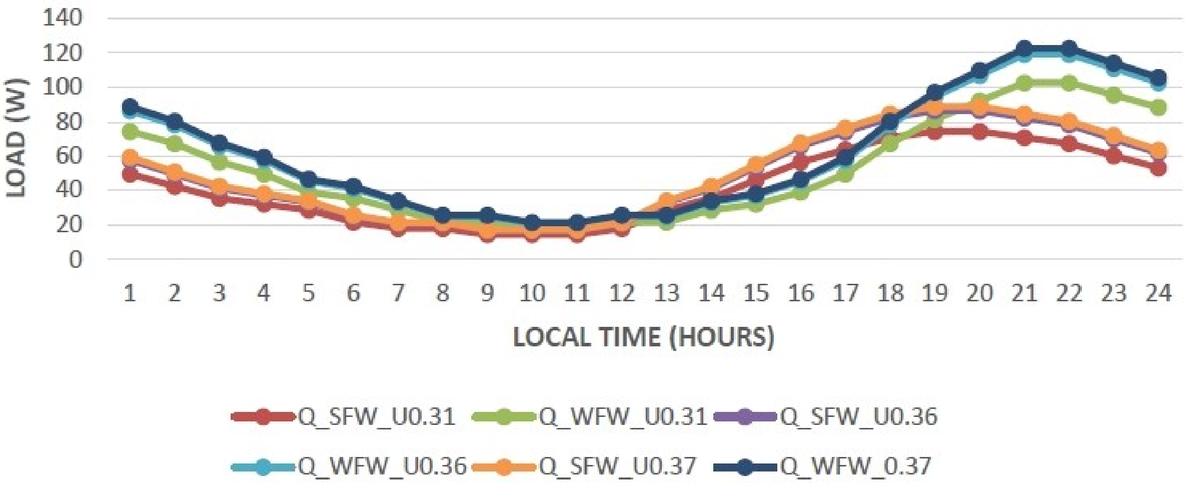

Figure 10. Effect of the wall U-values on the cooling loads.

The parameters of the incorporated solar PV system are presented in **Table 9**. It shows the quantity of solar panels and batteries needed to provide the required power for the building. Economic analysis of the system was carried out to determine the comparative energy cost of the conventional system and the renewable energy driven system, and the results of the analysis are shown in **Table 10**. It shows that about ₦3,450,695.61 will be saved if the recommended passive solar techniques are used rather than the regular conventional sources. From **Table 11**, a total of ₦24,301,950 is needed as initial capital cost of installing a solar PV system. However, with the annual savings of about ₦3,450,695.61 for adopting the alternative system, the payback period is 7 years when it is adopted to provide the energy needed in the building.

Table 9. Solar PV system design parameters.

Parameters	**Design values**
Module power (watt)	315
No. of modules in series	04
No. of modules in parallel	27
Total capacity of solar panel arrays	34
Operating DC voltage	24
Regulator efficiency	0.9
Output power capacity of inverter (Kw)	24

Table 9. (*Continued*).

Parameters	**Design values**
Inverter efficiency	0.9
Battery depth discharge	0.6
Battery backup days	2
Battery cell capacity	1000 Ah
Battery cell voltage	2 V
No. of cells in series	12
No. of cells in parallel	8

Table 10. Cost savings using the recommended passive techniques.

	Regular model	**Recommended model**
Total Energy in a day (W)	2,227,140	1,968,056.4
Total energy in a year (365 days)	812,906,100	718,340,586
Daily bill (@ (₦36.49 per kWhr) + ₦383.14 VAT) (₦)	81,651.48	72,197.52
Yearly bill (₦)	**29,663,326.73**	**26,212,631.12**

Table 11. Payback period for the solar PV system.

S/N	**Parameters**	**Estimate**
1	Cost of solar system installation	₦24,301,950
2	Annual savings	₦3,450,695.61
3	Payback period	7 years

4. Conclusion

A net-zero energy building has been designed and analyzed using Excel statistical tool. By implementing some passive cooling techniques to cut down on the cooling load of the building, space cooling costs and carbon footprints are amenable to drastic reduction. The major findings from this study are:

- Cooling loads of a building are dependent on the amount of heat gained from the outside through the fenestrations. The brick masonry reduced the amount of cooling loads compared to the regular solid and hollow blocks normally used for building constructions in Owerri.
- The optimum orientation for energy efficiency and best performance is the North-South direction as it ensures that the building has a lower cooling load.
- Windows facing the east and west directions contributed higher heat gains during the morning and evening hours of the day, respectively; therefore, it is advisable to minimize window openings in those directions, while maximizing window openings in the north and south directions, especially the north direction, as it contributed the least amount of heat gain.
- The amount spent on electricity bill to meet the cooling load requirement of the building was reduced by ₦3,450,695.61 when the optimum orientation and low energy wall materials were used, with a payback period of 7 years for integrating a solar PV system as a sole energy source for the building.

Author contributions: Conceptualization, GNN; methodology, GNN and KCD, software, GNN validation, GNN and KCD; formal analysis, GNN and KCD; investigation, GNN and KCD; resources, KCD; data curation, KCD, OCN; writing—original draft preparation, KCD and GNN; writing—review and editing, GNN, OCN and NVO; visualization, NVO and EEA; supervision, GNN, OCN, NVO and EEA; project administration, EEA; funding acquisition, EEA. All authors have read and agreed to the published version of the manuscript.

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References

1. Lee JW, Jung HJ, Park JY, et al. Optimization of building window system in Asian regions by analyzing solar heat gain and daylighting elements. Renewable Energy. 2013; 50: 522-531. doi: 10.1016/j.renene.2012.07.029
2. Mebarki C, Djakab E, El Hassar SMK, et al. Impact of glazing type and orientation on the optimum dimension of windows for office room in hot climate. Journal of Architectural Environment & Structural Engineering Research. 2018; 1(1): 10-15. doi: 10.30564/jaeser.v1i1.271
3. Federal Ministry of Power, Works and Housing (Housing). Building energy efficiency guideline for Nigeria. Federal Ministry of Power, Works and Housing (Housing); 2016.
4. Abdullahi ML. Integrating principles of passive cooling in the design of five star hotel in Minna. Ahmadu Bello University, Zaria, Nigeria; 2017; Unpublished work.
5. Morrissey J, Moore T, Horne RE. Affordable passive solar design in a temperate climate: An experiment in residential building orientation. Renewable Energy. 2011; 36(2): 568-577. doi: 10.1016/j.renene.2010.08.013
6. Littlefair P. Daylight, sunlight and solar gain in the urban environment. Solar Energy. 2001; 70(3): 177-185. doi: 10.1016/S0038-092X(00)00099-2
7. Pacheco R, Ordóñez J, Martínez G. Energy efficient design of building: A review. Renewable and Sustainable Energy Reviews. 2012; 16(6): 3559-3573. doi: 10.1016/j.rser.2012.03.045
8. Odunfa KM, Nnakwe CJ, Odunfa VO. Building Energy Efficiency in Nigeria Major Climatic Zones. Journal of Building Construction and Planning Research. 2018; 06(04): 251-266. doi: 10.4236/jbcpr.2018.64017
9. Ochedi DET, Taki DA. Energy Efficient Building Design in Nigeria: An Assessment of the Effect of the Sun on Energy Consumption in Residential Buildings. JOURNAL OF ENGINEERING AND ARCHITECTURE. 2019; 7(1). doi: 10.15640/jea.v7n1a6
10. Aksoy UT, Inalli M. Impacts of some building passive design parameters on heating demand for a cold region. Building and Environment. 2006; 41(12): 1742-1754. doi: 10.1016/j.buildenv.2005.07.011
11. Akande OK, Fabiyi O, Mark IC. Sustainable Approach to Developing Energy Efficient Buildings for Resilient Future of the Built Environment in Nigeria. American Journal of Civil Engineering and Architechture. 2015; 3(4): 144-152.
12. Akbari H, Davis S. Cooling Our Communities: A Guidebook on Tree Planting and Light-Colored Surfacing. (Huang J, Dorsano S, Winnett S, eds.). Office of Scientific and Technical Information (OSTI); 1992. doi: 10.2172/5032229
13. Ede AN, Olofinnade ON, Enyi-Abonta E, Bamibgoye GO. Implications of Construction Materials on Energy Efficiency of Buildings in Tropical Regions. International Journal of Applied Engineering Research. 2017; 12(18): 7873-7883.
14. Ahmed EK. Effect of Windows Size, Position and Orientation on the Amount of Energy Needed for Winter Heating and Summer Cooling. Journal Of Engineering Research and Technology. 2017; 1(1): 1-8.

15. Fariha S, Ashikur RJ. Performance Evaluation of Window Location and Configuration to Improve Daylighting of Residential Apartment Buildings. In: Proceedings of the 2018 International Conference on Green Architecture (ICGrA); 12-14 July 2018; Dhaka, Bangladesh. pp. 12-14.
16. Rashid M, Ahmad T, Malik AM, et al. Effects of orientation and glazing material on heat gain in semi-arid climate of Lahore. University of Engineering and Technology Taxila. Technical Journal. 2016; 21(4): 38.
17. Soudbaksh K, Etminan M, Hakimazari M, Salavatian S. Impacts of Window Factors and Building Orientation on Energy Consumption in Residential Buildings of Humid Temperate Climatic Zone in Iran. Journal of Construction in Developing Countries. 2022; 27(2): 235-262. doi: 10.21315/jcdc-04-21-0061
18. Detsi M, Manolitsis A, Atsonios I, et al. Energy Savings in an Office Building with High WWR Using Glazing Systems Combining Thermochromic and Electrochromic Layers. Energies. 2020; 13(11): 3020. doi: 10.3390/en13113020
19. Djoković JM, Nikolić RR, Bujnak J, et al. Selection of the Optimal Window Type and Orientation for the Two Cities in Serbia and One in Slovakia. Energies. 2022; 15(1): 323. doi: 10.3390/en15010323
20. Rawat V, Shivankar S, Das B, et al. Effect of Orientation of Window on Building Heat Load: Perspective of N-E India. IOP Conference Series: Materials Science and Engineering. 2017; 225: 012166. doi: 10.1088/1757-899x/225/1/012166
21. Usman M. Design and performance analysis of energy efficient building in Pakistan. University of Engineering and Technology, Taxila, Pakistan; 2016; Unpublished work.
22. Dalal R, Bansal K, Thapar S. Bridging the energy gap of India's residential buildings by using rooftop solar PV systems for higher energy stars. Clean Energy. 2021; 5(3): 423-432. doi: 10.1093/ce/zkab017
23. Parker DS, Sherwin JR, Hermelink AH, et al. NightCool: a nocturnal radiation cooling concept. Available online: https://www.researchgate.net/publication/237282947_NightCool_A_Nocturnal_Radiation_Cooling_Concept (accessed on 25 September 2024).
24. Hollick J. Nocturnal radiation cooling tests. Energy Procedia. 2012; 30: 930-936. doi: 10.1016/j.egypro.2012.11.105
25. Okoronkwo CA, Nwaigwe KN, Ogueke NV, et al. An Experimental Investigation of the Passive Cooling of a Building Using Nighttime Radiant Cooling. International Journal of Green Energy. 2014; 11(10): 1072-1083. doi: 10.1080/15435075.2013.829775
26. Nwaji GN, Okoronkwo CA, Ogueke NV, et al. Transient simulation of a building-integrated hybrid solar collector/nocturnal radiator with in-built thermal storage for space cooling in Owerri, Nigeria. Journal of Energy Engineering. 2021; 147(2): 04021003. doi: 10.1061/(ASCE)EY.1943-7897.000074
27. Trane. Cooling and Heating Load Estimation: One of the fundamental series, A publication of Trane, a business of Ingersoll Rand [www] Trane. Available online: https://www.tranebelgium.com/files/book-doc/13/fr/13.5cbzdt11.pdf (accessed on 25 September 2024).
28. ASHRAE. ASHRAE Cooling and Heating Load Calculation Manual [www] ASHRAE. Available online: https://pdfcoffee.com/ashrae-cooling-and-heating-load-calculation-manual-pdf-free.html. (accessed on 25 September 2024).