http://dx.doi.org/10.21622/MACI.2024.01.2.1070

REGENERATIVE FACADES FOR HOTEL RETROFITTING IN HOT-DRY CLIMATE

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Received on, 26 October 2024 Accepted on, 19 December 2024 Published on, 25 December 2024

ABSTRACT:

Nigeria, despite its vast oil and gas resources, faces significant challenges in electricity generation, resulting in an average daily power supply of only nine hours. This inadequate power supply poses a major obstacle to economic diversification in non-oil-producing states like Kebbi. The hospitality sector in Birnin Kebbi struggles with high operational costs due to reliance on diesel generators, contributing to environmental degradation and hindering investments. This study evaluates the regenerative energy potential of retrofitting hotel facades in a Hot-Dry climate. Energy audits in target hotel and data collection on electricity bills, diesel consumption, and building characteristics reveal significant energy-saving opportunities. The data collected are used to simulate regenerative energy facade strategies for retrofitting hotels, including shading, glazing, thermal mass, and insulation. Base-case modelling shows that wall improvements and insulation materials like rock wool or glass wool can reduce energy consumption by over 30%. Using lighter-coloured wall surfaces with higher Solar Reflectance Index (SRI) can further enhance energy savings. Additionally, implementing windows with improved insulation properties and shading devices can reduce energy consumption. These findings underscore the importance of incorporating regenerative energy facade strategies in building designs and policies in Nigeria to promote sustainable development. Further research should focus on long-term performance evaluations and cost-benefit analyses of these strategies.

KEY-WORDS: Climate change, Energy efficiency, Energy use, Tourism, Hospitality facilities.

http://dx.doi.org/10.21622/MACI.2024.01.2.1070

1. INTRODUCTION

About 95% of Nigeria's income is generated from exporting crude oil [1]. However, despite Nigeria's abundant oil and gas resources, electricity generation hovers around 7000MW for over 200 million population (National Bureau of Statistics) [2] with an average power supply of only nine hours daily. This is grossly inadequate and especially challenging for the non-oil-producing states to diversify their economies.

Birnin Kebbi is the capital city of Kebbi state. Like most state capitals in Nigeria, enjoys the privilege of being the seat of governmental administration. The state borders Sokoto, Zamfara and Niger states (Figure 1). On the international level, it borders Niger Republic and Benin Republic to its North and West, respectively. This makes it a centre of trade at both national and international levels.

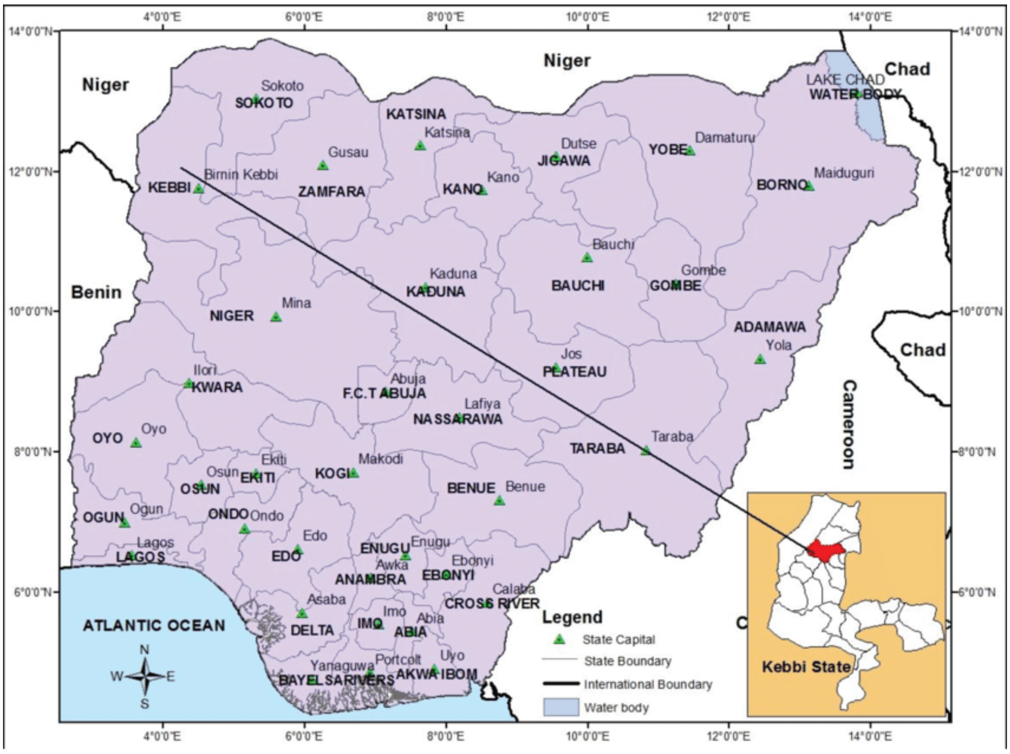

Fig. 1. Geographical location of Kebbi State. [3]

Kebbi state is internationally recognised as the location for three renowned festivals; Argungu International Fishing Festival, Uhola Agric Festival Zuru, and Yauri Rigata Agricultural Show [4]. As a result of these, Birnin Kebbi witnesses a constant influx of visitors throughout the year adding to the need to invest in providing accommodation facilities within and around the metropolis.

Tourism has been identified as a potential source of Internally Generated Revenue (IGR), especially for the non-oil-producing states in Nigeria like Kebbi [5] [6]. However, hospitality facilities require a steady power supply to operate [7] [8]. This further challenges the diversification of the hospitality sector and hinders investments across the region due to the enormous cost involved in operating or maintaining facilities.

From a global perspective, Heating Ventilation and Air Conditioning (HVAC) and Transportation are the major consumers of energy, with demand estimates of over 80% [9]. This is a cause for concern and likely a potential focus for stakeholders in the building industry in catalysing new ideas that would substantially reduce energy demand in buildings, particularly HVAC loads, through design, materials, and construction techniques in all phases of the building life cycle.

According to the European Commission [10], non-residential buildings are 40% more energy intensive, and they consume up to 250kWh/m² of energy as against 180kWh/m² for residential buildings [10] [11]. The energy use in hotels plays a crucial role in both environmental degradation and poverty. Many hotels in this region heavily rely on conventional energy sources such as diesel and petrol generators, due to inconsistent power supply from the national grid. This heavy use of fossil fuels contributes to environmental degradation not only through the exploration and refining of fossil fuels which exacerbates the effects of climate change, but also through air and noise pollution. Additionally, the high operational costs associated with diesel generators often result in increased hotel prices, limiting access to accommodation for those in lower-income brackets and perpetuating poverty. The environmental and economic impacts of unsustainable energy practices in hotels are interconnected, with vulnerable communities experiencing the harshest consequences [12].

Transitioning to cleaner and more sustainable energy sources in the hotel industry is not only essential for mitigating environmental degradation but can also contribute to poverty alleviation by reducing operational costs and making accommodations more affordable.

There is a significant research gap in the analysis of retrofitting the building façade to achieve higher thermal efficiency [13] and this research aims to evaluate the regenerative energy potential of retrofitting the facades of hotels in Hot-Dry Climates, with a focus on Birnin-Kebbi, Nigeria.

Literature shows that shifting to regenerative energy is capital intensive and requires a longer payback period [11], as such there is a need to devise means of retrofitting old stock of buildings. Retrofitting hotel facades with regenerative technologies presents a promising approach to enhance energy efficiency and reduce environmental impact.

2. LITERATURE REVIEW

Hotel buildings consume large amounts of energy to provide the best service possible for guests [11] [14] [15]. The energy used in running hotels is largely from fossil fuels, which not only aggravates Climate Change but also reduces profits due to high energy costs [16].

From the available data on energy consumption of hotels in North America, Europe, and Asia between the years 1990 to 2000 [17] an average of 401kWh/m² of energy is consumed in the United States per year, out of which about 41% is electricity. In Canada, an average annual energy consumption between 612 kWh/m² to 689kWh/m² is consumed over the same period, out of which electricity accounts for about 29%. In Europe, hotel energy consumption accounts for 1% of the total (39TWh), 50% of which is electricity [18]. In Singapore, a study conducted in 1993 on energy consumption of hotel buildings indicates that an annual average of 468 kWh/m², is consumed annually, and a later study in the same location of 29 hotels conducted between 2005 and 2006 reported an annual electricity consumption of 361 kWh/m² per annum. In Hong Kong, two-year research conducted between 1995 and 1997 indicates that consumption of energy in hotels in that location ranges between 406 kWh/m² to 564 kWh/m² per annum.

Studies conducted in Nigeria show similar results. In 2015, six hotels were audited in northern Nigeria. It was estimated that an average of 303 kWh/m² is consumed annually [19]. In the south-eastern part of Nigeria, an assessment conducted in 2019 estimated a higher annual consumption of 403 kWh/m² [20], with a total average of 438 kWh/m² seen in the cases mentioned. Results (Figure 2) indicate that electricity is the main form of energy used to power these hotels.

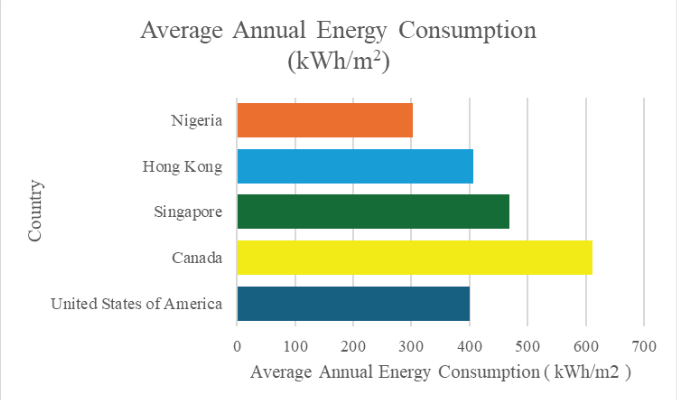

Fig. 2. Bar-Chart diagram showing different countries and their hotel annual average energy consumption with a total average of 438 kWh/m².

There is a need for hotels to have energy-efficient facades that can reduce heat gain, enhance natural ventilation, regulate daylight, and provide insulation [21]. Some of the possible solutions include smart facades that can adapt to environmental

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conditions, ventilated facades that can create an air gap between the inner and outer layers, and integrated glass facades that can incorporate films, coatings, or frit patterns to control solar radiation [22]. By having energy-efficient facades, hotels can benefit from lower energy bills, higher guest satisfaction, better indoor air quality, and lower environmental impact. Moreover, they can contribute to the national and global goals of reducing greenhouse gas emissions and mitigating climate change [23].

Wang et. al [24] utilised 15 existing hotels in Jiangsu Province as case studies for implementing energy-saving retrofits. The top five energy-saving retrofit technical measures, applied most frequently, were heating, ventilation and air conditioning, monitoring, lighting, domestic hot water, and building envelope systems. A study by Tushar [12] examines methods to enhance thermal efficiency by retrofitting building façades, focusing on adding extra insulation to floors and walls, both internally and externally, and replacing old windows with new ones that have lower U-values. Table 1 lists the most common and suitable insulation materials for a Nordic climate. Reducing the U-value of the building envelope through insulation leads to lower final energy use, which in turn reduces primary energy use and heating costs. However, achieving a constant decrease in U-value necessitates thicker insulation and resulting in increased primary energy use and costs [26].

Table 1: Retrofit materials for a Nordic Case Study [26]

Insulation materials	Thermal conductivity (W/mK)	Density (kg/m³)
Glass wool	0.042,	20
Rock wool	0.037	40
Wood fibre	0.038	40
Extruded polystyrene XPS for basement walls	0.030	32
Double-glazed windows having a single low-e coating, and argon and krypton gas fills	1.2 and 1.0	
Triple-glazed windows with double low-e coating, and argon or krypton gas fills	0.8 and 0.6	

The general design guidelines for comfort in this type of climate in literature [27] [28] [29] [30] [31] show the variables recommended for a composite climate include: shading, geometry, orientation, glazing, thermal mass, internal gains minimization, outdoor living and insulation.

Excellence in Design for Greater Efficiencies (EDGE) is a no-cost software tool, a standard for green buildings, and a global certification system for sustainable construction. EDGE is developed by the International Finance Corporation (IFC), and is part of the World Bank Group, to demonstrate green buildings financial benefits and stimulate investment in such projects EDGE [32]. EDGE calculations are based on climatic conditions of the location already built in the software, the building type, and occupant use. In this instance, the hotel category is selected for the research. Assumptions for area, occupancy, and the type of support services are based on the star rating of the property which is 3-star for Saffar Guest Inn and Conference Centre.

The thermal properties of the building envelope reflect the typical practice in Nigeria.

Simulations, such as those supported by EDGE, are a critical tool in designing and retrofitting buildings, particularly in the context of sustainable and energy-efficient practices [33]. Before implementing retrofitting measures, it is essential to simulate the potential outcomes to understand their effectiveness and impact. This is particularly relevant in the case of regenerative facades for retrofitting hotels, where energy efficiency and environmental sustainability are paramount.

The use of simulation tools, such as the Excellence in Design for Greater Efficiencies (EDGE) software, can provide valuable insights into the potential benefits of retrofitting measures [34]. EDGE is specifically designed to assess the environmental impact of building designs and retrofitting strategies, allowing designers and architects to optimize their solutions for maximum efficiency and sustainability.

By simulating the results of retrofitting measures, stakeholders can make informed decisions about the most effective strategies to implement. This not only ensures that the retrofitting process is cost-effective but also minimizes the environmental impact of the building [35]. In the context of regenerative facades for hotels, simulation can help identify the most suitable materials, technologies, and design strategies to improve energy efficiency and sustainability.

EDGE assessment uses 'a monthly quasi-steady-state calculation method based on European Committee for Standardization (CEN) and International Standards Organization (ISO) 13790 standards to estimate annual energy consumption for heating and cooling in both residential and non-residential buildings'. In order to better illustrate efficiency improvements to users, energy usage outputs are shown as delivered energy, rather than primary energy or carbon dioxide emissions. Further details on the EDGE methodology can be found in EDGE [32]. The calculation methodology was verified using dynamic simulation software (eQuest11) for buildings across nine different locations.

EDGE has advantages, compared to other building performance methodologies [35] [36], as it is free, relatively easy to use, and has an interactive and instant response. However, the most attractive benefit is that it has an extensive and expanding built-in database that is customized adaptively to a location determined by the user and suited to developing economies with data for sub-Saharan Africa. Despite Leadership in Energy and Environmental Design (LEED) being the most certified green building certification system in the world, for example, the list of top ten countries with the most LEED-certified projects (US excluded) does not include any African country.

3. METHODOLOGY

This study focuses on Saffar Guest Inn and Conference Centre, a 65-room hotel located within Birnin Kebbi metropolis. Recognized by state authorities as a prominent hotel in the area, it is selected for an energy audit. The hotel classification as a medium-class establishment guided the audit scope.

During the audit, the following data are collected:

1. One year electricity bills.
2. Diesel consumption data from fuel log book.
3. A log of average daily power outage from the grid.
4. A log of average monthly patronage from the guest register.
5. Gross floor area of the facility.
6. Floor area of the conditioned space.
7. Energy rating of all electrical devices used in a facility.

The Energy Commission of Nigeria (ECN) is the foremost research institute in Nigeria. The energy audit model adopted is based on the ECN energy audit format [37]. However, while comparing its adequacy introduced to improve both the economy and the quality of life with other standard models, it is observed that this model lacks a behavioural aspect and formulae to estimate demand and supply.

Therefore, this study adapts the ECN model by adding a behavioural section. Another addition is required to account for power supply inadequacy in Nigeria. Within the data collection process, there is a notable difference between the demand and supply. The model is further adapted to accommodate this inconsistency as shown in the results section.

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Considering the power inadequacy experienced in Nigeria, a methodology [38] is presented to account for this inadequacy. However, it is updated to include water supply in the disaggregated energy demand end.

The data estimated from the audit are used to analyze the current situation; and then used as input data for the simulation of regenerative energy facade strategies for the retrofit potential in the hotel industry in north-western Nigeria:

1. Shading
2. Glazing
3. Thermal mass
4. Insulation

The regenerative energy facade strategies are categorised under walls and windows in Table 1.

Table 2: Building components, strategies, and thermal conductivity

Building component	Strategies	Thermal conductivity (U-Value)			Cost (NGN*)
		Existing 230mm + 12mm render on both sides	Retrofit mat. (w/m^{2}K)	Total (w/m^{2}K)	
Exterior wall improvements/insulation					
• Single leaf exterior wall with synthetic insulation	Retrofitting of existing exterior wall with cladding filled with a 50mm thick **rock-wool** batt.	2.75 W/m^{2}K	0.037W/m^{2}K	0.0365 W/m^2·K.	98,000.00
• Single leaf exterior wall with organic insulation	Retrofitting of existing exterior wall with: Cladding filled with **rice husk** batt.	2.75 W/m^{2}K	1.067Wm^{2}K	0.7685Wm^{2}K	79,300.00
• Single leaf exterior wall with interior insulation	Retrofitting with **polystyrene** sandwiched in interior decorative pvc wall panels.	2.75 W/m^{2}K	0.038W/m^{2}K	0.0375 W/m^2·K	24,000.00
• Double leaf exterior wall with dynamic air layer insulation	Construction of additional wall leaf on the exterior façade with **static air layer** as the insulation medium.	2.75 W/m^{2}K	2.75 W/m^{2}K	1.6 W/m2K	7,000.00
• Double leaf exterior wall with dynamic air layer insulation	Construction of additional wall leaf on the exterior façade with **horizontal air vent.**	2.75 W/m^{2}K	0.18 w/m^{2}k	0.169W/m^{2}K	7,000.00
• Green wall insulation	Exterior wall **vine planting**.	2.75 W/m^{2}K	2.9w/50mm^{2}K	0.5131W/m^{2}K	2,000.00
Exterior wall surface improvements					
• Light Reflectance Value (LRV)	Using Light Reflective Index (RI) of most common exterior wall paint shades on the exterior wall.	-	-	**Light Reflectance Value (%) Colours**	
				- White = 85%	700.00
				- Off-White =72%	700.00
				- Cream = 69%	700.00
				- Brown = 57%	700.00

Window					
• Single pane glazing	Using **anti Ultra violet single pane** glass on windows along sun path.	-	-	7 Wm²K	2,280.00
• Double pane glazing	Use of **double pane glazing filled with argon gas** on all windows.	-	-	1.3 W/m²K	3,280.00
• Double pane glazing	Use of double pane glazing with **vacuum space.**	-	-	- 0.5 W/m²K	1,725.00
Shading device					
• Steel horizontal shading device	Installing **horizontal steel grill shading device** on windows along the sun path direction.	-	-	**Solar Shading Coefficient (SSC)** 0.2969 SSC @ 65% window coverage	21,700.00
• Vertical shading device	Installing **vertical steel shading device** on windows situated along sun path.	-	-	0.4931 SSC @ 42% window coverage	21,700.00
• Horizontal & Vertical shading devices	Installing a combination of **horizontal and vertical shading devices** on windows.	-	-	0.068 SSC @ 92% window coverage	31,750.00
Roof					
• Light reflectance Value	Trying different colour shades on the roof. The colours are:	-	-	Light Reflectance Value (%)	
				- White = 85%	3,300.00
				- Off-White =72%	3,300.00
				- Cream = 69%	3,300.00
				- Brown = 57%	3,300.00
Roof insulation					
• Roof insulation	Install roof installation in the attic space, this includes	-			
	• Rockwool			- 0.035 w/m²K	27,000.00
	• Glass wool			-0.032w/m²K	19,000.00
Green roof					
• Intensive	Replacing the existing conventional roofing sheets with an **intensive green roof.**	-	-1.325W/m²K	-1.325W/m²K	17,000.00

** Cost of items and installations per square meter in Nigerian Naira (NGN)*

Source: Authors Field work, 2024

4. RESULTS AND DISCUSSION

This section analyses the base-case modelling and simulation results to achieve the objectives of the study and to analyse the regenerative energy facade strategies.

4.1. Base Case Modelling

Design and specifications: Other input data for the modelling of the base case include:

1. Exterior Wall Improvements/ Insulation.
2. Exterior Wall Surface (Solar Reflectance Index).
3. Fenestrations (Windows).
4. Shading Device.
5. Roof (Insulation / Green Roof).

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4.1.1. Exterior Wall Improvements/Insulation:

The analysis under the Exterior Wall Improvement/ Insulation table compares different wall types and their energy use in kWh/m2/year, as well as the percentage of energy savings compared to the base case.

The base case, which consists of a 230mm hollow sancrete wall with 12mm screeding, has an energy use of 60.01 kWh/m²/year and no energy savings.

Other wall types such as rockwool + clad had savings of 4.9%, rice husk insulation showed energy savings of 3.16%, polystyrene + PVC cladding had energy savings of 4.9%, cavity + stat air had energy savings of 4.62%, cavity + vent had energy savings of 4.59%, and vine on wall showed energy savings ranging from 3.75% (Figure 3).

These findings suggest that certain wall improvements and insulation materials can contribute to reducing energy consumption in buildings.

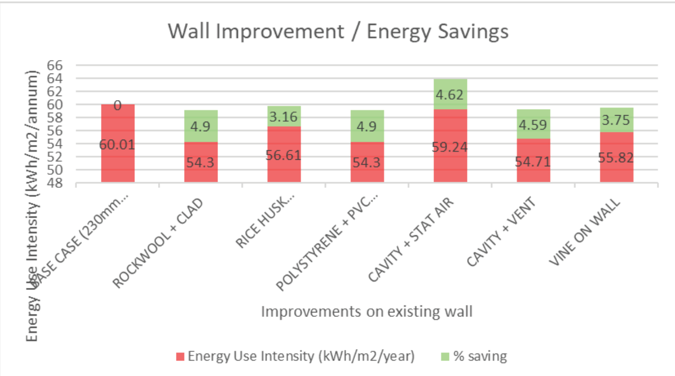

Fig. 3. Wall Improvement/energy Savings.

4.1.2. Exterior Wall Surface (Solar Reflectance Index):

The analysis under the Exterior Wall Surface (SRI) figure, compares various wall surface colors based on their Solar Reflectance Index (SRI), energy use (kWh/m²/year), and percentage savings relative to the base case.

The results show that the white wall surface with SRI 100 reduces the base case consumption to 47.17 kWh/m²/year, leading to 9.99% energy savings; Off-white wall surface with SRI 72 reduces the base case consumption to 53.87 kWh/m²/year with potential energy saving of 5.08%; Cream colour wall surface which has SRI 69 reduces the base case consumption to 54.6 kWh/m²/year, corresponding to 4.54% energy savings; similarly, Beige (base case colour) has SRI 53, which is 60.01 kWh/m²/year and is used as yard stick for the possible colour choices.

Conversely, Brown colour wall surface has SRI 25, which tends to go higher than the base case, with 65.59 kWh/m²/year, increasing the energy consumption when compared to base case with up to 3.49% (or -3.49%).

As illustrated in Figure 4, these findings suggest that selecting lighter-colored wall surfaces with higher solar reflectance indices can significantly reduce energy consumption in buildings.

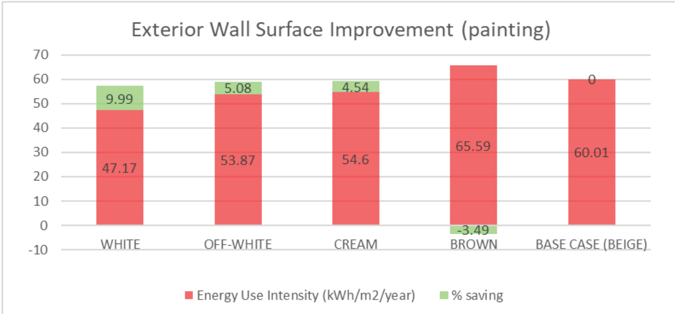

Fig. 4. Exterior surface improvement (painting).

4.1.3. Fenestrations (Windows):

Table 2 is a presentation of the data gotten from fenestration (windows) which compares different types of windows in terms of their energy use in kWh/m²/year and the percentage of energy savings compared to the base case, which is a single pane clear glass window. The base case, which is the single pane clear glass window, has an energy use of 60.82 kWh/m²/year and no energy savings.

Other window types such as anti-UV single pane glass, double pane with argon gas, and double pane with vacuum space show varying levels of energy savings ranging from 0.17% to 2.82%.

These findings (Figure 5) suggest that using windows with improved insulation properties, such as double pane windows with argon gas or vacuum space, can contribute to reducing energy consumption in buildings.

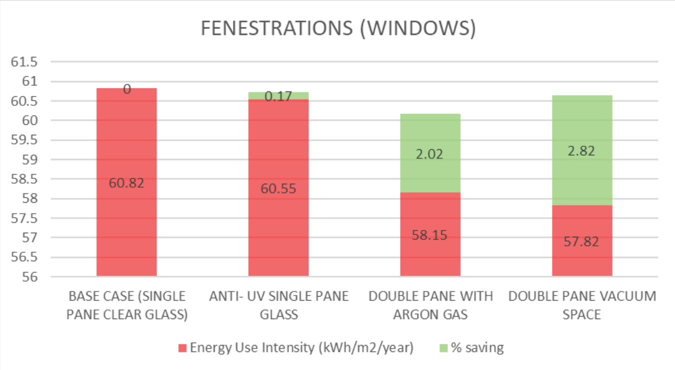

Fig. 5. Exterior Wall Improvement/Insulation.

4.1.4. Shading Device:

The analysis under the Shading Device table compares different types of shading devices in terms of their energy use in kWh/m²/year and the percentage of energy savings compared to the base case, which has no shading device. Figure 6 shows that steel horizontal shading device recorded 60 kWh/m²/year, providing just 0.6% energy savings. 59.46 kWh/m²/year is recorded from steel vertical shading device intervention, which is 1% energy savings, while combination of horizontal and vertical shading devices recorded 58.19 kWh/m²/year, equivalent to 4.26% energy savings. These results can be seen graphically in Figure 6.

The findings suggest that using shading devices, such as steel horizontal or vertical shades, can contribute to reducing energy consumption in buildings, although with relatively modest energy savings compared to the base case without any shading devices.

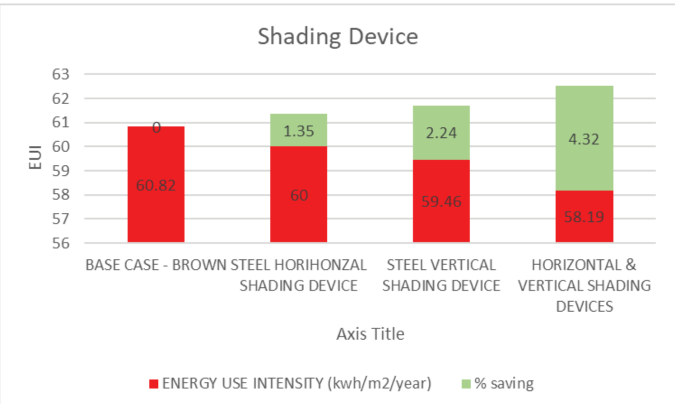

Fig. 6. Shading Device.

4.1.5. Roof (Insulation)

Under the roof (insulation/green roof) this analysis compares different types of roof insulation and the energy savings they provide in kWh/m²/year.

The base case, which is a brown roof without any insulation, has an energy use of 60.82 kWh/m²/year and no energy savings. Rockwool insulation reduces energy use to 19.28 kWh/m²/year, resulting in a 31.07% energy savings. Glass wool insulation also reduces energy use to 19.17 kWh/m²/year, with a slightly higher energy savings of 31.16%. The green roof, specifically an intensive green roof with a thickness of 300mm, has an energy use of 40.95 kWh/m²/year and provides a 14.85% energy savings, as highlighted in Figure 7. Similarly, a general overview of the all the energy saving potentials is indicated in Figure 8.

These results suggest that both rock wool and glass wool insulation can significantly reduce energy consumption in buildings, with energy savings exceeding 30%. Additionally, implementing a green roof can also contribute to energy reduction, although to a lesser extent as compared to insulation options.

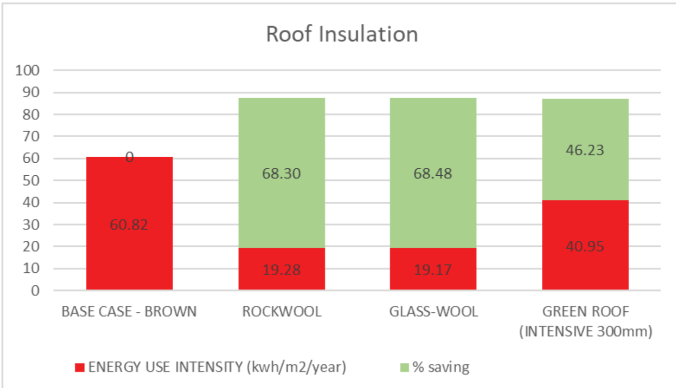

Fig. 7. Roof Insulation.

4.1.6. Cost analysis:

Table 2, gives breakdowns of tree potential intervention (Wall, Windows and Roof) strategies to reduce energy consumption in hotels located in Birnin Kebbi, a region within a tropical hot-dry climate. The proposed interventions focus on optimizing thermal performance and minimizing cooling energy loads.

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For walls, retrofitting options include synthetic insulation using cladding filled with 50mm rock-wool batt, which achieves a U-value of 0.0365 W/m²·K at a cost of ₦98,000, and organic insulation with rice husk batt, offering a U-value of 0.7685 W/m²·K for ₦79,300. Interior insulation, using polystyrene sandwiched in decorative PVC panels, is a cost-effective solution at ₦24,000 with a U-value of 0.0375 W/m²·K. Double-leaf walls with a horizontal air vent provide efficient insulation (U-value of 0.169 W/m²·K) for ₦7,000, while green walls improve insulation (U-value of 0.5131 W/m²·K), which is relatively cheaper than previous interventions, but require continuous maintenance at ₦2,000.00. For enhanced heat reflectivity, light reflective paint coatings, such as white with a light reflectance value (LRV) of 85%, offer an economical option at ₦700 per square meter.

For windows, double-pane glazing with vacuum space is the most efficient, with a U-value of 0.5 W/m²·K and a cost of ₦1,725, while argon-filled double-pane glazing provides a U-value of 1.3 W/m²·K for ₦3,280. Anti-UV single-pane glazing is less efficient (U-value of 7 W/m²·K) but is priced at ₦2,280. Shading devices, including horizontal, vertical, and combined options, are effective in reducing solar heat gain. Combined shading devices, offering a solar shading coefficient (SSC) of 0.068 at 92% coverage, are the most effective but cost ₦31,750.

Roof treatments include reflective coatings in shades like white (LRV of 85%), off-white (72%), and cream (69%), priced at ₦3,300 per square meter. Roof insulation options include rock wool and glass wool, achieving U-values of 0.035 W/m²·K and 0.032 W/m²·K, at costs of ₦27,000 and ₦19,000, respectively. Intensive green roofs provide superior thermal performance (U-value of -1.325 W/m²·K) at ₦17,000. These strategies offer a range of options for hotel owners to balance cost and performance in improving energy efficiency.

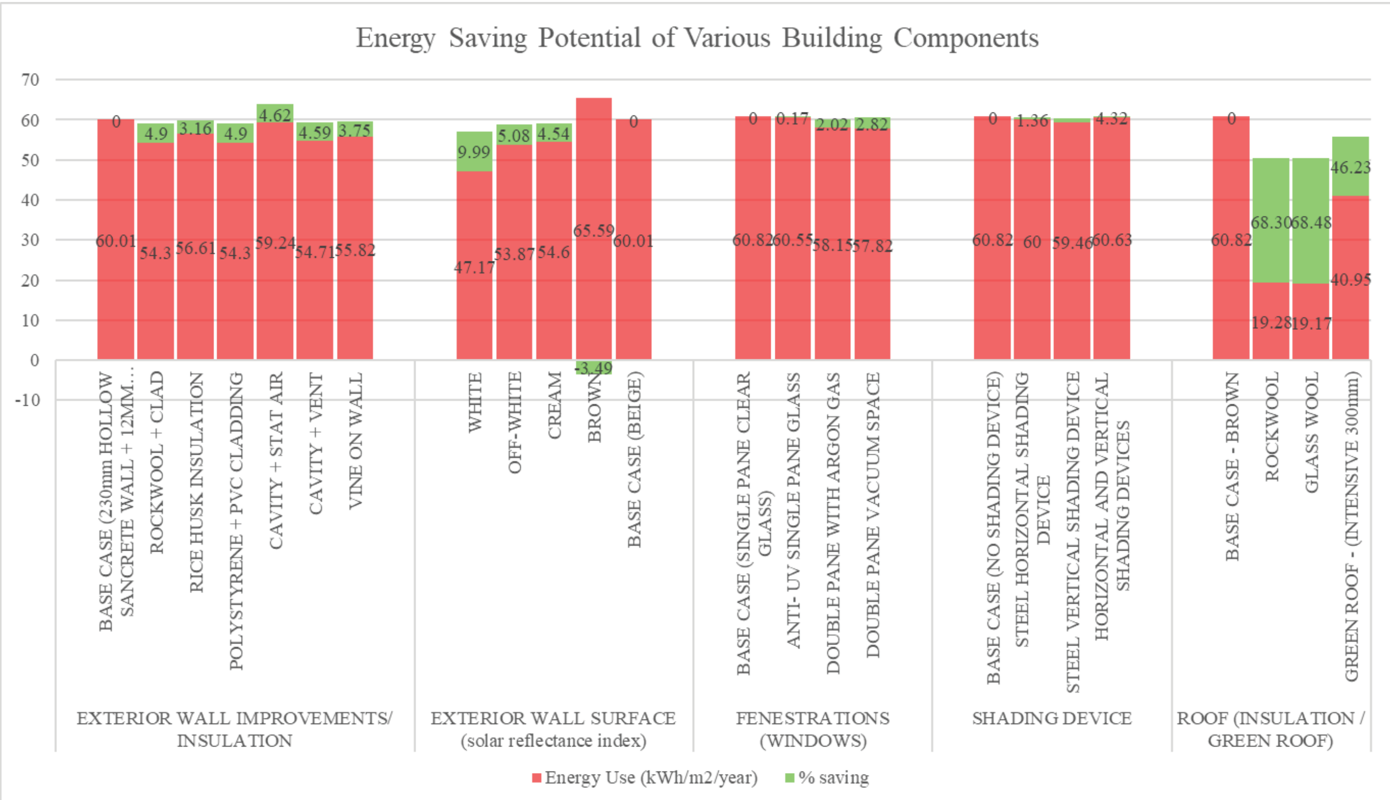

Fig. 8. Energy Saving Potential of Various Building Components.

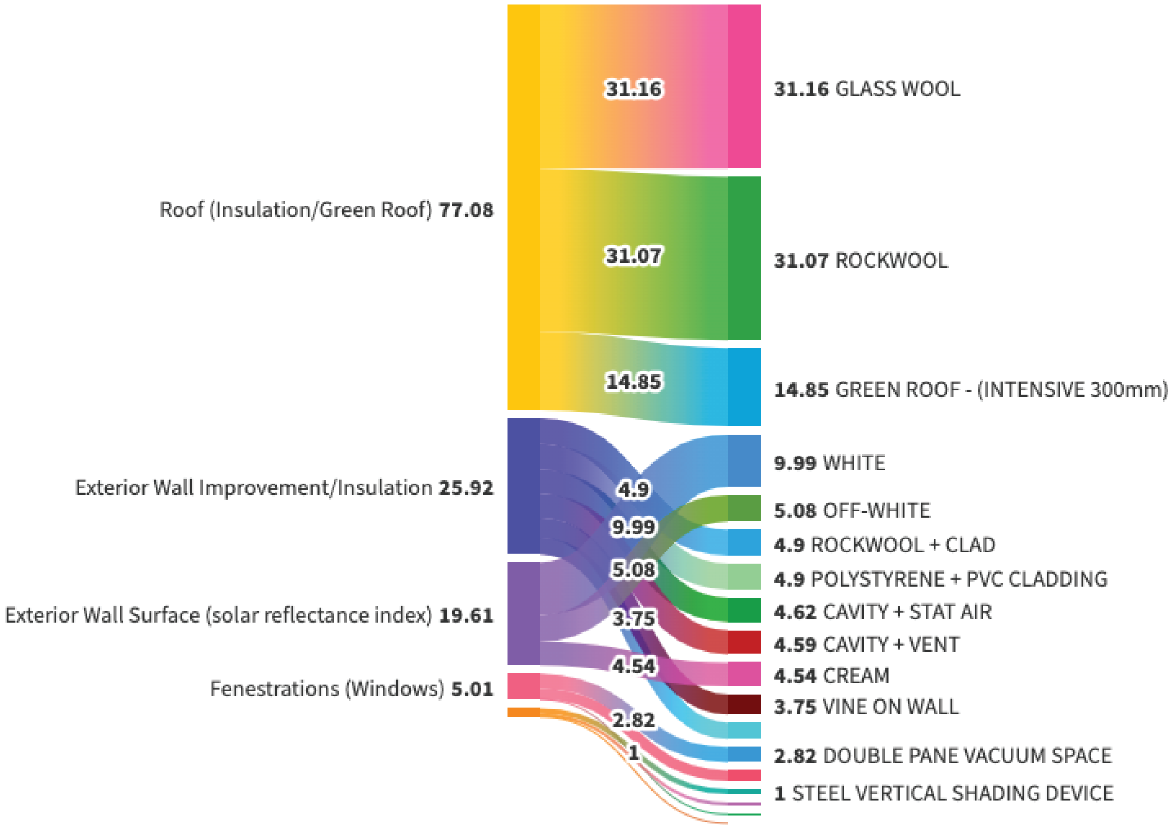

Fig. 9. Sankey diagram showing optimized cases for various building components in kWh/m²/year.

5. CONCLUSION

The results of the study highlight the potential of regenerative energy facade strategies in reducing energy consumption in buildings. The analysis of base-case modelling revealed that certain wall improvements and insulation materials can lead to significant energy savings. For example, using rock wool or glass wool insulation can reduce energy consumption by over 30% compared to the base case.

Similarly, choosing lighter-colored wall surfaces with higher solar reflectance index (SRI) can also contribute to energy savings. The study found that wall surfaces with higher SRI values had lower energy use and higher energy savings compared to darker-colored surfaces.

Furthermore, the analysis of different types of windows and shading devices showed that using windows with improved insulation properties, such as double-pane windows with argon gas or vacuum space, and implementing shading devices, can also help in reducing energy consumption in buildings.

Through detailed analysis of different building components, including exterior walls, fenestrations, shading devices, and roofs, the study highlighted the significant energy savings that can be achieved through the implementation of these strategies. Stakeholder perceptions gathered during the study revealed widespread support for regenerative energy facade strategies, particularly among architects, policymakers, and building owners who recognized their potential to balance energy efficiency with long-term economic benefits. However, stakeholders also emphasized the importance of addressing challenges such as upfront costs, material availability, and user education to maximize adoption and effectiveness.

The findings suggest that designers and policymakers in Nigeria and similar regions should consider incorporating regenerative energy facade strategies in building designs and policies to promote sustainable development. The findings also suggest that implementing regenerative energy facade strategies can play a significant role in reducing energy consumption in buildings and moving towards more sustainable building

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practices. However, it is essential to consider the specific context and requirements of each building to determine the most suitable strategies for energy efficiency and sustainability.

Researchers can look into conducting long-term studies to evaluate the performance and effectiveness of regenerative energy facade strategies in different climatic regions and building types and explore the integration of regenerative energy facade strategies with smart technologies to enhance energy efficiency and user comfort.

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