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Research paper

AN EXAMINATION INTO THE ARCHITECTURAL ELEMENTS THAT PROMOTE ENERGY EFFICIENCY IN RESIDENTIAL BUILDINGS IN ABUJA, NIGERIA.

Ezinne Chinwe Orjiako[1], Oluwafemi Kehinde Akande[2], Ekeme Angela Otemeata[3]

Abstract

The steady rise in energy usage within Nigeria's residential building sector has raised concerns about sustainability, cost-efficiency, and environmental damage. This paper examined the architectural features that contribute to energy efficiency in residential structures in Asokoro, an affluent neighbourhood in Abuja, Nigeria. The objective was to evaluate how design elements including building orientation, fenestration, shading devices, insulation, natural ventilation, and material choices influence energy demand for lighting and cooling. The study uses field questionnaires (N=140) to identify current design approaches and assess their effectiveness in reducing energy use. The findings show that completely integrated passive design in residential buildings is rather uncommon in Abuja, Nigeria. This reveals a considerable disparity between the building's design aims and performance achievements for decreasing energy use. This is attributable to a variety of causes, according to the findings, including the perception of high initial costs, which discourages developers and clients who prioritise short-term budgets above long-term energy savings. Other issues include overreliance on mechanical systems and insufficient regulatory enforcement. The study proposes context-specific design principles for improving energy performance, reducing reliance on fossil fuel-based energy, and improving environmental sustainability in Abuja's residential sector. The study's significance lies in the fact that architects, developers, and policymakers would be more informed about adopting energy-efficient architectural design, practices, and construction, particularly in increasingly urbanising countries like Nigeria.

Key words: *Architectural Elements, Energy Efficiency, Passive Design, Residential Buildings, Nigeria.*

[1] Department of Architecture, Nile University of Nigeria, 20220878@nileuniversity.edu.ng (https://orcid.org/0009-0000-3547-3121)
[2] Department of Architecture, Nile University of Nigeria, oluwafemi.akande@nileuniversity.edu.ng (https://orcid.org/0000-0001-7895-6000)
[3] Department of Architecture, Nile University of Nigeria, angela.ekeme@nileuniversity.edu.ng (https://orcid.org/0000-0003-0813-2705)

1. INTRODUCTION

There is a global problem, as well as a unique concern in Nigeria, with regard to energy usage in residential buildings. According to the International Energy Agency, buildings account for around 40% of total global energy consumption, with residential buildings accounting for the vast majority of this consumption in Nigeria [1]. The built environment is currently thought to be the world's largest single user of energy, with residential buildings making significant contributions. Chen *et al.* [2], expressed that buildings account for around 40% of global energy consumption, with heating, cooling, lighting, and residential appliances accounting for a significant portion of overall energy demand. In Nigeria, growing urbanisation has produced an urgent demand for home energy, putting strain on the national infrastructure and resulting in frequent power outages [3]. The residential sector accounts for approximately half (50%) of Nigeria's overall energy use, mostly through heating, cooling, lighting, and appliances [4].

In parts of Nigeria's climates with exceptionally high temperatures, air conditioning is a significant energy consumer. However, when properly used, shading devices and cross-ventilation can significantly reduce indoor temperatures and energy demand. Yusuf and Akande [5], opined that material choices, notably high-performance insulation, energy-efficient glass, and locally produced materials, can improve a building's thermal efficiency and sustainability. As a result, architectural design is critical to achieving energy efficiency in residential buildings. According to Akande [6] and Yusuf & Akande [7] studies on passive design principles, good building orientation, thermal mass utilisation, the use of shading devices, and facilitating cross-ventilation have all proved effective in reducing reliance on mechanical heating and cooling systems. Abuja requires between 400 and 500 MW of energy every day, but only receives 200 to 300 MW, resulting in unpredictable power interruptions.

The argument and the emphasis of this study predicated on the importance of promoting energy efficiency in buildings, particularly residential buildings where people spend the majority of their time. Meanwhile, research on architectural components that promote energy-efficient housing in Abuja is severely inadequate, despite the fact that energy-efficient housing solutions are desperately needed [8]. Furthermore, compliance with current energy-efficiency requirements is often low. In accordance with the Nigerian Building Energy Efficiency Code (BEEC), energy efficiency was not attained throughout the mass construction of Abuja housing developments, revealing a significant gap between policy and reality [5]. Thus, the existing dearth of research into energy-efficient design aspects in Abuja structures is most likely contributing to the ongoing energy problem [8]. Again, without context-specific methods, architects and politicians will lack the tools required to implement effective energy-saving measures in residential structures [8].

This study aims to close the gap by looking into architectural elements that reduce energy efficiency. The purpose is to research architectural components that promote energy efficiency in residential building designs in Abuja, Nigeria, with the intention of lowering energy usage. The objectives are to: (i) determine the extent to which energy-efficient architectural components are integrated into residential buildings. (ii) investigate the impediments to the implementation of energy-efficient architectural features. (iii) evaluate the use and efficacy of smart building technology.

2. LITERATURE REVIEW

Existing research [6,7,9-15] have extensively investigated both passive and active solutions for lowering energy usage in Nigerian residential structures. One major limitation in these studies is the limited evaluation of passive design solutions in Nigeria's high-income residential neighbourhoods. For example, Yusuf and Akande [7] did a study on passive cooling solutions but purposefully excluded urban areas like Abuja from their coverage. This omission creates an important study gap on the effectiveness of passive cooling techniques, such as shading devices, natural ventilation, and thermal mass, in Abuja's high-density housing complexes. While these solutions have been successful in other places with similar conditions, their applicability in Abuja's current architectural context is unknown. The dearth of empirical studies on how passive energy-saving methods interact with new dwelling typologies in Abuja emphasises the importance of context-specific research.

Other studies have focused on broad theoretical frameworks or foreign case studies, with little research on their usefulness in Nigeria's unique meteorological and socioeconomic settings [16,17]. As a result, there is a scarcity of localised data on how energy-efficient architectural elements function in Abuja's urban housing sector, where factors such as high energy consumption, financial limits, and policy limitations influence the adoption of sustainable building methods. In terms of active energy-efficient technologies, such as smart building systems and renewable energy integration, Oyedepo [18] evaluated the feasibility and economics of current building technologies in Nigerian homes. The available studies primarily focus on commercial or public structures, with little emphasis on high-end dwellings. Meanwhile, the financial consequences, technical limits, and policy support needed to integrate smart energy management systems, automated shading, and renewable energy solutions into Abuja's housing constructions are largely unknown [19,20]. This creates another significant gap in the assessment of active energy-efficient technology, such as smart building systems and renewable energy integration, in Nigeria's luxury residential market. Thus, understanding the viability of these technologies in Abuja's socioeconomic setting is critical for supporting sustainable residential architecture in Nigeria.

There may be a further deficit in policy-related studies on energy-efficient housing in Abuja. While worldwide studies such as the IEA [1] have emphasised the relevance of government incentives and regulatory frameworks in encouraging sustainable architecture, little study has been conducted to investigate how Nigerian policies influence the adoption of energy-efficient home design. Numerous researchers [21,22] have noticed insufficient building code enforcement, a lack of financial support for households investing in green technologies, and ineffective awareness initiatives. According to their results, these factors have contributed to a sluggish adoption of sustainable housing options in places such as Abuja. Addressing these policy gaps will provide valuable insights into how regulatory measures might be enhanced to help with the transition to energy-efficient residential buildings.

Despite the rising amount of knowledge on energy-efficient architecture design, there are substantial gaps in the implementation of energy-efficient solutions in high-end residential neighbourhoods like Abuja. This study intends to fill these research gaps by investigating the viability of energy-efficient architectural features in residential structures in Abuja. It gave empirical data on the feasibility and environmental benefits of passive and active design solutions in high-end urban housing in Nigeria. Finally, the findings will help to produce context-specific suggestions for improving energy efficiency in Nigeria's high-income housing sector, while also addressing important implementation challenges.

2.1. Theoretical Framework

The theoretical frameworks for this study are based on sustainable architecture and energy efficiency concepts in the context of building design and performance in hot, humid climates. It gives a understanding through which this study can be examined and comprehended. For this investigation, the following theories are deemed most appropriate: Bioclimatic Architecture Theory (BAT), Sustainable Architecture Theory (SAT), Energy Performance Theory (EPT), and Ecological Modernisation Theory (EMT). BAT was proposed by scholars including Olgyay [23] and Givoni [24]. It focusses on how buildings interact with their surrounding climate conditions. Its significance to this study stems from its emphasis on climate-responsive building design (for example, Abuja's hot-humid conditions) through the use of passive methods such as shade, orientation, natural ventilation, thermal mass, and green roofing. Scholars such Edwards and Turrent [25] and Kibert [26] are prominent scholars known for SAT. The theory focusses on incorporating the environmental, social, and economic aspects of sustainability into architectural design. The fundamental elements of the theory are resource efficiency, low-carbon design, and life cycle analysis. It is relevant to this study because it provides advise on the selection and usage of architectural features (such as insulation, materials, shape, and glazing systems) to reduce energy consumption.

The EPT is well-known among scholars, including Santamouris [27] and Crawley *et al.* [28]. The theory focusses on assessing the relationship between building design elements and energy consumption. It is relevant to this study because it allows for a quantified assessment of architectural components (for example, window-to-wall ratio and orientation) in terms of energy efficiency. Scholars such Mol and Sonnenfeld [29] and Spaargaren [30] advocate for the EMT. The goal of this approach is to encourage the use of technology and innovation to lessen environmental problems while promoting development. Its significance to this study stems from its emphasis on incorporating modern energy-efficient technologies into domestic architecture without sacrificing comfort or aesthetic appeal.

3. METHODOLOGY

3.1. Study Area

The study was carried out in the Abuja metropolitan. Nigeria's capital city, Abuja, is located in the country's centre region, between latitudes 8.25°N and 9.20°N and longitudes 6.45°E and 7.39°E. It lies in the tropical savannah climate zone, which is distinguished by high temperatures and distinct wet and dry seasons. Abuja's location within Nigeria's climatic zone is characterised by extreme heat throughout the dry season, making it an ideal case study place for investigating energy-efficient residential design solutions. Abuja is divided into six area councils, but the study is conducted in Asokoro, a well-known residential sector in Abuja, Nigeria. The region is distinguished by modern residential estates, government-owned quarters, and privately-owned dwellings. As a result, it is suitable for analysing a wide range of architectural styles and energy saving measures.

3.2. Population and Sample Selection

The research population consists of occupants of high-end, low-rise residential buildings. The target demographic includes homeowners and residents of both new and older buildings, with a focus on identifying energy-efficient architectural features and determining user knowledge. A purposive sample strategy was used to focus on residential buildings in the study area that were relevant to the study's aims. Random sampling was utilised to pick respondents from various neighbourhoods and dwelling types, including duplexes, bungalows, and flats, to provide a representative view of the district's residential categories. The study's sample size is 140 responders, based on participants' practical accessibility and the volume of distributed questionnaires. This number is within the permissible range for exploratory survey-based research on categorical data, which requires a minimum of 100-200 respondents for significant analysis [31]. The respondents were largely homeowners, tenants, and caretakers, ensuring a diversified viewpoint on building practices and energy consumption.

3.3. Development and Description of Questionnaire

This study's fieldwork consisted of a questionnaire survey. Questionnaires were used because they provide a highly structured method of data collection, which improves answer consistency and facilitates analysis [31]. They were also ideal for this study because of their low cost, ease of distribution, and capacity to cover a large community sample while minimising researcher bias. Furthermore, prior research [10,13] on energy use in residential buildings have successfully used questionnaire-based methodologies. The questionnaire was created using literature from the BAT, SAT, EPT, and EMT frameworks [23, 29, 32]. It contains eight sections: Section A: Demographics and Housing Type. Section B: Examined energy-efficient architecture features; Section C: Preferences and perceptions about energy-efficient features. Section D: Natural Ventilation Features Section E: Shading Devices and Their Effectiveness Section F: Smart Building Technologies. Section G: Renewable Energy Use and Challenges; Section H discusses overall energy performance and recommendations. Standardised analysis was conducted using Likert scale items (1-5), whereas contextual insights were gained using categorical and multiple-choice questions.

3.4. Data Collection Methods

The major data collection instrument was a standardised questionnaire, which was administered in person and, where practicable, online. In addition to the survey, non-intrusive observations were carried out to confirm physical characteristics such as orientation, shading, and visible smart technology installations. The questionnaire was created to assess occupants' impressions of natural ventilation, building attributes, energy consumption behaviour, and awareness of energy-efficient design measures. Given the difficulties in obtaining physical building performance data and the lack of detailed utility records for the majority of residents, the study relied on self-reported data. The decision to use an online distribution platform was based on cost-effectiveness, ease of management, and the opportunity to reach a larger audience quickly. Respondents were encouraged to engage willingly, and 140 valid replies were collected. This strategy guaranteed that data were collected with minimal logistical constraints while retaining consistency and organisation in responses.

3.5. Spaces Evaluated and Subjects Investigated

This study examined the four primary residential typologies in Asokoro, Abuja: detached houses, semi-detached houses, apartments, and duplexes. These building types were chosen specifically because they represent the district's primary dwelling forms and provide a variety of architectural layouts, construction materials, and energy-use characteristics. Evaluating a variety of typologies provided a more comprehensive understanding of how different residential designs affect energy efficiency and indoor comfort in Abuja's tropical environment. Furthermore, these housing styles serve a broad socioeconomic demographic, which aligns with the study's goal of documenting tenant views and practices across numerous residential situations. The study included adult male and female citizens over the age of 18. This age group was deemed appropriate for providing reliable and knowledgeable replies about their homes' thermal comfort, indoor air quality, and energy saving features. The responses received were crucial in determining user perception and satisfaction across the various architectural typologies under consideration.

3.6. Validity, reliability of the instrument and ethical considerations

Experts in sustainable architecture, building service engineering, and environmental design reviewed the content to confirm its authenticity. The instrument was tested against BAT, SAT, EPT, and EMT to determine that it was consistent with theoretical structures. The Cronbach's alpha coefficient was used to examine the internal consistency of the questionnaire's scale-based items (Table 1). A reliability coefficient of 0.653 (Table 1), indicating moderate dependability, was deemed satisfactory for the investigation [33]. Participation was voluntary in terms of ethics, with anonymity and confidentiality guaranteed. Respondents were notified of their rights, and the data was utilised solely for academic purposes.

Table 1. Reliability test

Section	Cases	Reliability	Interpretation
Section A	5	0.855	Highly reliable
Section A2	5	0.851	Highly reliable
Section A3	4	0.949	Highly reliable
Section B	5	0.648	Moderately reliable
overall reliability, cases = 19 reliability = 0.653, which moderately reliable			

3.7. Data Analysis Techniques

To evaluate correlations between architectural aspects and perceived energy efficiency, data were analysed using descriptive statistics (mean, standard deviation, frequency distribution). The spatial orientation data were analysed using frequency mapping.

4. RESULTS

4.1. Demographic information

Table 2 presents the demographic information of the respondents. It could be observed that 46.4% of respondents are between the ages of 18 and 30, 26.4% are between the ages of 31 and 45, 15% are between the ages of 46 and 60, and 12.1% are 60 years and over, implying that there are more responses from the ages of 18 and 30 and 31 to 45. The percentage of male respondents was 55.7%, while female respondents were 44.3%.

Table 2. Demographic information

Demographic of the respondents	Frequency	Percentage
Age		
18-30	65	46.4
31-45	37	26.4
46-60	21	15
60+	17	12.1
Gender		
Male	78	55.7
Female	62	44.3
Type of residence		
Detached house	43	30.7
Semi-detached house	25	17.9
Apartment	28	20
Duplex	44	31.4
How long have you lived in this residence?		
Less than a year	16	11.4
1-5 years	54	38.6
6-10 years	36	25.7
More than 10 years	34	24.3

4.2. Application of Energy-Efficient Architectural Elements

A 5-point Likert scale was used to measure the extent to which energy-efficient architectural components are incorporated into Abuja's residential buildings. Respondents were asked to score their agreement with various assertions about energy efficiency elements including as orientation, ventilation methods, and insulation. The scale ranged from strongly disagree (1) to strongly agree (5), and the weighted mean values were interpreted as follows: 4.51–5.00 = Strongly Agree; 3.51-4.50 = Agree; 2.51-3.50 = Neutral; 1.51-2.50 = Disagree; and 0.00-1.50 = Strongly Disagree. According to the data in Table 3, 34.3% agreed and 32.9% strongly agreed that their living rooms had big windows for natural and cross ventilation, with a mean score of 3.81. Regarding bedroom ventilation, 41.4% agreed and 15.7% strongly agreed on the existence of large bedroom windows (mean score 3.51). The total natural ventilation design shows that 30% agreed, 25.7% strongly agreed, and 26.5% disagreed. The average score of 3.47 indicates a neutral view overall. Regarding wall insulation, 22.1% agreed, 5.7% strongly agreed, and 37.9% opposed or strongly disagreed. Despite this, the mean score was 3.81, showing agreement that wall insulation was present. The findings are consistent with BAT in terms of living room and bedroom ventilation, with high agreement scores (3.81 and 3.51, respectively), indicating intentional design components that encourage airflow, such as big windows. However, the neutral posture (3.47) on the general integration of cross ventilation (e.g., courtyards, window placement) suggests that, while some bioclimatic principles are used, the strategy is not fully implemented across all architectural sections.

Table 3. Energy Efficient Architectural Elements

Energy Efficient Architectural Elements	SD	D	N	A	SA	Mean value	Decision
My building has proper orientation that reduces direct sunlight exposure into my house	9 (6.4)	15 (10.7)	30 (21.4)	50 (35.7)	36 (25.7)	3.64	Agree
My living rooms have large windows that allows for natural and cross ventilation	8 (5.7)	11 (7.9)	27 (19.3)	48 (34.3)	46 (32.9)	3.81	Agree
My bedrooms have large windows that allows for natural and cross ventilation	9 (6.4)	13 (9.3)	38 (27.1)	58 (41.4)	22 (15.7)	3.51	Agree
Generally, my house is designed to use natural and cross ventilation (i.e., having large windows, courtyards, etc.)	11 (7.9)	26 (19.6)	25 (17.9)	42 (30)	36 (25.7)	3.47	Neutral
The walls of my house have high-performance insulation	20 (14.3)	33 (23.6)	48 (34.3)	31 (22.1)	8 (5.7)	3.81	Agree

The low usage of wall insulation (only 27.8% agreed/strongly agreed) and neutral ratings for passive design indicate a moderate alignment with SAT. While some energy-saving methods (such as natural ventilation) exist, irregular insulation application and the likely absence of renewable systems reduce the buildings' sustainability profile. The agreement on living room (3.81) and bedroom windows (3.51) suggests that natural ventilation can be used effectively to reduce cooling demands. However, neutral responses to overall design integration (3.47%) and poor adoption of insulation (although a mean of 3.81, real agreement levels were low) indicate inconsistent implementation of energy-saving components. The mean insulation score of 3.81 is deceiving, as more than 37.9% disagreed, indicating poor perception or insufficient application of proper insulation practices. The low adoption of improved insulation, as well as the anticipated limited usage of smart technologies or renewable systems (which are not addressed here), indicate that EMT principles are not fully implemented. The neutral or negative views of particular traits may represent a lack of institutional support or economic incentives, which is consistent with EMT accusations of poor policy backing in developing countries.

4.3. Barriers to Adoption of Energy-Efficient Architectural Elements

Using the Relative Importance Index (RII), the study identifies and classifies major barriers to the adoption of energy-efficient architectural elements. Using the Relative Important Index, identify important impediments to the adoption of energy-efficient design features.

$$RII = \frac{\sum W}{A * N} \quad (1)$$

Where: W = Weight given to each statement by the respondent, A = Highest response integer which is 5, N = Total number of respondents = 140.

The study identified five major impediments to the use of energy-efficient architectural components in residential buildings. According to Table 4, lack of awareness (RII = 0.49) was identified as the most significant barrier, implying that many citizens and possibly experts are unaware or confused about the long-term benefits and implementation of energy-efficient architecture.

Table 4. Key barriers hindering the adoption of energy-efficient architectural elements

Key barriers hindering the adoption of energy-efficient architectural elements	$\sum W$	RII	Ranking
High Initial Cost	255	0.364	3
Lack of Awareness	242	0.49	1
Resistance to Change by Homeowners	312	0.446	2
Limited Availability of Materials	312	0.446	2
Poor Government Policies and Incentives	238	0.34	4

Resistance to change and low material availability (RII = 0.446) are both placed second, indicating behavioural and supply-chain restrictions in the construction industry. High initial costs (RII = 0.364), while significant, were not the most relevant factor, showing that while costs inhibit adoption, socio-cultural and informational difficulties are more prevalent. Poor Government Incentives (RII = 0.34) had the lowest ranking, probably reflecting respondents' lack of awareness of policy frameworks or the absence of effective measures.

4.4. Adoption and effectiveness of smart building technologies

To determine the level of adoption and effectiveness of smart building technologies (e.g., smart thermostats, lighting, automated blinds) in improving residential energy efficiency. Table 5 summarises the findings on the uptake and perceived effectiveness of smart technology in improving energy efficiency in residential structures in Abuja, Nigeria. Out of 140 respondents, 65 (46.4%) claimed no use of smart technology. 23.68% used smart thermostats, 8.42% automatic blinds, and 33.64% smart lighting. Combinations of devices were also reported, with 6.4% using all three technologies and 20% adopting both smart thermostats and automated blinds. Other combinations were less common.

Table 5. Adoption and effectiveness of smart building technologies

Adoption of smart technologies	Frequency	Percentage
None	65	46.4
Smart thermostat	6	4.3
Smart thermostat and Automated blinds	28	20
Smart thermostat, automated blinds and Smart lightings	9	6.4
Smart thermostat and Smart lightings	2	1.4
Automated blinds	3	2.1
Automated blinds and smart lightings	1	0.8
Smart lightings	26	18.6

In terms of perceived effectiveness, Table 6 shows that 18.6% found smart technologies somewhat useful, 16.4% found them very effective, 15.7% found them highly effective, and 1.4% considered them ineffective.

Table 6: Effectiveness of smart technologies

Effectiveness of smart technologies	Frequency (percentage)
Not applicable	65 (46.4)
Not Effective	2 (1.4%)
Slightly effective	2 (1.4%)
Moderately effective	26 (18.6)
Very effective	23(16.4)
Highly effective	22 (15.7)

According to Bioclimatic Architecture Theory (BAT), natural environmental factors such as ventilation, solar orientation, and passive cooling measures can be used to increase energy efficiency [23]. The comparatively low acceptance rate of smart technology among respondents (53.6% claimed nil or moderate use) reflects a continued dependence on old bioclimatic solutions or a failure to integrate these modern technologies into bioclimatic design principles. This is largely consistent with BAT, but it highlights missing potential for hybridisation [34]. From the standpoint of Sustainable Architecture Theory (SAT), which emphasises reducing environmental impact through design innovations, material selection, and energy efficiency [32]. Smart lighting (33.64%) had the greatest adoption rate, indicating an increasing awareness of energy-saving technology. However, the poor overall integration (only 6.4% accepted all smart systems) indicates challenges to comprehensive sustainable design implementation, such as cost and awareness [35]. Users' response suggests a mainly positive assessment of the effectiveness of smart technologies, with 50.7% rating them as somewhat to highly successful. This validates EPT's claim, as asserted by Cabeza *et al.,* [36], that such technologies boost performance; yet, the low adoption rate contradicts its premise that high-performance tools should be integrated into building design. The moderate adoption of smart technologies and their perceived effectiveness are consistent with EMT's concept, which states that economic and environmental progress may coexist through innovation and green technologies [29]. However, the findings show that there are infrastructural and socioeconomic impediments, such as affordability and awareness, indicating that modernisation is incomplete.

5. DISCUSSION

This study's findings show varying degrees of alignment between residential building design practices in Abuja and four theoretical frameworks: Bioclimatic Architecture Theory (BAT), Sustainable Architecture Theory (SAT), Energy Performance Theory (EPT), and Ecological Modernisation Theory (EMT).Bioclimatic theory promotes architectural design that adapts to local climatic conditions, emphasising passive techniques such as natural ventilation, daylighting, and thermal comfort while avoiding overreliance on mechanical systems [23, 24]. The study's findings—particularly the high agreement scores on living room (3.81) and bedroom ventilation (3.51)—indicate that these principles are partially integrated, most likely via features such as big movable windows. However, the neutral mean score of 3.47 for the overall integration of cross-ventilation methods (e.g., strategic window placement, usage of courtyards) implies an inconsistent use of BAT. Furthermore, respondents' emphasis on hurdles such as "lack of awareness" and "resistance to change" contradicts BAT's assumption of cultural embeddedness. This demonstrates a gap between traditional climatic understanding and present architecture methods, undermining Abuja's overall acceptance of bioclimatic principles. Sustainable Architecture Theory emphasises ecologically responsible and resource-efficient design to reduce negative consequences throughout a building's life cycle [37, 26]. While natural ventilation elements appear to be marginally embraced, the studies highlight deficiencies in other crucial areas. The restricted usage of wall insulation—despite a mean score of 3.81, only 27.8% of respondents agreed or strongly agreed with its presence—indicates a distorted view of energy efficiency. Furthermore, the inconsistency with which various passive design principles are applied, as well as the potential absence of renewable energy sources, weaken these buildings' sustainability credentials. High initial costs, limited availability of sustainable materials, and a lack of regulatory incentives all pose challenges to SAT's practical implementation in Abuja. Though energy conservation may provide long-term cost savings, the initial financial load remains a substantial barrier. These obstacles suggest that, while SAT principles are theoretically recognised, their actual implementation is hampered by socioeconomic and institutional constraints. The Energy Performance Theory emphasises the technical optimisation of building components such as insulation, orientation, fenestration, and ventilation in order to increase energy efficiency and lower operational costs [38, 39]. The strong agreement on the existence of ventilation-enhancing design in living rooms (3.81) and bedrooms (3.51) suggests partial adherence to EPT. Nonetheless, neutral responses to cross-ventilation integration and low adoption of wall insulation indicate insufficient use of performance-based design concepts. The high mean score for insulation (3.81) is opposed by the fact that more than 37.9% of respondents disapproved or strongly disagreed with its presence, demonstrating a mismatch between perceived and real application. Furthermore, insufficient stakeholder awareness, a lack of appropriate materials, and high upfront costs impede the implementation of advanced energy-efficient technologies such as high-performance glass and smart systems, undercutting EPT's technological goals. According to Ecological Modernisation Theory, environmental sustainability may be achieved alongside economic progress by leveraging technical innovation, institutional reform, and policy-driven modernisation [29]. However, the study's findings indicate poor alignment with EMT. The low Relative Importance Index (RII) score for government incentives (0.34) and broad opposition to change point to a lack of institutional structures and favourable policy contexts. The absence of smart technology and renewable systems in studied households shows that technological modernisation is taking place without corresponding ecological innovation. This circumstance exemplifies one of the most common criticisms levelled at EMT in developing countries: legislative stagnation and ineffective regulatory engagement limit the realisation of long-term transformations. Overall, the findings indicate that, while passive features such as natural ventilation are partially integrated into Abuja residential architecture, other critical elements such as high-performance insulation, courtyard design, and smart energy systems are either underutilised or poorly understood. Informational, behavioural, and institutional limitations tend to be more substantial than strictly economic limits, preventing the successful implementation of sustainable and energy-efficient design theories.

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

This study investigated architectural components that enhance energy efficiency in residential structures in Abuja, Nigeria, using Bioclimatic Architecture Theory (BAT), Sustainable Architecture Theory (SAT), Energy Performance Theory (EPT), and Ecological Modernisation Theory (EMT). The findings suggest a partial but inconsistent use of energy-efficient design solutions, particularly in areas like natural ventilation and insulation. While living rooms and bedrooms were somewhat optimised for natural cross ventilation in accordance with BAT principles, the neutral position on the general use of passive ventilation solutions indicates that bioclimatic concepts are not fully integrated. Wall insulation practices were inconsistently reported, with a paradoxical mean agreement of 3.81 and high disagreement rates, indicating misunderstanding or insufficient insulation use. This represents a moderate alignment with SAT, in which sustainable design concepts are present but not fully implemented. EPT's emphasis on performance-driven technologies was partially supported by user evaluations of smart technology effectiveness, but adoption remained low (only 6.4% adopted all available systems), contradicting the theory's central claim of broad integration of high-performance tools. Finally, EMT's vision of innovation as a bridge between environmental protection and development was not fully realised due to institutional, socio-cultural, and economic constraints that hampered deeper technology integration. Key challenges identified included a lack of awareness, opposition to change, restricted material availability, and poor government incentives.

6.2. Recommendations

The recommendations listed below are intended to guarantee that energy efficiency is integrated into residential building design in Abuja, Nigeria. (I) Abuja architectural designs should be optimised holistically to incorporate passive cooling measures such as strategic window placements, courtyard systems, shaded apertures, and natural ventilation paths. (ii) Planning authorities should create design guidelines that promote the use of bioclimatic components appropriate to Abuja's climate zone. (iii) Policies should encourage the use of environmentally friendly building materials, insulation systems, and integrated passive and active energy-saving measures. (iv) Green building certification programs should be implemented or strengthened in Abuja to promote holistic sustainable practices. (v) There is a need for more adoption and education on the performance benefits of smart technology such as lighting, thermostats, and blinds. (vi) Developers should be encouraged to incorporate smart energy systems into the design stage, together with real-time monitoring systems to measure and improve performance. (vii) Government and institutional policies should prioritise reducing economic and informational barriers by giving subsidies, tax breaks, or grants for energy-efficient technologies. (viii) Public-private collaborations should be promoted to ensure the availability of sustainable technology and to foster innovation ecosystems in the construction industry. Overall, Abuja's residential architecture shows scattered progress towards energy-efficient design. A coordinated and theory-informed approach integrating natural and technical solutions, supported by strong institutional frameworks, can dramatically enhance building energy performance while also complying with national and global sustainability goals.

REFERENCES

[1] International Energy Agency. (2023). **The future of cooling: Opportunities for energy-efficient air conditioning**. https://www.iea.org/reports/the-future-of-cooling

[2] Chen, Y., Li, Y., & Zhang, D. (2021). **WattScale: A data-driven approach for energy efficiency analytics of buildings at scale**. *ACM Transactions on Data Science, 2*(1), Article 5. https://doi.org/10.1145/3406961

[3] Twum, M. A. A., & Beecham, E. O. (2024, June 20). **AD814: Nigerians lack reliable electricity, leaving most discontent with government's efforts**. *Afrobarometer.* https://www.afrobarometer.org/publication/ad814-nigerians-lack-reliable-electricity-leaving-most-discontent-with-governments-efforts/

[4] Statista. (2024, September 30). **Electricity consumption in Nigeria 2022, by sector**. *Statista.* https://www.statista.com/statistics/1307456/electricity-consumption-in-nigeria-by-sector/

[5] Yusuf, A. and Akande, O.K. (2023b) **Drivers, Enablers, Barriers and Technologies (DEBT) For Low-Energy Public Housing Delivery in Nigeria**. *Journal of Advanced Research in Applied Sciences and Engineering Technology 29, Issue 3. Pp.115-127*

[6] Akande, O. K. (2010). **Passive design strategies for residential buildings in a hot dry climate in Nigeria**. *WIT Transactions on Ecology and the Environment, 128*, 61–71. https://doi.org/10.2495/ARC100061

[7] Yusuf, A. and Akande, O.K. (2023a). **Passive Building Design Evaluation in Nigeria: The Case for Energy-Conscious Design of Residential Buildings for the Dynamics of Nature**. *Journal of Interior Designing and Regional Planning. Vol. 8 No. 1 Pp 19-29.*

[8] Gondal, I. A., Masood, S. A., & Khurram, M. (2019). **Role of passive design and alternative energy in building energy optimizatio**n. *Indoor and Built Environment, 30*(2), 1420326X19887486. https://doi.org/10.1177/1420326X19887486

[9] Akande, O.K. (2011) **Application of Architectural Techniques for Reducing Energy Consumption in Residential Building**. *African Journal for Research, Innovation and Discovery* Vol.5, No.1 (Special Issue) August. Pp.17-25.

[10] Akande, O.K. Fabiyi, O. and Mark, I.C. (2015) **Sustainable Approach to Developing Energy Efficient Buildings for Resilient Future of the Built Environment in Nigeria**. *American Journal of Civil Engineering and Architecture*, Vol. 3, No. 4, 144-152

[11] Akande, O.K. and Olagunju, R.E. (2016) **Retrofitting and Greening Existing Buildings: Strategies for Energy Conservation, Resource Management and Sustainability of the Built Environment in Nigeria**. *Journal of Sustainable Architecture and Civil Engineering,* Vol.2 No 15 pp 5 – 12

[12] Lembi, J.J., Akande, O.K., Ahmed, S. and Emechebe, C. (2021). **The Drivers for Low Energy Materials Application for Sustainable Public Housing Delivery in Nigeria**. *Landscape Architecture and Regional Planning*. Vol. 6, No. 2, 2021, pp. 19-24. doi: 10.11648/j.larp.20210602.11

[13] Akande O.K., Akoh S., Francis B., Odekina S., Eyigege E., Abdulsalam M (2021). **Assessing the potentials of low impact materials for low energy housing provision in Nigeria**. *Journal of Sustainable Construction Materials Technology*. 6:4:156–167

[14] Emechebe, L.C., Akande, O. K., Ahmed, S. and Lembi, J. J. (2021) **Barriers to Low Energy for Public Housing Delivery In Nigeria,** *International Journal of Science Academic Research* Vol. 02, Issue 07, pp.1785-1790,

[15] Akande, O.K., Obi-George, L.C., Lembi, J.J. and Nwokorie, A. J. (2023). **Energy Demand Reduction for Nigeria Housing Stock through Innovative Materials, Methods and Technologies**. *Journal of Sustainable Construction Materials and Technologies* Vol. 8 Issue 3, pp.1-17

[16] Akhimien, N. (2022). **A framework for incorporating circular economy in the design of energy efficient residential buildings in Nigeria** (*Doctoral dissertation*, Cardiff University).

[17] Ekechukwu, D. E., & Simpa, P. (2024). **A comprehensive review of renewable energy integration for climate resilience**. *Engineering Science & Technology Journal*, *5*(6), 1884-1908.

[18] Oyedepo, S. O. (2014). **Towards achieving energy for sustainable development in Nigeria**. *Renewable and sustainable energy reviews*, *34*, 255-272.

[19] Ezema, I. C., Izobo-Martins, O., & Owoseni, A. O. (2022). **Public School Buildings in Lagos, Nigeria: Renovations, Renewable Energy Retrofits and Implications for Technology-based Education**. *JEP*, *13*(17).

[20] Ayodele, T. R. (2025). **Cost of selected smart building elements and its level of implementation in Abuja**. *Journal of Financial Management of Property and Construction*.

[21] Odu, T. Y. (2019). **Making a Business Case for Green Housing Investment in Lagos, Nigeria** (*Doctoral dissertation*, University of KwaZulu-Natal, Howard College).

[22] Emezue, C. A., Nayeri, S., Hosseinian-Far, A., & Sarwar, D. (2024). **Bridging the Green Gap: Barriers to Sustainable Residential Construction in Nigeria**. In *Contemporary Sustainable Organisational Practices: A Roadmap for Transformation* (pp. 117-135). Cham: Springer Nature Switzerland.

[23] Olgyay, V. (1963). **Design with Climate: Bioclimatic Approach to Architectural Regionalism**. Princeton University Press.

[24] Givoni, B. (1994). **Passive and Low Energy Cooling of Buildings**.

[25] Edwards, B., & Turrent, D. (2002). **Sustainable housing: Principles and practice**. Taylor & Francis.

[26] Kibert, C. J. (2016). **Sustainable Construction: Green Building Design and Delivery**. John Wiley & Sons.

[27] Santamouris, M. (2001). **Energy and Climate in the Urban Built Environment**.

[28] Crawley, D. B., & Barnaby, C. S. (2019). **Weather and climate in building performance simulation**. In *Building performance simulation for design and operation* (pp. 191-220). Routledge.

[29] Mol, A. P., & Sonnenfeld, D. A. (2000). **Ecological Modernisation Around the World: Perspectives and Critical Debates**. Frank Cass Publishers.

[30] Spaargaren, G. (2000). **Ecological modernization theory and domestic consumption**. *Journal of Environmental Policy and Planning*, *2*(4), 323-335.

[31] Mugenda, O. M., & Mugenda, A. G. (2003). **Research methods: Quantitative & qualitative apporaches** (Vol. 2, No. 2). Nairobi: Acts press.

[32] Guy, S., & Farmer, G. (2001). **Reinterpreting Sustainable Architecture: The Place of Technology**. *Journal of Architectural Education*, 54(3), 140–148. https://doi.org/10.1162/10464880152632451

[33] Tavakol, M., & Dennick, R. (2011). **Making sense of Cronbach's alpha**. *International Journal of Medical Education*, 2, 53–55. https://doi.org/10.5116/ijme.4dfb.8dfd

[34] Lechner, N. (2014). **Heating, Cooling, Lighting: Sustainable Design Methods for Architects**. John Wiley & Sons.

[35] Omer, A. M. (2008). **Energy, environment and sustainable development**. *Renewable and Sustainable Energy Reviews*, 12(9), 2265-2300.

[36] Cabeza, L. F., Rincón, L., Vilariño, V., Pérez, G., & Castell, A. (2014). **Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review**. *Renewable and Sustainable Energy Reviews*, 29, 394-416.

[37] Vale, B., & Vale, R. (2000). **Green Architecture: Design for a Sustainable Future**. Thames and Hudson.

[38] ASHRAE (2010). ***Energy Efficiency Guide for Existing Commercial Buildings*. American Society of Heating**, Refrigerating and Air-Conditioning Engineers.

[39] Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). **A review on buildings energy consumption information**. *Energy and Buildings*, 40(3), 394–398.