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INVESTIGATING PASSIVE DESIGN STRATEGIES FOR ENERGY DEMAND REDUCTION IN RESIDENTIAL BUILDING IN GWAGWALADA, ABUJA

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ABSTRACT

Buildings are among the largest consumers of energy globally, with residential buildings in hot climates facing significant energy demands due to cooling and lighting needs. This study examined passive design strategies for energy demand reduction in residential buildings in Gwagwalada Area Council, Abuja. The objectives were to identify passive design strategies employed, assess energy demand levels, and examine their influence on energy demand reduction. A quantitative survey design was adopted, with structured questionnaires administered to 150 residents, yielding 121 valid responses (80.7% response rate). Data were analysed using descriptive statistics. Findings revealed that passive design strategies are largely absent; buildings lack proper solar orientation, lack cross-ventilation, and have no reflective surfaces. Energy demand was high, reporting excessive air conditioner use and reporting frequent generator dependency. Despite this, high percentage of respondents agreed that improved passive design would significantly reduce energy demand, natural ventilation and daylighting. The study concludes that passive design strategies are critically underutilised in Gwagwalada. It recommends mainstreaming passive design through building codes, professional practice, and public education to reduce household energy consumption and promote sustainable residential development in Nigeria's hot semi-arid climate.

Keywords: Passive design strategies, energy demand reduction, residential buildings, natural ventilation, daylighting, Gwagwalada.

1. INTRODUCTION

Buildings constitute one of the most significant consumers of energy globally and remain major contributors to greenhouse gas emissions, particularly through operational energy demands such as cooling, lighting, heating, and appliance use. According to the International Energy Agency (IEA) Energy in Buildings and Communities (EBC) Technology Collaboration Programme (TCP) (2023), buildings account for almost one-third of total energy use, with over 10% used for air conditioning and indoor thermal comfort in hot seasons. This growing energy demand has intensified global attention on energy efficiency as a critical component of sustainable architecture, environmental planning, and climate change mitigation strategies. Residential buildings account for more than 60% of the building sector's total energy consumption globally; while this figure is nearer 20% of national energy demand in developed economies, it exceeds 50% in Sub-Saharan Africa, owing to reliance on energy-intensive materials, inefficient building designs, and limited access to advanced technologies (Odoi-Yorke et al., 2026)

Across many developing countries, including those in the Global South, increasing temperatures associated with climate change and urban heat island effects have heightened reliance on mechanical cooling systems such as air conditioners and electric fans, leading to growing energy consumption in residential buildings (Mukhopadhyay et al., 2026). This challenge is especially pronounced in developing countries such as Nigeria, where electricity supply is often unstable and unreliable. Consequently, households frequently depend on fuel-powered generators to meet their energy needs, a situation that not only increases household expenditure but also contributes to air and noise pollution as well as elevated greenhouse gas emissions (UNEP & GlobalABC, 2022; IEA, 2023).

Nigeria's residential energy challenge is further compounded by rapid urbanization and population growth, which drive rising housing demand and the construction of new structures, in turn increasing energy consumption both directly through heating and cooling needs and indirectly through the manufacture of building materials (Abam et al., 2023). As urban areas continue to expand, residential developments are often executed with limited consideration for energy-efficient or climate-responsive design principles, a pattern linked to Nigeria's broader urbanization and sustainable development challenges (Abubakar & Aina, 2019), thereby intensifying overall energy consumption and environmental degradation. Within this context, the integration of climate-responsive architectural approaches becomes essential for reducing energy demand, enhancing indoor environmental quality, and promoting sustainable residential development.

Passive design strategies provide a sustainable and contextually appropriate response to these challenges by harnessing natural environmental forces such as solar radiation, wind flow, and the thermal properties of building materials to regulate indoor environmental conditions with minimal reliance on mechanical systems (Olgyay, 1963; Givoni, 1998; Sholanke, & Ganya., 2024). These strategies, including shading devices, thermal mass utilization, natural ventilation, and reflective surfaces, work collectively to reduce indoor temperatures and cooling loads when properly integrated into building design. A systematic review and meta-analysis of 42 studies found that passive cooling strategies achieve, on average, a 31% reduction in cooling load and 29% energy savings in hot climates (Hu, Zhang, Nguyen, & Tasdizen, 2023), while façade-based strategies such as shading devices and double-skinned façades have been shown to substantially reduce cooling loads in hot, dry tropical climates such as Nigeria’s (Akaainjo & Abdullahi, 2018). Simulations of a typical villa in Saudi Arabia’s hot, arid climate found that combined passive design measures could reduce cooling energy use by up to 68% compared with the base-case design (Rodrigues, Cherian, & Tokbolat, 2025).

The persistent increase in residential energy demand, coupled with inadequate and unreliable electricity infrastructure, has created a significant energy crisis in many urban settlements. This crisis is characterized by frequent power shortages, excessive dependence on alternative energy sources such as generators, and escalating household energy costs. Households and businesses compelled to rely on generators for electricity face heavy dependence that leads to environmental pollution and frequent exposure to carbon emissions, with the root cause lying in the unreliability of the national grid (Olujobi, Okorie, Olarinde, & Aina-Pelemo, 2023). In addition to economic burdens, the situation contributes to environmental pollution and undermines efforts toward achieving sustainable urban development. Residential buildings, therefore, represent a critical sector where energy efficiency interventions are urgently required to address both economic and environmental challenges.

The concept of passive design is rooted in the principle of achieving thermal comfort and adequate lighting conditions in buildings through natural means rather than mechanical intervention. It emphasizes the integration of building form (surface-to-volume ratio), orientation, material selection, and room/floor plan zoning in response to local climatic conditions in order to optimize thermal performance and reduce energy demand for cooling (Akande, 2010; Xi, et al., 2025). In warmhumid and hot-dry climates, passive strategies such as shading and cross ventilation are particularly effective in minimizing heat gain and reducing cooling energy demand (Givoni, 1998; Binarti, & Kubota, 2026). When appropriately applied, passive design becomes a fundamental component of sustainable architecture, offering a low-energy and environmentally responsive approach to residential building design.

Climate-responsive or passive design is increasingly recognized as a key strategy for addressing energy inefficiencies in the built environment. It focuses on adapting building characteristics such as form, orientation, envelope design, and material usage to local climatic conditions in order to reduce dependence on artificial energy inputs (Akande, 2010; Ayoobi, & Mehdizade, 2025). A simulation-based study of residential buildings in hot and humid Hong Kong found that combining sensitive passive design parameters could reduce annual and peak cooling loads by up to 56.7% and 64.5%, respectively (Liu, Kwok, Lau, Ouyang, & Ng, 2020). Research indicates that when effectively implemented, passive design strategies can significantly reduce building energy consumption by minimizing unwanted heat gain while maximizing natural ventilation (Akande, 2010; Mushtaha, et al., 2021). This makes climate-responsive design particularly important in regions facing energy scarcity and environmental stress.

Despite the established benefits of passive design strategies, many residential buildings in Gwagwalada Area Council, Abuja, are still designed and constructed without adequate consideration of climate-responsive principles. As a result, such buildings often experience excessive heat gain, poor ventilation performance, and insufficient natural lighting, which collectively increase dependence on mechanical cooling and artificial lighting systems. This design deficiency contributes to high and inefficient energy consumption, thereby increasing household energy costs and environmental impacts. The situation is further exacerbated by unreliable electricity supply, compelling residents to rely heavily on generators, which in turn increases operational expenses and environmental pollution (Oaikhena, & Akande, 2024).

Existing literature indicates that passive design strategies such as orientation, shading, natural ventilation, daylighting, and thermal mass play a significant role in reducing building energy consumption (Olgyay, 1963; Givoni, 1998; Tahan, Banihashemi, & Bagheri-Moghaddam, 2026). Furthermore, residential energy demand is largely driven by cooling and lighting needs, especially in hot climates where mechanical systems are heavily relied upon (Santamouris, 2014). However, despite this understanding, several barriers including cost constraints, limited awareness, inadequate technical knowledge, and poor construction practices continue to hinder the effective adoption of passive design strategies in many developing countries, including Nigeria (Zuo & Zhao, 2014; UNEP & GlobalABC, 2022). This underscores the importance of localized studies that examine how these strategies are applied in specific contexts such as Gwagwalada and how they influence residential energy demand patterns.

Although existing studies have emphasized the importance of passive design strategies in improving energy efficiency, there remains limited empirical evidence on their actual application in residential buildings within Gwagwalada and their direct influence on energy demand patterns. This gap in knowledge highlights the need for a systematic investigation into how passive design strategies are utilized in the study area and the extent to which they contribute to energy demand reduction in residential buildings.

The aim of this study is therefore to investigate the role of passive design strategies in reducing energy demand in residential buildings in Gwagwalada, Abuja. The specific objectives of the study are to identify the passive design strategies employed in residential buildings in Gwagwalada, Abuja; assess the level of energy demand in residential buildings within the study area; and examine the influence of passive design strategies on energy demand reduction in residential buildings in Gwagwalada, Abuja.

2. MATERIALS AND METHODS

This study was conducted in Gwagwalada Area Council, one of the eight area councils of the Federal Capital Territory (FCT), Abuja, Nigeria. Gwagwalada is characterized by a hot semi-arid (BSh) climate with high ambient temperatures, particularly during the dry season, making it an appropriate setting for investigating the role of passive design strategies in reducing residential energy demand for cooling. A quantitative research design was adopted to systematically investigate passive design strategies and their influence on energy demand reduction in residential buildings within the study area. The quantitative approach was considered most appropriate as it enables the measurement, analysis, and generalization of findings from a structured sample population (Creswell, 2014).

The target population comprised residential building occupants within Gwagwalada Area Council. A sample of 150 respondents was drawn using purposive and convenience sampling techniques, targeting residents who were occupying residential buildings and had been in their current dwelling for a sufficient period to provide informed responses on building characteristics and energy use patterns. A survey strategy was employed through the administration of structured questionnaires to the sampled residents. The questionnaire was divided into four sections: Section A captured demographic and building characteristics; Section B addressed the identification of passive design strategies (Objective One); Section C assessed the level of energy demand (Objective Two); and Section D examined the influence of passive design strategies on energy demand reduction (Objective Three). Section B used Yes/No/Not Sure response options, Section C used a four-point ordinal scale (Low, Moderate, High, Very High), and Section D employed a five-point Likert scale (Strongly Disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, Strongly Agree = 5). Of the 150 questionnaires distributed, 121 were returned and deemed valid for analysis, representing a response rate of 80.7%. Data were analysed using descriptive statistics including frequency counts, percentages, and mean scores.

A total of 150 questionnaires were distributed to residential building occupants across selected neighbourhoods in Gwagwalada. Of these, 121 completed questionnaires were retrieved and deemed valid for analysis, while 29 questionnaires were not returned. This yielded a response rate of 80.7%, which is considered adequate for quantitative survey research. Mugenda and Mugenda (2003) suggest that a response rate of 70% and above is sufficient for analysis and reporting. Data collected were analysed using descriptive statistics, including frequency counts, percentages, and mean scores. For Likert-scale items in the mean score was interpreted using the following scale: 1.00–1.79 = Strongly Disagree; 1.80–2.59 = Disagree; 2.60–3.39 = Neutral; 3.40–4.19 = Agree; 4.20–5.00 = Strongly Agree. Results are presented in tabular form to facilitate clarity and systematic discussion of findings in relation to each research objective.

3. RESULTS AND DISCUSSION

The demographic and background information of the respondents are presented in Table 1. Of the 121 valid respondents, 85 (70.2%) were male and 36 (29.8%) were female, a pattern consistent with the common tendency in Nigerian household surveys for male heads of household to respond to structured questionnaires on building and energy matters. With regard to age, respondents below 40 years accounted for 75.2% of the sample, indicating a predominantly young adult population that is consistent with the younger urbanizing demographic of emerging Nigerian urban areas. In terms of residence type, one-bedroom apartments (42.1%) and selfcontained units (38.8%) dominated the sample, reflecting the low-to-moderate income residential typology that characterises Gwagwalada, where compact and affordable housing is most common. Regarding length of stay, the majority of respondents (35.5%) had resided in their current building for 1–5 years, with a response rate of 97.5% recorded on this item. By drawing on a demographically varied but contextually representative sample, the study strengthens the credibility and practical relevance of its findings on passive design and energy demand in residential buildings.

Table 1: Demographic and Background Information of Respondents

Summary of Information	Frequency	Percentage (%)	Cumulative %
Gender			
Male	85	70.2%	70.2%
Female	36	29.8%	100.0%
Total	121	100.0%	—
Age Group			
Below 20	33	27.3%	27.3%
Summary of Information	Frequency	Percentage (%)	Cumulative %
21–30	31	25.6%	52.9%
31–40	27	22.3%	75.2%
41–50	21	17.4%	92.6%
Above 50	9	7.4%	100.0%
Total	121	100.0%	—
Type of Residence			
Self-contained	47	38.8%	38.8%
One-bedroom	51	42.1%	80.9%
Two-bedroom	13	10.7%	91.7%
Three-bedroom and above	10	8.3%	100.0%
Total	121	100.0%	—
Length of Stay in Building			

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Less than 1 year	33	27.3%	27.3%
1–5 years	43	35.5%	62.8%
6–10 years	31	25.6%	88.4%
Above 10 years	11	9.1%	97.5%
Total*	118	97.5%*	—

*Total for Length of Stay sums to 118 due to missing responses, representing a 97.5% response rate on this item.

3.1 Passive Design Strategies in Residential Buildings

The results reveal a generally low adoption of passive design strategies across residential buildings in the study area, as summarised in Table 2. With respect to building orientation, only 25.6% of respondents reported that their buildings were properly oriented to reduce direct solar heat gain, while 69.4% indicated that orientation had not been considered. This finding suggests that the majority of residential buildings in Gwagwalada are constructed without regard for solar orientation, a critical passive strategy for minimising heat gain. This is consistent with the observation by Akande (2010), who found that building orientation is frequently neglected in residential construction in hot-dry climate zones of Nigeria, resulting in unnecessary thermal discomfort and increased cooling energy demand.

With respect to natural ventilation, 47.1% of respondents reported an absence of adequate window openings, while only 28.1% confirmed the presence of large windows. Cross-ventilation was reported as absent in 71.9% of buildings, with only 25.6% confirming its effective provision. These findings indicate that natural ventilation, one of the most effective passive strategies in hot climates is largely absent in the sampled residential buildings. Givoni (1998) emphasised that cross-ventilation is among the most effective passive cooling strategies in warm-humid and hot-dry climates, and its absence significantly contributes to increased reliance on mechanical cooling systems.

Shading devices such as roof overhangs, awnings, and trees ranked as the most commonly identified passive strategy, with 38.8% confirming their presence. However, a notably high proportion of respondents (33.9%) were unsure whether shading devices existed in their buildings, suggesting limited deliberate integration of shading into building design. Lightcoloured roofing or walls showed the lowest adoption rate, with only 2.5% confirming their use, while 81.0% confirmed the absence of reflective surface treatments. This is a significant finding given that reflective surfaces are among the most cost-effective passive strategies for reducing solar heat gain in hot climates (Akaainjo & Abdullahi, 2018). Natural lighting ranked highest overall, with 42.1% confirming its effective use during daytime.

Table 2: Presence of Passive Design Strategies in Residential Buildings

Item	Yes %	No %	Not Sure %	Rank
Natural lighting used during daytime	42.1%	38.0%	19.8%	1st
Shading devices present	38.8%	19.0%	33.9%	2nd
Large windows provided for ventilation	28.1%	47.1%	17.4%	3rd
Building orientation reduces heat gain	25.6%	69.4%	5.0%	4th
Cross-ventilation provided	25.6%	71.9%	2.5%	4th
Light-coloured roofing/walls used	2.5%	81.0%	16.5%	6th

Items ranked by percentage of “Yes” responses on a Yes/No/Not Sure scale.

3.2 Level of Energy Demand in Residential Buildings

The level of energy demand in residential buildings was found to be high across most indicators, as shown in Table 3. Regarding electricity costs, 81.8% of respondents rated their costs as High or Very High, yielding the highest mean score among the items assessed (mean = 3.23, SD = 0.73) and reflecting the economic burden of energy consumption on households in the study area.

Air conditioner usage was rated High or Very High by 86.8% of respondents (mean = 3.18, SD = 0.72), indicating widespread reliance on mechanical cooling systems. This finding corroborates the observation by Santamouris (2014) that residential buildings in urban heat island-affected areas exhibit significantly elevated cooling energy demands, particularly in the absence of passive design features.

Generator use ranked third (mean = 3.04, SD = 0.95), reflecting the persistent unreliability of grid electricity supply in the area, a finding aligned with Olujobi et al. (2023), who identified dependence on fuel-powered generators as a major characteristic of Nigeria's residential energy landscape. Overall household energy consumption recorded a mean of 2.85 (SD = 0.80), rated High or Very High by 76.1% of respondents. Fan usage and daytime electric lighting recorded the lowest means (2.02 and 2.37 respectively), suggesting that fans are used as a supplementary rather than primary cooling mechanism, while daytime electricity use for lighting is consistent with the earlier finding that 38.0% of buildings lack sufficient natural lighting. Collectively, these findings establish a clear pattern of high energy demand, particularly for mechanical cooling and generator-powered electricity, which directly reflects the inadequacy of passive design integration in the buildings studied.

Table 3: Level of Energy Demand in Residential Buildings

Item	N	Mean Score	Std. Dev.	Rank
Cost of electricity is high	113	3.23	0.73	1st
Household uses AC frequently	121	3.18	0.72	2nd
Frequent generator use	120	3.04	0.95	3rd
Overall energy consumption is high	121	2.85	0.80	4th
Electricity used for daytime lighting	121	2.37	1.07	5th
Household uses fans for long hours	121	2.02	0.97	6th

Scale: 1 = Low, 2 = Moderate, 3 = High, 4 = Very High. Items ranked by mean score.

3.3 Influence of Passive Design Strategies on Energy Demand Reduction

Respondents' perceptions of the influence of passive design strategies on energy demand reduction are presented in Table 4. The majority of respondents acknowledged the potential of passive design to lower energy demand, with most items recording agreement rates above 60%. The item positing that improved passive design would significantly reduce energy demand in residential buildings ranked highest overall (mean = 4.25, SD = 0.93), indicating strong collective optimism about the energy-saving potential of passive design despite its low integration in existing buildings. Similar findings were reported by Liu et al. (2020) in a study of residential buildings in Hong Kong, where occupants demonstrated awareness of passive design benefits even in buildings that lacked such features.

Natural ventilation ranked second (mean = 4.03, SD = 1.22), with respondents agreeing that it reduces electricity consumption. This high agreement, combined with the earlier finding that 71.9% of buildings lack cross-ventilation, highlights a significant gap between resident awareness and actual design practice. Shading devices recorded the lowest mean among the perception items (3.03, SD = 1.20), with a high proportion of respondents remaining neutral a pattern that may reflect the earlier-identified ambiguity, where 33.9% of respondents were unsure whether shading devices existed in their buildings, making it difficult for them to assess impact. These findings are consistent with Akaainjo & Abdullahi (2018), who noted that while shading devices are effective in hot-dry tropical climates, their perceived impact may be underestimated when residents are not fully aware of their intended function.

Table 4: Influence of Passive Design Strategies on Energy Demand Reduction

Item	N	Mean Score	Std. Dev.	Rank
Improved passive design will reduce demand	110	4.25	0.93	1st
Natural ventilation reduces consumption	121	4.03	1.22	2nd
Passive design reduces electricity bills	121	4.01	1.08	3rd
Daylight reduces artificial lighting use	121	3.87	0.81	4th
Orientation reduces cooling need	121	3.31	1.35	5th
Shading devices reduce indoor heat	119	3.03	1.20	6th

Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree. Items ranked by mean score.

Overall, the findings demonstrate a clear and consistent pattern: passive design strategies remain poorly integrated into residential buildings in Gwagwalada with the partial exception of natural lighting and shading while energy demand, particularly for cooling and backup power, remains high. At the same time, residents show a strong latent awareness of the energy-saving potential of passive design, even though this awareness has not translated into widespread adoption in existing buildings. This gap between perception and practice underscores the need for greater awareness creation and the deliberate application of climate-responsive design principles in residential construction within the study area.

CONCLUSION

This study examined passive design strategies for reducing energy demand in residential buildings in Gwagwalada, Abuja, covering three objectives: identifying the strategies in use, assessing energy demand levels, and examining their influence on energy reduction. A structured questionnaire administered to 150 respondents yielded 121 valid responses, analysed using frequency counts, percentages, and mean scores. Passive design strategies are largely absent from residential buildings in Gwagwalada: most lack proper solar orientation, cross-ventilation, and reflective surfaces, while natural lighting and shading remain limited and inconsistent. This mirrors findings from Bauchi's residential buildings, in Nigeria's wider hot-dry belt, which were commonly built without proper orientation or ventilation, producing indoor temperatures up to 37°C, air velocities of 0.11–0.12 m/s, and occupants describing conditions as too warm. The persistence of this pattern over a decade later, in a different locality, points to a broader structural deficiency in Nigerian residential construction across hot climatic zones, not an isolated case.

Energy demand in the area is correspondingly high: electricity costs, air conditioner use, and generator dependency all scored High to Very High, with an overall consumption mean of 2.85 (High). This aligns with broader findings linking the absence of passive features to markedly higher cooling loads and energy use, and with generator dependency being identified as characteristic of Nigerian residential energy use amid grid instability; the present peri-urban FCT findings reflect comparable stress.

Yet residents widely recognise passive design's potential: a high percentage agreed or strongly agreed it would significantly cut energy demand (mean = 4.25), with natural ventilation, daylighting, and passive design generally scoring strongly (means 3.03–4.25). This optimism is well supported elsewhere in Nigeria. A simulation of an Abuja bungalow in EnergyPlus found combined low-cost measures orientation, roof colour, window-to-wall ratio, shading — cut annual cooling load by 30% (11,245 kWh to 7,928 kWh), with shading and material substitution contributing most. A meta-analysis of 32 Nigerian studies found passive design yields a medium-to-large effect on energy efficiency (Cohen's d = 0.65), with natural ventilation showing the largest effect on thermal comfort. A survey of 121 Abuja architects similarly ranked natural ventilation highest for thermal comfort (mean = 4.76), followed by shading (4.66), daylighting (4.64), and orientation (4.65) closely mirroring Gwagwalada residents' priorities despite different samples. This convergence suggests residents' optimism reflects measurable, climate-specific gains already demonstrated within Abuja and beyond.

The findings thus reveal a paradox: residents recognise passive design's benefits, yet most buildings lack it. Literature attributes this to limited builder knowledge, cost constraints, weak regulation, and poor construction practice. Similar studies likewise cite limited awareness, low acceptance, and restricted material/expertise availability nationwide, while research on trained Abuja architects found even they were insufficiently aware of certain strategies, identifying the design process and client engagement as the critical factors determining whether passive features survive into completed buildings. The study concludes that passive design is critically underutilised in Gwagwalada, a major and avoidable driver of elevated energy demand rooted not in lack of awareness but in the gap between awareness and practice.

5. RECOMMENDATIONS

Passive design should be mainstreamed into building codes, with FCT authorities requiring minimum standards for orientation, window sizing, shading, and reflective finishes in approvals and inspections, making it an enforceable, low-cost requirement. Shading and reflective treatments should be prioritised as low-cost interventions, given their near-absence in Gwagwalada, where only a few of buildings had adopted reflective surfaces. Natural ventilation pathways should be actively designed and retrofitted, since cross-ventilation was absent in high percentage of buildings despite 81.0% resident agreement on its benefit. Urban layout and density should also factor into residential planning, with future developments considering how road width, setback, and density affect neighbourhood-scale ventilation. Locally adapted guidelines and training should be developed to close the awareness-practice gap. Finally, further empirical and simulation-based research is needed, particularly retrofit-focused studies in Gwagwalada, to generate locally calibrated evidence beyond survey-based perception data.

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