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Context-Specific Energy Efficiency Framework For Residential Buildings In Southwest Nigeria: Integrating Climatic, Socioeconomic, And Behavioural Dimensions

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Abstract:** Buildings account for nearly 40% of global energy consumption, with tropical regions like Southwest Nigeria facing unique challenges due to high cooling demands, rapid urbanisation, and limited policy responsiveness. While Nigeria introduced the Building Energy Efficiency Code (BEEC) in 2017, its one-size-fits-all approach overlooks regional climatic variability, socioeconomic realities, and occupant behaviour, critical determinants of energy performance in residential buildings. This study addresses these gaps by developing a weighted, context-specific energy efficiency framework for residential buildings in Southwest Nigeria's tropical humid-dry zone. Using a mixed-methods sequential exploratory design, data were collected through a three-round Delphi survey with 30 experts (academia and practitioners) and a household survey across three urban density gradients: Ado-Ekiti (low), Ibadan (medium), and Ikeja (high). Factor analysis and consensus-building techniques identified six primary components influencing energy efficiency: Building Design (16.83%), Maintenance (16.73%), Equipment & Appliances (16.71%), Occupant Behaviour (16.69%), Climatic Factors (16.65%), and Socioeconomic Factors (16.39%). Sub-component analysis revealed that Building Envelope (33.98%) and Ventilation Features (33.59%) dominate design considerations, while Air Conditioning Systems (21.03%) and Energy Cost (20.94%) are key in equipment and socioeconomic domains, respectively. The study further identifies financial, technical, and awareness barriers as major impediments to implementation, with initial investment cost (mean = 4.48) and limited access to finance (mean = 4.34) being rated as the highest. The proposed framework integrates passive design strategies, behaviour-sensitive interventions, and tiered policy recommendations tailored to urban density. This research presents a replicable model for assessing energy efficiency in tropical developing regions. It provides actionable insights for policymakers, architects, and urban planners seeking to align building practices with Sustainable Development Goal 11 (Sustainable Cities and Communities).

***Keywords:** Energy efficiency, residential buildings, tropical climate, Delphi method, behavioural factors, building envelope, Nigeria, policy framework*

I. INTRODUCTION

The built environment is a major contributor to global energy consumption and greenhouse gas emissions, accounting for approximately 40% of total primary energy use and 30% of carbon emissions worldwide (World Economic Forum, 2021). In response, nations have adopted energy performance regulations such as the European Union's Energy Performance of Buildings Directive (EPBD) and Australia's 6-Star Standard to promote low-energy building practices (European Parliament and the Council of the European Union, 2002; Australian Building Codes Board, 2010). However, these frameworks often fail to account for the contextual realities of developing regions, where rapid urbanisation, climatic diversity, and socioeconomic constraints shape building energy dynamics differently.

Nowhere is this mismatch more evident than in Nigeria, Africa's most populous nation and largest economy. With an annual urbanisation rate of 4.1% (Buhari and Mambo, 2024), Nigeria's residential and commercial sectors consume approximately 80% of the nation's electricity (Elinwa *et al.,* 2021). The Southwest region home to 18.4% of Nigeria's population and enjoying 75% electricity access (National Bureau of Statistics, 2017; World Bank, 2017) exemplifies the tension between growing energy demand and inadequate policy frameworks. Characterised by a tropical humid-dry climate (Köppen Aw), the region experiences distinct wet and dry seasons that significantly influence thermal comfort and cooling loads (Lawal and Adesope, 2021).

In 2017, Nigeria launched the Building Energy Efficiency Code (BEEC), following the 2016 National Building Energy Efficiency Guideline (BEEG). The BEEC focuses on four indicators: window-to-wall ratio (WWR), lighting, roof insulation, and air conditioning. However, critical limitations undermine its effectiveness: (1) it applies a uniform standard across Nigeria's five diverse climate zones; (2) it employs an equal-weighting methodology that ignores the varying impacts of different factors; (3) it neglects key design parameters like building orientation, natural ventilation, and local materials; and (4) it inadequately integrates socioeconomic and behavioural dimensions (Ochedi and Taki, 2021; Alabi and Fapohunda, 2021; Maan *et al.,* 2021).

This study addresses these gaps by developing an empirically grounded energy efficiency framework tailored to residential buildings in Southwest Nigeria. Grounded in Socio-Technical Systems Theory (STST), which emphasises the co-evolution of technical and social subsystems (Zhang et al., 2023), the study integrates climatic, design, behavioural, and economic factors into a unified assessment model. The framework is designed to guide architects, policymakers, and homeowners in achieving energy-efficient, climate-responsive housing that aligns with local realities.

II. LITERATURE REVIEW

A. SOCIO-TECHNICAL SYSTEMS AND BUILDING ENERGY EFFICIENCY

Socio-Technical Systems Theory posits that optimal performance emerges from the joint optimisation of technical and social elements (Zhang *et al.,* 2023). In building energy contexts, this means that energy-efficient technologies must align with occupant behaviours, cultural practices, and economic conditions. Studies in developing countries have shown that technical solutions often fail when they overlook local customs or affordability (Kumar *et al.,* 2022). For instance, traditional Nigerian homes typically incorporate courtyards and passive cross-ventilation strategies that reduce cooling loads, but these are rarely recognised in formal codes like the BEEC.

B. DETERMINANTS OF RESIDENTIAL ENERGY CONSUMPTION

Recent literature identifies three interdependent pillars of building energy efficiency: materials, design, and occupant behaviour (Zhang and Wang, 2023). Material selection can reduce energy use by up to 35% in tropical climates (Ahmad *et al.,* 2023), while passive design strategies like orientation and natural ventilation can cut cooling demand by 40% (Juffle and Rahman, 2023). Occupant behaviour alone accounts for up to 30% variation in energy use (Liu and Gou, 2024), highlighting the need for behaviour-informed design.

C. LIMITATIONS OF EXISTING FRAMEWORKS

Global rating systems like BREEAM and LEED, while influential, are criticised for their geographic bias and lack of adaptability (Nguyen and Altan, 2011). BREEAM's heavy weighting on energy may not suit tropical regions where ventilation and shading are more critical than insulation. Similarly, the BEEC's equal-weighting approach fails to reflect the hierarchical importance of factors like envelope performance versus lighting in hot climates (Winkler *et al.,* 2020).

D. THE ENERGY EFFICIENCY GAP IN DEVELOPING CONTEXTS

The "energy efficiency gap" the difference between potential and actual savings is exacerbated in developing regions by financial, technical, and institutional barriers (Jaffe and Stavins, 1994). In Nigeria, upfront costs, lack of skilled labour, weak enforcement, and low awareness hinder adoption (Oyedepo *et al.,* 2023). Moreover, the landlord-tenant split incentive and cultural preferences for certain spatial layouts further complicate implementation (Pelenur and Cruikshank, 2012).

III. METHODOLOGY

This study employed a mixed-methods sequential exploratory design (Creswell and Creswell, 2018), beginning with qualitative expert input (Delphi) followed by quantitative validation (household survey).

A. STUDY AREA AND SAMPLING

The study focused on three cities representing low (Ado-Ekiti), medium (Ibadan), and high (Ikeja) residential density in Southwest Nigeria. A multistage sampling technique was used: neighbourhoods were clustered, stratified by street pattern, and households randomly selected. The final sample comprised 1,150 households (383 in Ado-Ekiti and Ikeja; 384 in Ibadan).

B. DATA COLLECTION

- ✓ *Delphi Survey:* A three-round Delphi process engaged 30 experts (15 academics, 15 practitioners) with ≥7 years'

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experience in energy efficiency. Round 1 used open-ended questions to identify factors; Rounds 2 and 3 presented aggregated feedback for rating refinement on a 5-point Likert scale. Consensus was defined as Mean ≥4.0, IQR ≤1.0, and CV ≤20%.

- ✓ *Household Survey:* A structured questionnaire collected data on building characteristics, energy consumption factors, and perceived barriers. Sections included socio-demographics, envelope materials, ventilation features, and factor importance ratings.
- ✓ *Field Observation:* On-site documentation validated self-reported data on materials, orientation, and shading devices.

C. DATA ANALYSIS

The descriptive statistics were employed to summarise building characteristics, while factor analysis was used to reduce 27 variables into six components. The interquartile range (IQR) and Coefficients of variation were adopted in the study of consensus in DELPHI response. A weighted framework was also applied, and the mathematical expression is expressed in equation 1:

$$Component\ Weight = \frac{Academia\ Weight + Professional\ Weight}{2}$$

$$Relative\ Weight = \frac{Component\ Weight}{Total\ Weight} * 100$$

IV. RESULTS

A. PHYSICAL CHARACTERISTICS OF HOUSING STOCK

The physical attributes of residential buildings across the three cities reveal a high degree of homogeneity in construction practices, despite differences in urban density. As shown in Table 1, detached bungalows dominate the housing typology (43.9–55.4%), though their prevalence declines with increasing urbanisation. Conversely, storey buildings (semi-detached flats) increase from 11.0% in Ado-Ekiti to 16.2% in Ikeja, reflecting land-use pressures in denser urban contexts.

Variable	Ado-Ekiti (n=383)	Ibadan (n=384)	Ikeja (n=383)
Detached bungalow (%)	55.4	48.4	43.9
Storey building (%)	11	14.6	16.2
3-bedroom units (%)	48.6	51.6	53.5
Sandcrete block walls (%)	90.9	92.7	95
Sliding windows (%)	40.7	46.4	51.7
Glass/Aluminum windows (%)	56.1	63	67.6
POP ceilings (%)	59.5	64.1	70
WWR 20–30% (%)	47.5	50	51.7
Cross ventilation (%)	74.7	77.6	81.5
North–South orientation (%)	43.9	46.4	44.9

Note: WWR = Window-to-Wall Ratio.

Table 1: Building Typology and Key Physical Attributes by City

Material selection is highly standardised, with sandcrete blocks used in over 90% of external walls across all cities (Table 1). Window types show a transparent urban gradient: sliding windows, associated with better thermal control, rise from 40.7% in Ado-Ekiti to 51.7% in Ikeja, while traditional louvre windows decline. Similarly, modern glass/aluminium window frames increase with urbanisation, suggesting a shift toward materials that support mechanical cooling systems.

Notably, 74.7–81.5% of homes employ cross ventilation, and 47.5–51.7% maintain a window-to-wall ratio (WWR) of 20–30%, which aligns with optimal passive design recommendations for tropical climates (Fasola and Mohammed, 2022). Building orientation also shows a slight preference for north–south alignment (43.9–46.4%), though plot constraints often override climatic considerations.

An ANOVA test confirmed no statistically significant differences in building characteristics across the three cities (p = 1.000 for all variables), indicating a regionally consistent approach to residential construction (Table 2).

Characteristic	F-value	p-value
Building type	0	1
Number of bedrooms	0	1
Wall material	0	1
Window type	0	1
WWR	0	1
Natural ventilation	0	1
Shading devices	0	1

Table 2: ANOVA Results for Building Characteristics Across Cities

B. CRITICAL FACTORS INFLUENCING ENERGY CONSUMPTION

A three-round Delphi survey achieved consensus (Mean ≥ 4.0, IQR ≤ 1.0, CV ≤ 20%) on all 27 sub-factors by Round 3. Experts identified six primary components that influence residential energy consumption: Building Design, Climatic Factors, Occupant Behaviour, equipment and appliances, Socioeconomic Factors, and Maintenance. Table 3 presents the final consensus ratings from Round 3. Temperature (Mean = 4.45), Air Conditioning Systems (4.45), Energy Cost (4.35), and Building Envelope (4.35) emerged as the highest-rated individual factors.

Component	Sub-factor	Academia Mean	Practitioners Mean	Overall Mean
Building Design	Building Envelope	4.35	4.35	4.35
	Ventilation Features	4.25	4.35	4.3
	Spatial Configuration	4.15	4.15	4.15
Climatic Factors	Temperature	4.45	4.45	4.45
	Humidity	4.35	4.35	4.35
	Solar Radiation	4.15	4.15	4.15
Equipment & Appliances	Air Conditioning Systems	4.45	4.45	4.45

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	Lighting Fixtures	4.25	4.35	4.3
Socioeconomic Factors	Energy Cost	4.35	4.35	4.35
	Household Income	4.15	4.15	4.15
Occupant Behaviour	Natural Ventilation Usage	4.25	4.33	4.29
	Occupancy Patterns	4.25	4.35	4.3
Maintenance	Equipment Servicing	4.25	4.35	4.3
	Building Maintenance	4.25	4.35	4.3

Table 3: Delphi Consensus Ratings (Round 3, 5-point Likert Scale)

Residents' survey responses corroborated expert findings. For instance, temperature variations received the highest aggregate score (4.36), followed by solar radiation (4.25) and humidity (4.15) (Table 4). Air conditioning systems (3.84) and operating hours of appliances (4.04) were rated highly, especially in Ikeja, where mechanical cooling is more prevalent.

Factor Category	Sub-factor	Ado-Ekiti	Ibadan	Ikeja	Aggregate
Climatic	Temperature variations	4.22	4.35	4.52	4.36
	Solar radiation	4.05	4.24	4.45	4.25
Equipment	Operating hours of appliances	3.64	4.05	4.42	4.04
	Air conditioning systems	3.15	3.85	4.52	3.84
Behaviour	Natural ventilation usage	4.25	3.92	3.65	3.94
Socioeconomic	Energy cost	4.24	4.42	4.65	4.44

Table 4: Resident Ratings of Energy Consumption Factors (5-point Likert Scale)

Notably, natural ventilation usage was rated highest in Ado-Ekiti (4.25) but lowest in Ikeja (3.65), reflecting reduced feasibility in high-density urban settings.

C. BARRIERS TO ENERGY EFFICIENCY IMPLEMENTATION

Respondents identified significant barriers across five domains. Financial constraints were most severe, with initial investment costs (Mean = 4.48) and limited access to finance (4.34) rated as the highest (Table 5). Technical barriers, such as limited expertise (4.21) and lack of skilled personnel (4.14), were more acute in Ado-Ekiti than in Ikeja, suggesting a capacity gap in less urbanised areas.

Barrier Type	Specific Barrier	Ado-Ekiti	Ibadan	Ikeja	Overall Mean
Financial	Initial investment cost	4.65	4.48	4.32	4.48
	Limited access to finance	4.52	4.35	4.15	4.34
Technical	Limited technical expertise	4.42	4.25	3.95	4.21
	Lack of skilled personnel	4.35	4.18	3.88	4.14
Awareness	Limited information	4.48	4.32	4.05	4.28
	Low energy efficiency awareness	4.42	4.25	3.95	4.21
Market	High product costs	4.42	4.25	3.92	4.2
Regulatory	Weak policy framework	4.38	4.22	3.95	4.18

Table 5: Barriers to Energy Efficiency Implementation (5-point Likert Scale)

Awareness-related barriers were also pronounced, with "limited information" (4.28) and "low energy efficiency awareness" (4.21) indicating a critical knowledge gap, particularly in Ado-Ekiti.

D. WEIGHTED ENERGY EFFICIENCY FRAMEWORK

Using expert ratings, a weighted framework was developed. The six primary components contribute nearly equally to overall energy efficiency, with a standard deviation = 0.15 (Table 6), underscoring the need for integrated interventions.

Component	Weight (%)
Building Design	16.83
Maintenance	16.73
Equipment & Appliances	16.71
Occupant Behaviour	16.69
Climatic Factors	16.65
Socioeconomic Factors	16.39
Total	**100**

Table 6: Weighted Components of the Energy Efficiency Framework

Sub-component analysis reveals key priorities within each domain (Table 7). In Building Design, the envelope (33.98%) and ventilation (33.59%) dominate. For Equipment & Appliances, AC systems account for 21.03% of influence. Energy cost is the leading socioeconomic factor (20.94%), while temperature control is a key climatic consideration (21.11%).

Component	Top Sub-components (Weight %)
Building Design	Building Envelope (33.98), Ventilation Features (33.59), Spatial Configuration (32.42)
Climatic Factors	Temperature Control (21.11), Humidity Management (20.63), Solar Radiation (19.68)
Occupant Behaviour	Occupancy Patterns (20.34), Natural Ventilation Usage (20.29)
Equipment & Appliances	AC Systems (21.03), Lighting Fixtures (20.32)
Socioeconomic	Energy Cost (20.94), Household Income/Size (19.98 each)
Maintenance	Building Maintenance (25.36), Equipment Servicing (25.36)

Table 7: Sub-component Weights Within Each Primary Component (%)

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V. DISCUSSION

A. A HOLISTIC, WEIGHTED FRAMEWORK

The near-equal weights of the six components (SD = 0.15) underscore the need for integrated interventions. Unlike the BEEC's narrow focus, this framework recognises that energy efficiency emerges from the interplay of design, climate, behaviour, and economics. For instance, even the best envelope design is undermined by poor maintenance or inefficient appliance use.

The prominence of Maintenance (16.73%) challenges the common focus on new construction. In a region with significant older stock (22.6% of buildings in Ikeja are >20 years), retrofitting and upkeep are critical. Similarly, Occupant Behaviour's high weight validates STST: energy-efficient design must accommodate user practices like natural ventilation usage, which was rated highest in Ado-Ekiti (4.25) but lowest in Ikeja (3.65)—likely due to urban constraints.

B. URBAN GRADIENT AND CONTEXTUAL ADAPTATION

The framework supports tiered implementation:

- ✓ Low-density (Ado-Ekiti): Emphasise passive strategies (natural ventilation, shading).
- ✓ Medium-density (Ibadan): Balance passive and active systems.
- ✓ High-density (Ikeja): Optimise mechanical systems (AC efficiency, envelope performance).

This aligns with findings that sliding windows and glass/aluminium frames better for thermal control are more common in urban areas, yet shading remains underutilised (only 5% of buildings in the pilot study had shading).

C. POLICY IMPLICATIONS

The BEEC's equal-weighting approach is empirically unsupported. Instead, policies should:

- ✓ Prioritise envelope performance and ventilation in codes.
- ✓ Introduce differentiated standards by climate zone and urban density.
- ✓ Integrate behavioural nudges (e.g., energy labelling, awareness campaigns).
- ✓ Address financial barriers through subsidies or green mortgages.

The low consensus on Equipment Efficiency Ratings (aggregate = 3.48) and Environmental Awareness (3.49) reveals a critical awareness gap, especially in rural areas, highlighting the need for education.

VI. CONCLUSION

This study presents a holistic context-specific energy efficiency framework for residential buildings in Southwest Nigeria. By integrating technical, behavioural, and socioeconomic dimensions through empirical weighting, it moves beyond the limitations of existing codes like the BEEC. The framework's emphasis on maintenance, occupant behaviour, and urban-context adaptation offers a replicable model for tropical developing regions.

Key contributions include:

- ✓ Quantification of six equally critical energy efficiency components.
- ✓ Identification of sub-component priorities (e.g., envelope over lighting).
- ✓ Evidence of urban-rural gradients in barriers and design practices.
- ✓ A tiered implementation strategy for policymakers.

Future work should test the framework's predictive accuracy through energy simulations and pilot retrofits. Nonetheless, this study provides a foundation for achieving SDG 11 in Nigeria and similar contexts where sustainable cities must be built not just with efficient materials, but with people and place in mind.

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