Managing the Implementation of Energy Efficiency Frameworks in Residential Buildings: A Delphi-Weighted Approach to Technology Management in Southwest Nigeria

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ABSTRACT

The management of energy-efficiency adoption in residential buildings remains a critical challenge in emerging economies, where institutional fragmentation, weak regulatory enforcement, and limited technical capacity impede effective implementation of technologies. This study develops and validates a weighted energy efficiency framework for residential buildings in Southwest Nigeria, a region characterised by a tropical humid climate and a rapidly urbanising built environment. Using a sequential mixed-methods design, the study applied a three-round Delphi technique among academic and industry experts, complemented by a structured questionnaire survey of 1,149 residential households across three urban centres: Ado-Ekiti, Ibadan, and Ikeja. Principal component analysis was employed to quantify the relative weights of six framework components: Building Design (16.83%), Maintenance (16.73%), Equipment and Appliances (16.71%), Occupant Behaviour (16.69%), Climatic Factors (16.65%), and Socioeconomic Conditions (16.39%). The near-equal distribution of component weights reveals that energy efficiency in the region is governed by an integrated set of technical, behavioural, and managerial factors, rather than by any single dominant variable. Financial barriers (mean = 4.48), awareness deficits (mean = 4.28), and regulatory weaknesses (mean = 4.18) were identified as the most significant systemic impediments to framework adoption. From a technology management perspective, the findings challenge prevailing single-factor policy interventions and argue for multi-dimensional, context-sensitive implementation strategies. The validated framework offers both a diagnostic instrument and a management roadmap for practitioners and policymakers seeking to close the energy efficiency gap in tropical urban settings.

Keywords: *energy efficiency; technology management; Delphi method; framework development; residential buildings; Nigeria; tropical climate*

1. INTRODUCTION

The imperative to manage energy consumption in the built environment has moved decisively from a technical engineering concern to a central problem in technology and innovation management. Buildings account for approximately 40% of global final energy consumption and nearly one-third of worldwide greenhouse gas emissions [1]. In Sub-Saharan Africa, these pressures are intensified by rapid urbanisation, acute infrastructure deficits, and the absence of institutionally embedded energy management systems. Nigeria, as Africa's most populous nation and one of its largest energy consumers, exemplifies the governance and management challenges that confront energy efficiency transitions in emerging economies.

The country's formal policy response to the National Building Energy Efficiency Guideline (BEEG) of [2] and the subsequent Building Energy Efficiency Code (BEEC) of [3] has produced a limited measurable impact. Research consistently identifies the code's principal weaknesses: an equal-weighting methodology that fails to distinguish the relative contributions of different energy-influencing factors, an absence of region-specific provisions for tropical climatic conditions, and a negligible enforcement capacity [4, 5]. The consequence is a persistent and widening energy efficiency gap, the divergence between optimal and actual energy use that cannot be closed through technical prescription alone.

From a technology management perspective, this gap reflects a deeper problem: the failure to manage the socio-technical transition toward energy-efficient building practices. The Socio-Technical Systems Theory (STST) posits that technological outcomes in any domain are co-determined by technical artefacts, organisational structures, regulatory institutions, and user behaviour [6]. Building energy efficiency is therefore not merely an engineering output; it is the product of a management system. The design and implementation of an effective framework must account for the full range of interacting factors, physical, behavioural, economic, and institutional, and must assign them empirically derived weights that reflect their actual significance in specific regional contexts.

This study addresses that challenge directly. It develops and validates a weighted energy-efficiency framework for residential buildings in Southwest Nigeria, a region comprising six states, accounting for more than 18% of the national population, and a rapidly diversifying urban built environment. The research employs a three-round Delphi expert elicitation technique, structured resident surveys across three cities of contrasting urbanisation levels, and principal component analysis to derive defensible component weights. The outcome is a multi-dimensional management instrument that practitioners, policymakers, and technology managers can operationalise to guide investment decisions, inform regulatory design, and prioritise implementation actions.

The paper makes three specific contributions to the literature on technology and innovation management. First, it shifts the analytical frame from technical building performance to the management of technology adoption systems in low-income tropical contexts. Second, it demonstrates empirically that energy efficiency governance failures in Nigeria are systemic, rooted in institutional, financial, and awareness barriers rather than in technical ones. Third, it produces a validated, context-specific framework with empirically grounded component weights, offering a replicable methodology for developing frameworks in similar emerging-economy settings.

The remainder of the paper is structured as follows. Section 2 reviews relevant literature on energy efficiency frameworks, technology management barriers, and the Nigerian policy context. Section 3 describes the research methodology. Section 4 presents empirical results and framework development. Section 5 discusses implications for technology management theory and practice. Section 6 concludes with recommendations and directions for future research.

2. LITERATURE REVIEW AND THEORETICAL CONTEXT

The energy efficiency gap, the disparity between technically available, cost-effective energy savings and their actual uptake, has long been recognised in the economics literature [7]. Classical economic explanations focus on market failures: information asymmetries, split incentives between landlords and tenants, and the underpricing of negative externalities. These explanations, while valid, are insufficient. They do not account for the organisational, institutional, and behavioural dimensions that determine whether technological solutions are adopted, maintained, and scaled.

The technology management literature offers a more comprehensive lens. Socio-Technical Systems Theory, as applied in building energy research, frames adoption as a process of alignment between three sub-systems: the technical (materials, systems, design), the social (occupant behaviour, cultural practices, community norms), and the institutional (regulatory frameworks, enforcement mechanisms, market structures). [6] demonstrated that technical solutions fail systematically when they are misaligned with the social and institutional sub-systems in which they operate. In the Nigerian context, this misalignment is acute: the BEEC mandates technical specifications that many developers lack the technical capacity to implement and that enforcement agencies lack the resources to monitor.

A related concept is the innovation management challenge of framework development. Frameworks that guide technology adoption require three properties to be effective: empirical grounding in the specific context where they will be applied, multi-dimensionality that reflects the real complexity of the system being managed, and operational usability, the ability to translate diagnostic insights into actionable management decisions [8]. These properties are largely absent from Nigeria's current regulatory instruments, which were developed without systematic empirical validation and apply uniform national standards to a geographically and climatically diverse country.

2.1 Determinants of Building Energy Efficiency in Tropical Climates

The literature identifies six primary categories of factors governing residential building energy consumption in tropical settings. Building design characteristics, including envelope construction, window-to-wall ratio, orientation, and ventilation configuration, are widely regarded as the most consequential physical determinants. [9] found that building-envelope decisions alone account for 30–40% of the variation in thermal loads in tropical residential buildings. [10] demonstrated that facade orientation significantly alters solar heat gain and cooling energy demand, findings directly relevant to the West African context, where buildings frequently exhibit suboptimal orientation due to land use constraints.

Climatic factors constitute the second major category. Temperature, humidity, solar radiation, and wind patterns collectively determine a building's passive cooling potential and the intensity of its mechanical cooling load. The Southwest Nigerian region, classified as a tropical humid dry zone, experiences pronounced seasonal variation in humidity and solar intensity, making climate-responsive design essential but contextually complex.

Occupant behaviour has emerged as an increasingly critical and variable determinant of energy consumption. [11] found that behavioural factors account for up to 30% of variance in residential energy use, even in buildings with identical physical specifications. Equipment and appliances, particularly air conditioning systems, are major drivers of consumption in urban contexts where income and thermal discomfort converge. Socioeconomic factors mediate all of the above: household income determines appliance ownership, educational level influences energy awareness, and energy cost sensitivity shapes behavioural responses to tariff signals.

Finally, maintenance, a frequently neglected dimension in policy frameworks, governs the longevity of energy efficiency gains. Deteriorating building envelopes, poorly serviced HVAC systems, and degraded insulation progressively erode the performance advantages of energy-efficient design. The Nigerian BEEC makes no provision for post-occupancy maintenance management, a gap that this study's framework is designed to address.

2.2 The Delphi Method in Technology Framework Development

The Delphi technique is a structured expert consensus method widely applied in technology management research to develop, weight, and validate frameworks for complex multi-criteria decisions. Its core strengths, iterative feedback, anonymity, and controlled convergence, make it particularly well-suited to contexts where empirical data is sparse and expert judgment must substitute for longitudinal performance data [12]. In building energy research, [13] employed a Delphi approach combined with the Best-Worst Method to identify and weight factors driving energy efficiency in buildings, finding that motivation, education, and awareness ranked among the top management drivers. [4] used a similar Delphi-interview hybrid method to develop a context-based energy efficiency framework for Nigerian residential buildings, though their study stopped short of quantified weighting of framework components. This study advances that body of work by completing the full Delphi cycle three rounds with pre-defined consensus criteria and integrating the expert outputs with a large-scale household survey to produce empirically grounded component weights.

Nigeria's energy governance in the building sector is characterised by institutional fragmentation and a significant implementation deficit. The [3] sets prescriptive standards for four indicators: window-to-wall ratio, lighting systems, roof insulation, and air-conditioning efficiency. Critics have identified three fundamental weaknesses. First, the equal-weighting methodology assigns identical policy priority to factors that research shows to have profoundly different impacts across different climatic zones and building typologies [5]. Second, the code's provisions are insufficiently adapted to the material and construction practices prevalent in Southwest Nigeria, where sandcrete hollow block construction dominates (>90% of the housing stock), and professionally installed insulation is rare. Third, enforcement is hampered by institutional fragmentation between federal, state, and local building control agencies and a shortage of qualified building energy inspectors.

These gaps create the conditions for the adoption–implementation–impact failure chain that characterises many regulatory technology management interventions in developing economies: policies are adopted but not implemented, implemented but not enforced, and enforced but without measurable energy impact. Closing this chain requires a fundamentally different approach, one grounded in regional empirical evidence, structured to reflect the actual relative importance of different factors, and designed for operational use by actors with varying technical capacity.

3. RESEARCH METHODOLOGY

3.1 Research Design and Study Area

This study adopted a sequential mixed-methods design, a strategy suited to framework development research where qualitative expert insight informs the structure and content of quantitative measurement instruments [14]. The design comprised three sequential phases: a systematic literature reviews to establish candidate framework components, a three-round Delphi expert panel to validate and refine those components, and a structured household survey to quantify the relative weights of validated components across three urban study areas. The philosophical positioning of the study is pragmatic realism: acknowledging that energy efficiency in the built environment is an objective, measurable phenomenon, while recognising that its determinants are socially and institutionally mediated and therefore require both quantitative measurement and expert interpretive input for full understanding. This positioning justifies the use of mixed methods and the sequential integration of Delphi and survey data.

The study was conducted in Southwest Nigeria, comprising three state capital cities selected to represent a spectrum of urbanisation levels: Ado-Ekiti (Ekiti State), representing a smaller, lower-density urban centre; Ibadan (Oyo State), representing a high-density, intermediate urban environment; and Ikeja (Lagos State), representing the high-density metropolitan end of the urban continuum. This purposive stratification allows the framework and its component weights to be validated across different urban contexts, increasing their generalisability within the region. Southwest Nigeria is climatically characterised by a tropical humid dry zone, with mean annual temperatures between 24°C and 28°C, relative humidity averaging 75–85%, and high solar radiation intensity throughout the year. These climatic conditions generate strong cooling loads in residential buildings and make passive design strategies, such as natural ventilation, shading, and envelope performance, economically significant management decisions.

3.2 Population, Sampling and Data Collection Instruments

The study population comprised residential households in the three study cities. Using population projections derived from the 2006 National Census base figures and applying a standard growth rate, projected household populations were estimated at 487,547 for Ado-Ekiti, 3,552,000 for Ibadan, and 493,646 for Ikeja. Applying the [15] sample size formula at a 95% confidence level and 5% margin of error, minimum sample sizes of 383, 399, and 383 were determined for the three cities respectively, yielding a combined target of 1,165 households. Following data cleaning, 1,149 complete questionnaires were retained for analysis. A multistage probability sampling procedure was employed. At the first stage, local government areas within each city were stratified and selected using proportionate random sampling. At the second stage, residential neighbourhoods were systematically selected within each LGA. In the third stage, individual households were selected using systematic random sampling from household lists provided by community leaders and from available administrative records. For the Delphi panel, purposive sampling was used to recruit 24 experts from academia and professional practice in the fields of building engineering, energy management, and architectural design 12 from each domain. Eligibility criteria required a minimum of five years of experience in building energy research or practice and demonstrable familiarity with Nigerian building regulations. This panel size is consistent with established guidelines for Delphi studies in building and engineering management research [16].

The Delphi questionnaire was structured around six candidate framework components derived from the literature review: Building Design, Climatic Factors, Occupant Behaviour, Equipment and Appliances, Socioeconomic Conditions, and Maintenance. Each component contained three to six sub-items rated on a five-point importance scale. Panellists were also invited to suggest additional components or sub-items not captured in the initial instrument. The instrument was piloted with three academic peers not participating in the panel to assess clarity and face validity before the first round was administered. The household questionnaire comprised four sections: sociodemographic characteristics; building envelope and physical characteristics; self-assessed energy consumption patterns; and a structured five-point Likert-scale rating section assessing the perceived influence of each framework component and subcomponent on residential energy consumption. Building physical characteristics were supplemented by field observation, in which trained enumerators recorded objective measurements of window type, wall construction material, orientation, height, and shading features for each sampled dwelling.

3.3 Delphi Consensus Protocol

Consensus in each Delphi round was defined by the simultaneous satisfaction of at least two of three criteria: mean score ≥ 4.0 on the five-point scale; inter-quartile range (IQR) ≤ 1.0; and coefficient of variation (CV) ≤ 20%. Items not achieving consensus in a given round were returned to the panel in the subsequent round with aggregated feedback on group ratings and the distribution of responses. Items achieving consensus were retained in the framework and excluded from subsequent rounds. Three rounds were completed, at which point all remaining items had either achieved consensus or been agreed for exclusion by the panel. Pearson moment correlation was computed between academic and practitioner CV values at each round to assess convergence between the two expert groups. Correlation coefficients increased from $r = 0.71$ in Round 1 to $r = 0.89$ in Round 3, indicating strong and improving alignment between the two constituencies as the process progressed. Following completion of the Delphi process, principal component analysis (PCA) was applied to the household survey data to derive empirical weights for the six validated framework components and their constituent sub-items. PCA identifies the variance structure within the data in effect, the dimensions along which households' energy consumption profiles most meaningfully differ and assigns proportional weights to each component based on its contribution to total explained variance. Component weights were calculated as follows:

$$\textit{Component Weight (\%)} = [\textit{Component variance} / \textit{Total variance}] \times 100$$

Sub-component weights were calculated analogously within each primary component, enabling the identification of the specific factors most influential within each domain. This PCA-based approach improves on the current Nigerian BEEC's equal-weighting methodology by grounding component priorities in empirical data from the specific regional context. Barriers to energy efficiency implementation were assessed using a five-point Likert scale in the household questionnaire. Five barrier categories were examined: financial, technical, awareness, market, and regulatory. Mean scores were computed and interpreted using the following impact classification: Very High Impact (4.50–5.00), High Impact (4.00–4.49), Moderate Impact (3.50–3.99), Low Impact (3.00–3.49), and Very Low Impact (1.00–2.99). Barrier scores were compared across the three study cities using descriptive statistics to identify urban-gradient patterns in constraint severity.

4. RESULTS

4.1 Delphi Expert Consensus: Round-by-Round Convergence

Round One of the Delphi process revealed considerable variability in expert assessments, particularly for Occupant Behaviour items (CV = 22.3–25.4%) and Socioeconomic items among practitioners (CV = 21.8–26.4%). Building Design sub-components, Building Envelope, Ventilation Features, and Spatial Configuration, showed higher initial agreement among academics (mean scores 4.15–4.45), reflecting greater convergence on the physical dimensions of energy performance. Air-Conditioning Systems consistently attracted the highest ratings across both expert groups (academics: 4.25; practitioners: 4.65), underscoring its recognised importance as a dominant energy consumer in the tropical context.

By Round Two, consensus achievement improved substantially across most categories. All Building Design factors achieved consensus among academics. Climatic factors showed near-complete consensus, with Temperature (mean = 4.45, IQR = 0.80, CV = 15.5%) and Humidity (mean = 4.35, IQR = 0.65, CV = 12.8%) leading. Wind Patterns and Seasonal Changes remained slightly below consensus thresholds and were carried over to Round Three. The Pearson correlation between academic and practitioner CV values was r = 0.81, indicating strong group convergence.

Round Three produced full consensus across all retained items in both expert groups. Building Envelope emerged as the highest-rated Building Design sub-component (mean = 4.52, IQR = 0.55, CV = 10.8%). Air-Conditioning Systems demonstrated the strongest consensus across all categories (mean = 4.45, IQR = 0.60, CV = 11.8%), and Energy Cost achieved the highest rating among Socioeconomic sub-items (mean = 4.35, IQR = 0.70, CV = 13.4%). The Round Three correlation between academic and practitioner CVs reached r = 0.89, confirming robust expert convergence.

4.2 Resident Assessment: Perceived Influence of Framework Components

Building Design sub-items particularly Building Envelope (aggregate: 3.89), Wall Material (3.84), and Window Type (3.82) achieved consensus across all three cities. Ikeja consistently recorded the highest scores for all design-related items, reflecting greater awareness and implementation of energy-conscious design in the more urbanised context. Natural Ventilation features achieved aggregate consensus (3.75–3.94), with Ado-Ekiti rating natural ventilation usage highest (4.25), consistent with its lower air-conditioning penetration and greater reliance on passive cooling.

Among climatic factors, Temperature Variation emerged as the most influential (aggregate: 4.36), approaching the high-consensus threshold (4.50). Humidity Levels followed closely (4.15). Energy Cost ranked the highest among socioeconomic factors (4.44), reflecting strong sensitivity to electricity tariff volatility. Household Income was also significant (4.16), consistent with its role in mediating appliance ownership and adoption of cooling technologies. Equipment-related factors showed strong consensus for Air-Conditioning Systems (Ikeja: 4.52, high consensus) and moderate consensus for Lighting Fixtures (aggregate: 3.82). Equipment Efficiency Ratings was the only sub-item that failed to achieve consensus at the aggregate level (3.48), indicating that energy labelling awareness remains low across the region, particularly in Ibadan and Ado-Ekiti. Maintenance factors were consistently rated above consensus thresholds, with Material Deterioration achieving the highest aggregate score (3.91) and Building Age at 3.81. These findings underscore the significance of maintenance management as a long-term challenge for energy efficiency governance.

4.3 Weighted Energy Efficiency Framework: Component Weights

Principal component analysis was applied to the household survey data (n = 1,149) covering all six validated framework components. The analysis extracted six components with eigenvalues exceeding 1.0, collectively explaining 100% of the total variance in the dataset. Component weights were computed as the ratio of each component's variance contribution to the total variance, expressed as a percentage, in accordance with the formula specified in Section 3.6. Table 1 presents the six primary components of the validated framework and their empirically derived weights from the PCA. The remarkably narrow range of component weights from 16.39% to 16.83% is a substantively significant finding. It reveals that energy efficiency in Southwest Nigerian residential buildings is governed by a genuinely multi-dimensional system in which no single factor exerts decisive dominance.

Table 1: Weighted Energy Efficiency Framework — Primary Components

Framework Component	Weight (%)	Highest Sub-Component	Sub-Component Weight (%)
Building Design	16.83	Building Envelope	33.98
Maintenance	16.73	Building Maintenance / Equipment Servicing	25.36 (each)
Equipment & Appliances	16.71	Air-Conditioning Systems	21.03
Occupant Behaviour	16.69	Occupancy Patterns	20.34
Climatic Factors	16.65	Temperature Control	21.11
Socioeconomic Conditions	16.39	Energy Cost	20.94
TOTAL	100.00	—	—

Table 1a: PCA Summary — Eigenvalues and Variance Explained by Component

Framework Component	Eigenvalue	% Variance Explained	Cumulative % Variance
PC1 — Building Design	1.010	16.83	16.83
PC2 — Maintenance	1.004	16.73	33.56
PC3 — Equipment & Appliances	1.003	16.71	50.27
PC4 — Occupant Behaviour	1.001	16.69	66.96
PC5 — Climatic Factors	0.999	16.65	83.61
PC6 — Socioeconomic Conditions	0.983	16.39	100.00
Total	**6.000**	**100.00**	**—**

Note: Eigenvalues are back-computed from component weights (Weight% × 6 / 100). All six components exceed the Kaiser criterion (eigenvalue ≥ 1.0), with the exception of PC5 and PC6 which marginally approach unity, consistent with the near-uniform variance distribution across components. Total variance explained = 100%.

Within the Building Design component (16.83%), three sub-components had nearly equal weights: Building Envelope (33.98%), Ventilation Features (33.59%), and Spatial Configuration (32.42%). This distribution implies that design-based energy management cannot be reduced to envelope improvement alone; ventilation strategy and spatial planning are of comparable significance. Within Climatic Factors (16.65%), Temperature Control emerged as the most influential sub-component (21.11%), followed by Humidity Management (20.63%) and Solar Radiation (19.68%). The Socioeconomic component (16.39%, the lowest-weighted) is nonetheless substantial, with Energy Cost (20.94%) and Household Income and Size (19.98% each) as the dominant sub-items. The framework's path analysis revealed distinct implementation emphases across urban contexts. Ikeja's profile, higher air-conditioning penetration, greater building density, and stronger energy cost sensitivity calls for prioritising Equipment Management and Envelope Performance. Ibadan requires balanced attention across Design, Maintenance, and Behaviour sub-systems. Ado-Ekiti's profile, with higher reliance on natural ventilation and lower income levels, warrants greater emphasis on Passive Design, Socioeconomic support mechanisms, and Maintenance capacity building.

4.4 Barriers to Framework Adoption and Implementation

Table 2 summarises the impact ratings of barriers identified across the five barrier categories, averaged across all three study cities. All five barrier categories registered High Impact ratings at the aggregate level, a finding that reinforces the multi-systemic nature of the adoption challenge. Financial barriers were rated most severely (mean = 4.48), with initial investment cost, the upfront capital requirement for energy-efficient materials, systems, or retrofits, rated at 4.52 (approaching Very High Impact) in Ado-Ekiti. This reflects the acute affordability constraint in lower-income urban contexts where households cannot absorb premium costs for energy-efficient design, even when long-term savings are demonstrable.

Table 2: Barriers to Energy Efficiency Implementation — Impact Ratings

Barrier Category	Overall Mean	Impact Level	Principal Sub-Barrier
Financial	4.48	High Impact	Initial investment cost (mean: 4.52)
Awareness	4.28	High Impact	Limited information (mean: 4.28)
Technical	4.21	High Impact	Limited technical expertise (mean: 4.21)
Market	4.20	High Impact	High product costs (mean: 4.20)
Regulatory	4.18	High Impact	Weak policy framework (mean: 4.18)

Awareness barriers (mean = 4.28) reflect a systemic information management failure: households, developers, and contractors lack accessible, trusted, and contextually relevant information on energy-efficient technologies, their costs, and their benefits. Technical barriers (mean = 4.21) indicate a shortage of qualified professionals, architects, engineers, and contractors, who can correctly specify, install, and verify energy-efficient building systems. Market barriers (mean = 4.20), including limited product availability and high costs of energy-efficient materials, reflect supply-side constraints that compound demand-side affordability problems.

Regulatory barriers (mean = 4.18), while rated fifth, are the most systemic conceptually. Weak policy frameworks and limited enforcement capacity undermine all other intervention strategies:

without credible regulation, market incentives are distorted, information provision is fragmented, and technical standards are inconsistently applied. The near-uniform severity of all five barrier categories across the three cities confirms that the adoption challenge is not location-specific but structural.

5. DISCUSSION

The most consequential finding of this study is the near-equal weighting of all six framework components. The narrow range (16.39%–16.83%) is not a methodological artefact but a substantive empirical statement: in Southwest Nigeria, energy efficiency outcomes are determined by a genuinely integrated system in which technical performance, behavioural patterns, institutional conditions, economic constraints, and maintenance practices are mutually constitutive. No single lever design optimisation, regulatory reform, or awareness campaigns in isolation is sufficient. This finding directly challenges the prevailing approach of the Nigerian BEEC, which focuses regulatory attention on four prescriptive technical indicators and assigns them equal weighting. It also challenges the tendency in the technology adoption literature to identify a dominant barrier (typically financial or informational) and design single-focus interventions around it. The data from this study suggest that such approaches are likely to achieve marginal gains at best. Effective technology management in this context requires portfolio interventions simultaneous attention to design, maintenance, equipment management, behaviour change, climate response, and socioeconomic enablement calibrated to the specific urban context.

The three-round Delphi process proved an effective management instrument for navigating the complexity of framework development in a data-sparse environment. The convergence from r = 0.71 in Round 1 to r = 0.89 in Round 3 between the academic and practitioner expert groups demonstrates that the method successfully bridges the research–practice knowledge divide that commonly frustrates adoption of technology management frameworks. Practitioners' initially high ratings for Air-Conditioning Systems (4.65 in Round 1) moderated slightly toward academic assessments by Round 3, while academic ratings for Socioeconomic factors increased, suggesting productive cross-pollination of perspectives. The method's value lies not only in what it produces, validated framework components, but in what it reveals about the knowledge structure of the expert community. The high initial variability on Occupant Behaviour and Socioeconomic items reflects genuine professional uncertainty about how to measure and manage these dimensions in building energy policy, a gap that this study's quantitative weighting exercise begins to close.

The differential adoption profiles across Ado-Ekiti, Ibadan, and Ikeja carry important implications for technology management strategy. Ikeja's higher urbanisation level is associated with greater equipment dependency (particularly air conditioning), stronger energy cost sensitivity, and higher awareness scores across most framework dimensions. These characteristics define a context where equipment management interventions, energy-efficient air-conditioning standards, equipment labelling, and demand-side management programmes are likely to yield the strongest returns.

Ado-Ekiti's lower urbanisation and income levels shift the management priority toward passive design, natural ventilation, building orientation, shading and toward socioeconomic enablement through affordable financing mechanisms. Ibadan's intermediate profile suggests a balanced approach. These context-sensitive strategies cannot be derived from a uniform national code. They require the kind of empirically grounded, regionally differentiated framework that this study provides.

The barrier analysis reveals that effective implementation of the framework requires structural changes to Nigeria's governance architecture for building energy management. Three priority interventions follow from the findings. First, reducing financial barriers demands innovative financing instruments: performance-based subsidies tied to energy-efficiency ratings, green mortgage products, and tax incentive frameworks that reduce the effective upfront cost of energy-efficient design and materials. Second, technical capacity development training programmes for architects, engineers, and building inspectors in energy-efficient design and assessment are a prerequisite for any enforcement-based strategy to function. Third, regulatory reform must extend the BEEC to include regionally differentiated weightings based on empirical data of the kind produced in this study, performance-based compliance pathways that accommodate diverse construction contexts, and post-occupancy maintenance standards that protect the longevity of energy efficiency investments.

6. CONCLUSION

This study has developed and validated a weighted energy-efficiency framework for residential buildings in Southwest Nigeria, using a Delphi expert consensus method, combined with a large-scale household survey and principal component analysis. The resulting framework identifies six components: Building Design (16.83%), Maintenance (16.73%), Equipment and Appliances (16.71%), Occupant Behaviour (16.69%), Climatic Factors (16.65%), and Socioeconomic Conditions (16.39%) whose near-equal empirical weights establish that energy efficiency in this context is a genuinely multi-dimensional management challenge. In the technology management scholarship, this study demonstrates that the adoption of energy-efficiency technologies in residential buildings in emerging economies cannot be adequately governed by prescriptive technical codes or single-factor policy interventions. It requires integrated management frameworks that are empirically calibrated to specific regional contexts, sensitive to the urban gradient within those contexts, and supported by governance architectures that simultaneously address financial, technical, awareness, market, and regulatory barriers. All five barrier categories in this study registered High Impact ratings, confirming the systemic nature of the adoption challenge and the inadequacy of isolated interventions. The validated framework offers both a diagnostic instrument enabling practitioners and policymakers to assess the relative severity of energy efficiency deficits across different dimensions and a management roadmap, providing empirically grounded prioritisation for resource allocation and policy design. The Delphi methodology employed is replicable in other Sub-Saharan African contexts where empirical energy performance data is sparse and where bridging academic and practitioner knowledge is a prerequisite for credible framework development. Future research should extend the framework's application to other climatic zones in Nigeria, validate its weights using longitudinal energy-consumption measurements in instrumented buildings, and explore the feasibility of performance-based compliance pathways within the Nigerian regulatory environment. The integration of remote sensing and GIS-based building stock characterisation with the framework's diagnostic components also offers significant potential for scaling its application at municipal and regional levels.

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