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Evaluating the Role of Advanced Energy-Efficient Technologies in Promoting Sustainability in Nigeria's Construction Industry

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ABSTRAK

Studi ini mengevaluasi dampak teknologi canggih hemat energi terhadap keberlanjutan di sektor konstruksi Nigeria dengan fokus pada pengaruhnya terhadap konsumsi energi, pengurangan biaya, manfaat lingkungan dan dampak sosial. Penelitian ini menggunakan pendekatan kuantitatif dengan menyebarkan kuesioner terstruktur kepada total 123 profesional konstruksi di 150 proyek infrastruktur di Nigeria. Responden terdiri atas arsitek (n=30), insinyur sipil dan struktur (n=38), manajer proyek (n=32), serta spesialis konstruksi lainnya seperti *quantity surveyor* dan staf pendukung (n=23). Analisis mencakup statistik deskriptif, ANOVA dan analisis regresi berganda untuk mengevaluasi hubungan antara adopsi teknologi dan hasil keberlanjutan. Hasil penelitian menunjukkan adanya konsensus kuat diantara responden bahwa teknologi hemat energi menyebabkan penurunan konsumsi energi (rata-rata=4,2; SD=0,83) dan penghematan biaya jangka panjang (rata-rata=4,0; SD=0,92). Manfaat lingkungan dinilai sangat tinggi (rata-rata=4,3; SD=0,68), sementara dampak sosial dianggap kurang signifikan (rata-rata=3,7; SD=0,75). Hasil ANOVA mengungkapkan perbedaan persepsi yang signifikan secara statistik berdasarkan peran professional ($F(3,119)=5,24$; $p=0,002$), dengan arsitek menunjukkan tingkat persetujuan tertinggi terhadap efektivitas teknologi tersebut. Analisis regresi berganda mengidentifikasi bahwa persepsi penghematan biaya ($\beta=0,34$; $p<0,001$) dan dampak lingkungan ($\beta=0,29$; $p<0,001$) merupakan prediktor paling berpengaruh terhadap adopsi teknologi, diikuti oleh kesadaran pemangku kepentingan ($\beta=0,22$; $p<0,001$) dan manfaat sosial ($\beta=0,15$; $p=0,003$). Model ini menjelaskan 76% varians dalam tingkat adopsi ($R^2=0,76$), yang menunjukkan daya penjelas yang kuat. Temuan ini menyoroti peran penting teknologi canggih hemat energi dalam mendorong keberlanjutan di sektor konstruksi Nigeria. Temuan ini juga menekankan perlunya program pendidikan yang terarah dan reformasi kebijakan untuk meningkatkan kesadaran pemangku kepentingan, terutama mengenai manfaat sosial dan kemasyarakatan guna mendorong adopsi yang lebih luas dan inklusif.

Keywords: *cost reduction; environmental impact; Nigerian construction sector; social benefits; sustainability*

ABSTRACT

This study evaluates the impact of advanced energy-efficient technologies on sustainability within the Nigerian construction sector, focusing on their effects on energy consumption, cost reduction, environmental benefits, and social impacts. A quantitative research approach was employed, using structured questionnaires administered to a total of 123 construction professionals across 150 infrastructure projects in Nigeria. The respondents included architects (n=30), civil and structural engineers (n=38), project managers (n=32), and other construction specialists such as quantity surveyors and support staff (n=23). The analysis included descriptive statistics, ANOVA, and multiple regression analysis to evaluate the relationships between technology adoption and sustainability outcomes. The results indicate strong consensus among respondents that energy-efficient technologies lead to reduced energy consumption (mean=4.2, SD=0.83) and long-term cost savings (mean=4.0, SD=0.92). Environmental benefits were rated highly (mean=4.3, SD=0.68), while social impacts were perceived as less significant (mean=3.7, SD=0.75). ANOVA results revealed statistically significant differences in perceptions based on professional roles ($F(3,119)=5.24$, $p=0.002$), with architects showing the strongest agreement regarding the effectiveness of these technologies. Multiple regression analysis identified perceived cost savings ($\beta=0.34$, $p<0.001$) and environmental impact ($\beta=0.29$, $p<0.001$) as the most influential predictors of technology adoption, followed by stakeholder awareness ($\beta=0.22$, $p<0.001$) and social benefits ($\beta=0.15$, $p=0.003$). The model accounted for 76% of the variance in adoption rates ($R^2=0.76$), suggesting robust explanatory power. These findings highlight the critical role of advanced energy-efficient technologies in promoting sustainability in the Nigerian construction sector. They also emphasize the need for targeted educational programs and policy reforms to improve stakeholder awareness, especially of the social and community benefits, to drive broader and more inclusive adoption.

INTRODUCTION

The construction industry is a fundamental component of national development because it provides the buildings, transportation systems, energy facilities, and other physical infrastructure required to support economic activities and improve societal well-being. In Nigeria, the sector supports urban development, employment creation, industrial activity, and the delivery of essential infrastructure. Its importance extends beyond the direct execution of construction projects because construction activities generate demand for materials, professional services, equipment, transportation, finance, and labour. Consequently, improvements in the performance and sustainability of the sector can produce wider economic and social benefits. Despite its developmental importance, the Nigerian construction sector is under increasing pressure to address climate change, energy insecurity, rapid urbanisation, environmental degradation, and the growing demand for buildings and infrastructure. Buildings account for a substantial proportion of global energy consumption and energy-related carbon emissions, making energy efficiency an important pathway for improving the sustainability of the built

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environment. Energy-efficient building technologies can reduce energy demand, improve building performance, lower operating costs, and minimise the environmental effects associated with fossil-fuel-based electricity generation (Hafez et al., 2023).

The need for energy-efficient construction is particularly important in Nigeria, where unreliable grid electricity has encouraged extensive dependence on diesel and petrol generators. This dependence increases operating costs, local air pollution, noise pollution, and greenhouse gas emissions. The combination of rapid construction activity, energy poverty, climate vulnerability, and dependence on off-grid fossil-fuel generation presents significant challenges for the long-term resilience of the Nigerian built environment (Unuigbe et al., 2022). Therefore, the integration of passive design strategies, efficient building envelopes, renewable energy systems, efficient lighting, smart energy-management technologies, and low-energy cooling systems is increasingly necessary. Evidence from Nigeria indicates that appropriate building materials and passive design measures can produce substantial improvements in building energy performance. Okonta (2023), for example, found that the use of insulation and shading devices in residential buildings across different Nigerian climatic zones significantly reduced annual cooling loads and electricity consumption. Such technologies can also improve indoor thermal comfort, reduce dependence on mechanical cooling, and lower the lifecycle operating costs of buildings. These benefits are particularly relevant in Nigeria, where cooling and lighting constitute major components of building energy demand.

However, the adoption of energy-efficient and sustainable construction technologies in Nigeria remains relatively limited. Major barriers include high initial investment costs, inadequate financing, insufficient technical infrastructure, limited awareness, shortages of relevant expertise, weak institutional coordination, and inadequate regulatory enforcement. Oke et al. (2025) identified financial constraints, policy and regulatory deficiencies, insufficient technological infrastructure, limited awareness and education, and stakeholder-related challenges as the principal obstacles to the application of energy-related sustainability principles in Nigerian building projects. Similarly, Chan et al. (2024) found that inadequate technical knowledge, limited workforce expertise, resistance to changes in established practices, insufficient government support, and weak sustainability standards restrict the adoption of smart and sustainable construction practices in Nigeria. Financial considerations are especially influential because clients and developers frequently evaluate energy-efficient technologies according to their initial capital costs rather than their lifecycle economic benefits. Although such technologies may reduce energy bills, maintenance requirements, and operational expenditure over time, their comparatively high acquisition and installation costs can discourage investment. This challenge is compounded by limited access to green financing, insufficient fiscal incentives, uncertain returns on investment, and the continued emphasis on lowest-cost procurement in the Nigerian construction sector. Studies of sustainable procurement in

Nigeria similarly indicate that financial limitations, insufficient government commitment, limited stakeholder understanding, and regulatory weaknesses impede the incorporation of sustainability criteria into construction decisions (Ogunsanya et al., 2019; Oyewobi & Jimoh, 2022).

Regulatory and institutional conditions also affect technology adoption. Nigeria has introduced the Building Energy Efficiency Guidelines and the Building Energy Efficiency Code to promote climate-responsive design and establish minimum energy-performance requirements for buildings. Nevertheless, the effectiveness of these instruments depends on professional awareness, institutional capacity, monitoring, compliance assessment, and consistent enforcement. Geissler et al. (2018) emphasised that energy codes in Nigeria must be clearly structured, adapted to local climatic conditions, and supported by practical compliance procedures if they are to achieve meaningful reductions in building energy consumption. Another important constraint is the limited availability of reliable building-performance and energy-consumption data. Assessing the effectiveness of energy-efficient technologies requires information on building geometry, construction materials, occupancy patterns, energy use, cooling demand, and indoor environmental conditions. However, building documentation in Nigeria is frequently incomplete, outdated, poorly preserved, or inconsistent with the completed structure. Omoragbon et al. (2023) found that the lack of reliable as-built information and the limited use of advanced data-capture technologies complicate building-performance evaluation, energy simulation, and retrofit planning. This evidence gap limits the ability of professionals and policymakers to compare technological alternatives, estimate potential savings, and develop evidence-based energy-efficiency interventions.

Notwithstanding these constraints, energy-efficient technologies offer important environmental, economic, and social benefits. Environmentally, they can reduce electricity consumption, dependence on fossil-fuel generators, greenhouse gas emissions, and pressure on energy resources. Economically, they can lower operational expenditure, reduce lifecycle costs, improve asset performance, and protect building users from rising energy prices. Socially, energy-efficient design can improve indoor thermal comfort, air quality, occupant health, satisfaction, and productivity. A systematic review by Hafez et al. (2023) demonstrated that energy efficiency contributes simultaneously to the environmental, economic, and social dimensions of sustainable building performance. The transition towards energy-efficient construction can also stimulate innovation in building materials, architectural design, energy modelling, renewable energy systems, building automation, and professional services. It can create demand for new technical competencies and strengthen collaboration among architects, engineers, builders, quantity surveyors, facility managers, energy specialists, policymakers, financial institutions, and technology providers. Unuigbe et al. (2022) observed that the diffusion of renewable energy technologies in Nigerian commercial buildings is influenced by interacting professional, organisational, economic,

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institutional, and market conditions. This suggests that technology adoption cannot be achieved through technical solutions alone but requires coordinated policy, financing, training, stakeholder engagement, and institutional reform.

The promotion of energy-efficient construction also supports the achievement of Sustainable Development Goal 7, which seeks access to affordable, reliable, sustainable, and modern energy, and Sustainable Development Goal 11, which focuses on inclusive, safe, resilient, and sustainable cities. In the Nigerian context, these objectives are particularly relevant because urban growth and the expansion of the building stock are likely to increase future energy demand. Integrating energy efficiency into the design, construction, operation, and renovation of buildings can therefore contribute to national energy security, climate resilience, emissions reduction, and sustainable urban development. Although previous studies have examined specific aspects of green construction, renewable energy diffusion, sustainable procurement, energy policy, building materials, and environmental performance, the combined influence of advanced energy-efficient technologies on the economic, environmental, and social sustainability of the Nigerian construction sector remains insufficiently understood. Existing research is often restricted to particular technologies, building types, geographical locations, or categories of professionals. There is therefore a need for empirical research that simultaneously evaluates the sustainability outcomes of energy-efficient technologies and the factors affecting their adoption.

This study addresses this gap by evaluating the influence of advanced energy-efficient technologies on the sustainability performance of Nigeria’s construction sector. It examines the extent to which such technologies reduce building energy consumption, lower operational and lifecycle costs, minimise carbon emissions and other environmental impacts, and improve indoor environmental quality and occupant well-being. The study also identifies the principal technological, financial, organisational, professional, institutional, and regulatory factors that facilitate or constrain their adoption. The study is significant because it provides empirical evidence on the relationship between energy-efficient technology adoption and the three interconnected dimensions of sustainability: economic performance, environmental protection, and social well-being. Its findings are expected to support the development of more effective building-energy policies, professional training programmes, financing mechanisms, investment strategies, and industry guidelines. The results may also assist construction clients, policymakers, designers, contractors, developers, and facility managers in making informed decisions concerning the selection and implementation of energy-efficient technologies within the Nigerian built environment. Accordingly, the primary aim of this research is to evaluate the impact of advanced energy-efficient technologies on the sustainability of the Nigerian construction sector. Specifically, the study seeks to assess their effects on energy consumption, operational and lifecycle costs, carbon emissions, resource efficiency, indoor environmental quality, and

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occupant comfort. It further seeks to identify and evaluate the principal drivers and barriers influencing the adoption of these technologies in Nigeria.

LITERATURE REVIEW

Overview of Energy-Efficient Concepts and Importance

Energy efficiency refers to using less energy to provide the same or an improved level of service. In the built environment, it involves designing, constructing, operating, and maintaining buildings so that heating, cooling, lighting, ventilation, water heating, and equipment require the minimum practicable amount of energy without reducing functionality, comfort, health, or productivity. It therefore combines passive design, efficient building envelopes, high-performance equipment, renewable energy systems, intelligent controls, and responsible occupant behaviour. Energy efficiency is central to sustainable construction because buildings represent a major source of global energy demand and energy-related emissions. Improving their performance can reduce resource consumption, operating expenditure, and environmental impacts across the building lifecycle (Hafez et al., 2023). From an environmental perspective, energy efficiency reduces the electricity and fuel required to operate buildings. Where electricity generation depends heavily on fossil fuels, lower energy demand directly reduces greenhouse-gas emissions, local air pollution, and pressure on generation infrastructure. It can also reduce dependence on diesel and petrol generators, which is especially important in Nigeria because unreliable electricity supply encourages extensive self-generation. Energy efficiency therefore supports climate-change mitigation, energy security, and the transition towards a lower-carbon built environment.

Economically, efficient buildings generally have lower energy bills and may require smaller mechanical systems because their cooling and lighting loads are reduced. Although some technologies involve higher initial expenditure, their lifecycle benefits can include reduced utility costs, lower maintenance requirements, longer equipment life, and greater resilience to energy-price increases. Energy efficiency can also stimulate investment and employment in energy auditing, retrofitting, renewable-energy installation, building simulation, automation, and facility management. Socially, well-designed efficient buildings can improve thermal comfort, daylight, ventilation, and indoor air quality, thereby supporting occupant health, satisfaction, and productivity. Passive cooling and effective envelope design are particularly important in hot climates, where excessive indoor temperatures may create discomfort or dependence on costly air-conditioning systems (Zhang et al., 2023).

Sustainability in Construction and Energy Efficiency

Energy efficiency contributes to the environmental, economic, and social dimensions of construction sustainability. Environmentally, buildings with efficient envelopes and systems require less energy for cooling, lighting, and other operational needs. This reduces fossil-fuel consumption and associated emissions. The choice of

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walls, roofs, windows, insulation, shading, orientation, and ventilation strategy is especially important in tropical climates because uncontrolled solar heat gain can substantially increase cooling demand. Nigerian evidence shows that appropriate insulation and shading can improve indoor cooling conditions and reduce annual building-energy consumption across different climatic zones (Okonta, 2023). Energy efficiency should nevertheless be considered from a lifecycle perspective. A material or technology may reduce operational energy while requiring significant energy and resources during manufacture, transportation, installation, maintenance, or replacement. Sustainable assessment should therefore consider embodied impacts, durability, service life, maintenance needs, and end-of-life options rather than evaluating operational savings alone.

Economically, efficient technologies can reduce long-term operating and lifecycle costs. Their financial attractiveness depends on capital cost, energy prices, climatic conditions, operating hours, maintenance expenditure, equipment lifespan, discount rates, and access to finance. In Nigeria, adoption may be constrained when clients and developers prioritise the lowest initial cost instead of whole-life value. Inflation, currency depreciation, limited green financing, and dependence on imported equipment can further weaken investment confidence. Research on sustainable procurement in Nigeria similarly identifies limited sustainability knowledge, governance problems, policy inconsistencies, and unsuitable procurement practices as significant barriers (Ogunsanya et al., 2019). Socially, energy-efficient buildings can provide healthier and more comfortable living and working conditions. Better thermal regulation, daylight, ventilation, and air quality can improve well-being and productivity. Reduced energy expenditure can also lessen energy poverty where savings are passed to occupants. However, these benefits are not automatic. Technologies that raise housing costs or require specialised maintenance may be inaccessible to low-income households. Social sustainability therefore requires affordable, locally maintainable, and context-appropriate solutions.

Energy-Efficient Technologies in Construction

High-performance building envelopes are among the most effective methods of reducing cooling demand. Measures include roof and wall insulation, reflective finishes, external shading, appropriate window-to-wall ratios, low-emissivity glazing, and climate-responsive orientation. Advanced products such as aerogels and vacuum insulation panels provide high thermal resistance with limited thickness, but high cost, installation sensitivity, ageing, and maintenance requirements may restrict their application. In many Nigerian projects, affordable passive measures, locally available materials, roof insulation, shading, and natural ventilation may offer more practical benefits than imported high-technology products. Smart windows and glazing systems can regulate solar heat gain and daylight. Electrochromic windows alter their optical properties when an electrical signal is applied, whereas thermochromic windows respond to temperature. These technologies can reduce cooling and lighting loads, but their effectiveness depends on climate, orientation, control strategy, cost, durability, and user acceptance. Their near-term applicability in Nigeria may therefore be greater in high-value commercial and institutional buildings than in cost-sensitive housing.

Building-integrated photovoltaics incorporate photovoltaic modules into roofs, façades, windows, or shading devices. They perform both a building-envelope and electricity-generation function. Nigeria’s strong solar resource gives these systems considerable potential to reduce dependence on grid electricity and fossil-fuel generators. Their successful deployment, however, requires appropriate orientation, shading control, electrical design, product standards, trained installers, storage planning, safety measures, and reliable maintenance. LED lighting provides a simpler and more accessible efficiency measure. It consumes less electricity and generally lasts longer than incandescent and many fluorescent lamps. Greater savings can be achieved through occupancy sensors, daylight-responsive controls, timers, and zoning. Building automation and smart meters can further improve performance by monitoring energy use and adjusting cooling, lighting, and ventilation according to occupancy and environmental conditions. Nevertheless, complex controls can fail to achieve expected savings when they are poorly commissioned, inadequately maintained, or difficult for occupants and facility managers to operate.

Energy-recovery ventilation systems transfer heat, and sometimes moisture, between incoming and exhaust air streams. They can reduce the energy required to condition fresh air in heavily air-conditioned buildings such as offices, hospitals, hotels, and educational facilities. Their suitability in Nigeria depends on humidity, filtration, condensation control, maintenance, and the actual ventilation load. Green roofs and walls can also improve energy performance through shading, evapotranspiration, and reductions in surface temperature. They may additionally reduce stormwater runoff and urban heat, but their performance depends on vegetation, substrate depth, irrigation, waterproofing, structural capacity, and maintenance. In practical terms, the selection of an energy-efficient technology should be based on measurable performance rather than novelty. Decision-makers should compare expected energy savings, initial cost, maintenance burden, local technical support, user requirements, and compatibility with existing building systems. Technologies also need to be evaluated under actual Nigerian climatic and operational conditions. A system that performs well in a temperate country may deliver different results under high temperatures, humidity, dust exposure, unstable electricity supply, or irregular maintenance. For this reason, demonstration projects, post-occupancy evaluation, and locally calibrated simulation models are necessary before large-scale adoption.

Recent Research Trends, Gaps, and Thematic Critique

Recent research increasingly combines building information modelling, energy simulation, smart metering, automation, machine learning, and predictive controls. BIM-based energy analysis allows designers to compare alternative materials,

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orientations, glazing systems, and mechanical configurations before construction. Data-driven systems can forecast demand, detect equipment faults, and optimise operating schedules. However, their usefulness depends on accurate building information and reliable consumption data. In Nigeria, incomplete drawings, limited metering, weak documentation, and insufficient use of advanced data-capture methods constrain performance assessment and retrofit planning (Omoragbon et al., 2023). Research also shows that technology availability alone does not guarantee adoption. Building codes, procurement rules, fiscal incentives, client demand, professional education, product standards, and institutional enforcement strongly influence implementation. Nigeria's Building Energy Efficiency Code provides an important regulatory foundation, but its impact depends on clear requirements, professional awareness, practical compliance procedures, institutional coordination, and effective enforcement (Geissler et al., 2018). Studies of smart and sustainable construction in Nigeria further identify inadequate expertise, limited technical knowledge, resistance to established-practice changes, insufficient government support, weak standards, and high investment costs as key barriers (Chan et al., 2024).

Another emerging concern is the need to connect technical research with implementation practice. Many studies identify potential energy savings, yet fewer explain how developers, contractors, regulators, financial institutions, and occupants can coordinate adoption. Greater attention is required to financing mechanisms, performance verification, professional certification, procurement criteria, and maintenance responsibility. Without these supporting arrangements, even technically effective solutions may remain limited to isolated projects rather than becoming normal industry practice. Several gaps remain. First, Nigerian studies rarely provide long-term evidence on the actual performance, degradation, maintenance, and adaptability of energy-efficient technologies across the country's climatic zones. Second, many studies focus on energy or carbon outcomes without simultaneously measuring lifecycle costs, indoor environmental quality, health, employment, affordability, and equity. Third, imported technologies are often discussed without sufficient consideration of local skills, supply chains, materials, electricity reliability, and maintenance capacity. Fourth, the informal construction sector remains underrepresented, despite its importance in housing delivery. Fifth, economic assessments do not always test the effects of inflation, exchange-rate movements, financing costs, and equipment replacement. Finally, the gap between predicted and actual energy use is insufficiently examined. Occupant behaviour, construction defects, poor commissioning, equipment changes, and maintenance failures can cause completed buildings to perform differently from design expectations.

These limitations justify an integrated Nigerian study that evaluates environmental, economic, and social outcomes while examining adoption conditions. The present research therefore assesses how advanced energy-efficient technologies affect energy consumption, lifecycle expenditure, emissions, resource efficiency, indoor

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environmental quality, and occupant well-being. It also examines differences across construction roles and identifies the financial, technical, organisational, behavioural, regulatory, and institutional factors that encourage or constrain implementation. By addressing these issues together, the study provides a localised evidence base for policy development, professional training, investment decisions, and sustainable construction practice

METHODS

Research Philosophy, Design, and Rationale for Method Selection

This study adopted an embedded mixed-methods design in which a predominantly quantitative survey was supplemented with qualitative responses obtained from open-ended questionnaire items. The overall study was informed by pragmatism because the research problem required both numerical evidence and contextual explanations from construction professionals. Within this framework, the quantitative strand reflected a positivist orientation by emphasising observable variables, standardised measurement, hypothesis testing, and statistical analysis of the relationships between energy-efficient technologies and sustainability outcomes. The qualitative strand complemented this approach by capturing participants' practical experiences, explanations, and recommendations. Integrating both forms of evidence enables researchers to obtain a more complete understanding than either quantitative or qualitative evidence could provide independently (Guetterman et al., 2020).

The study employed a cross-sectional survey design, with data collected from participants during a defined period. This design was appropriate because the research sought to examine current levels of technology adoption and differences in professional perceptions, rather than changes occurring over an extended period. Cross-sectional designs are useful for measuring characteristics, practices, and associations within a population at a particular point in time, although causal interpretations must be made cautiously because temporal relationships cannot be firmly established (Setia, 2016). The design allowed information to be obtained from professionals associated with different project types and geographical settings across Nigeria. Quantitative responses provided comparable evidence on the economic, environmental, and social effects of energy-efficient technologies, while narrative responses assisted in explaining observed patterns and identifying context-specific implementation challenges.

Sampling Method and Sample Size

The study considered two related units of analysis: construction professionals and the projects with which they had direct professional involvement. A total of 123 construction professionals participated in the survey. These comprised 30 architects, 38 civil and structural engineers, 32 project managers, and 23 other professionals, including quantity surveyors and administrative or technical personnel. Collectively, the respondents provided information relating to 150 construction projects. The project

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sample consisted of 65 residential projects, 52 commercial developments, and 33 civil or public infrastructure projects. Because some professionals reported on more than one project, the number of projects exceeded the number of individual respondents.

A stratified purposive sampling procedure was adopted. The sampling frame was first divided according to project function, comprising residential, commercial, and civil or public infrastructure projects, and geographical context, comprising urban and rural locations. Participants were subsequently selected based on their direct involvement in the planning, specification, installation, management, or evaluation of energy-efficient technologies. Stratified purposive sampling is appropriate where researchers need to obtain information-rich cases while ensuring that important subgroups are represented in the study (Robinson, 2014). However, because participant selection was partly purposive, the findings should be generalised analytically and with appropriate caution rather than treated as estimates derived from a completely random national sample.

The study targeted information from 150 projects, taking account of the size of the accessible project population, the required level of precision, subgroup coverage, and available research resources. Sample-size determination for finite populations should ordinarily consider population size, confidence level, margin of error, anticipated variability, and the statistical analysis to be conducted (O'Neill, 2022). Of the 150 professionals initially approached, 123 returned usable questionnaires, producing a response rate of 82%. This response level reduced the risk of substantial non-response and provided adequate observations for the descriptive and inferential procedures employed in the study. Nevertheless, the adequacy of the sample was assessed not only through the response rate but also through its coverage of the professional, project, and geographical categories relevant to the research objectives.

Data Collection Procedures

Data were collected using a structured questionnaire designed to obtain quantitative measurements and supplementary qualitative information on the adoption and effects of energy-efficient technologies. The questionnaire contained six sections: demographic and professional information; energy consumption; cost savings and lifecycle implications; environmental effects; social benefits; and barriers and drivers influencing technology adoption. The items were developed from the research objectives and relevant literature on building energy efficiency and construction sustainability.

Closed-ended items were measured primarily on a five-point Likert-type scale, allowing respondents to indicate the degree of agreement, importance, occurrence, or perceived effect associated with each statement. Likert-type response formats are suitable for transforming attitudes and professional perceptions into ordered quantitative categories that can be analysed statistically, provided that the items and response anchors are clearly formulated (Jebb et al., 2021). Open-ended questions were included

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at the end of the relevant sections to enable participants to describe implementation challenges, organisational experiences, maintenance concerns, regulatory limitations, and recommendations that could not be adequately captured by predetermined response options.

Before the main survey, the questionnaire was pre-tested with 10 construction professionals drawn from different professional backgrounds, project categories, and locations. The pre-test evaluated item clarity, relevance, comprehensiveness, response options, completion time, and the suitability of terminology for the Nigerian construction context. Pre-testing is an important component of questionnaire development because it can reveal ambiguous wording, misunderstood concepts, missing response categories, and weaknesses in the logical sequencing of questions (Mohorko & Hlebec, 2016). Feedback from the participants resulted in minor revisions to wording, layout, and instructions before the instrument was finalised.

The final questionnaire was distributed electronically through email, professional networks, construction organisations, and relevant institutional contacts. Electronic administration made it possible to reach respondents across Nigeria's geographically dispersed construction industry while reducing printing and travel requirements. Reminder messages were sent at appropriate intervals to participants who had not completed the questionnaire. Evidence from web-survey research indicates that carefully designed invitations and follow-up reminders can improve participation and questionnaire completion rates (Wu et al., 2022). Completed responses were screened for missing data, duplication, response consistency, and eligibility before being included in the analysis. The complete questionnaire and its corresponding measurement items are presented in Table 1.

Table 1. Questionnaire for Assessing Energy-Efficient Technologies in Construction

SN	Question
	Demography
1	What is your age? (Open-ended)
2	What is your gender? (1. Male, 2. Female, 3. Other)
3	What is your highest level of education? (1. High school diploma, 2. Bachelor's degree, 3. Master's degree, 4. PhD or higher, 5. Other)
5	What is your job role? (1. Project Manager, 2. Site Engineer, 3. Architect, 4. Other Construction Professional, 5. Administrative/Support Staff)
6	How many years of experience do you have in the construction industry? (1. Less than 2 years, 2. 2-5 years, 3. 5-10 years, 4. 10-20 years, 5. More than 20 years)
7	What type of construction projects do you primarily work on? (1. Residential, 2. Commercial, 3. Industrial, 4. Infrastructure, 5. Other)
8	What is the size of your organization? (1. 1-50 employees, 2. 51-200 employees, 3. 201-500 employees, 4. 501-1000 employees, 5. More than 1000 employees)
9	What region of Nigeria is your project located in? (1. North, 2. South, 3. East, 4. West, 5. Central)
10	How many projects incorporating energy-efficient technologies have you been involved in? (1. None, 2. 1-3 projects, 3. 4-7 projects, 4. 8-12 projects, 5. More than 12 projects)

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SN	Question
	Energy Consumption
11	I believe that energy-efficient technologies significantly reduce the energy consumption of projects.
12	The projects I've been involved with have documented energy savings from using advanced technologies.
13	Energy monitoring systems are regularly used in my projects to track energy savings.
14	The use of energy-efficient technologies contributes to lower utility bills for the end users.
15	Renewable energy sources (solar, wind, etc.) are effectively integrated into our projects.
16	Energy-efficient practices are a priority from the planning stage of our projects.
17	Clients often request energy consumption data before project approval.
18	There is a significant difference in energy consumption between projects that use energy-efficient technologies and those that do not.
19	Energy-efficient lighting and appliances are standard in projects I work on.
20	The adoption of green building certifications (like LEED, Green Star) influences our project's energy consumption.
	Cost Savings
21	Initial cost concerns are a significant barrier to adopting energy-efficient technologies.
22	The long-term cost savings justify the initial higher costs of energy-efficient technologies.
23	Financial incentives (tax breaks, subsidies) are necessary to promote the adoption of energy-efficient technologies.
24	Clients are aware of the cost benefits of energy-efficient technologies.
25	Energy-efficient technologies have led to a decrease in the overall project costs over time.
26	Maintenance costs for energy-efficient systems are lower than traditional systems.
27	The payback period for investments in energy-efficient technologies is reasonable.
28	There is sufficient financial support from the government for projects that use energy-efficient technologies.
29	The market for energy-efficient materials and technologies is competitively priced.
30	Our company would invest more in energy-efficient technologies if the cost-to-benefit ratio was clearer.
	Environmental Impact
31	The use of energy-efficient technologies in our projects significantly reduces carbon emissions.
32	Our projects comply with national environmental regulations due to the implementation of energy-efficient technologies.
33	We actively measure the environmental impact of our projects (carbon footprint, waste reduction).
34	The environmental sustainability of a project is a major factor in technology selection.
35	Stakeholders are increasingly demanding environmentally sustainable construction practices.
36	Our projects contribute to local biodiversity through sustainable construction practices.
37	The materials used in our construction projects are sourced sustainably.
38	Water-saving technologies are integrated into our projects to reduce environmental impact.
39	Waste reduction strategies are effectively implemented in our construction projects.
40	Our construction practices aim to achieve long-term environmental benefits.
	Social Benefits

SN	Question
41	Energy-efficient technologies improve the quality of life for building occupants.
42	There is a high level of satisfaction among users/occupants regarding the energy efficiency of buildings.
43	The adoption of energy-efficient technologies creates more skilled job opportunities in the construction sector.
44	Our projects involving energy-efficient technologies serve as educational tools for the community on sustainability.
45	The use of energy-efficient technologies promotes a healthier indoor environment.
46	Community engagement is a critical component of our sustainable construction projects.
47	There is an increase in public awareness about sustainability because of our projects.
48	Energy-efficient projects foster a sense of community pride and ownership.
49	Local governments support our energy-efficient projects through policies and initiatives.
50	Implementing energy-efficient technologies helps in achieving social equity in housing.
	Barriers and Drivers
51	Lack of adequate information on energy-efficient technologies is a major barrier to their adoption.
52	High upfront costs deter clients from opting for energy-efficient solutions.
53	There is a general resistance to change within the industry towards new technologies.
54	Availability of subsidies and financial incentives drives the adoption of energy-efficient technologies.
55	Ongoing training and education about energy-efficient technologies are available for our staff.
56	The perceived reliability of energy-efficient technologies influences their adoption rate.
57	Partnerships with technology providers enhance our capacity to implement energy-efficient solutions.
58	Regulatory frameworks and building codes strongly influence our decisions regarding energy efficiency.
59	Client demand is a significant driver for the adoption of energy-efficient technologies.
60	Our organizational commitment to sustainability influences the integration of energy-efficient technologies.

Data Analysis Techniques

Quantitative data were coded, cleaned, and analysed using the Statistical Package for the Social Sciences (SPSS). Before the main analysis, the dataset was screened for missing values, duplicate responses, data-entry errors, outliers, and inconsistencies. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarise respondents' demographic characteristics and their assessments of energy consumption, cost savings, environmental effects, social benefits, adoption drivers, and implementation barriers. Frequencies and percentages were applied mainly to categorical variables, while means and standard deviations were used to describe the distribution and variability of Likert-scale responses.

Inferential statistical procedures were subsequently employed to examine differences and relationships among the study variables. One-way Analysis of Variance (ANOVA) was conducted to determine whether respondents' perceptions of energy-

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efficient technologies differed significantly across professional groups, including architects, engineers, project managers, quantity surveyors, and other relevant personnel. Before interpreting the ANOVA results, the assumptions of independence, approximate normality, and homogeneity of variance were examined. Where a statistically significant difference was identified, an appropriate post-hoc comparison was used to determine the professional groups between which the difference occurred.

Multiple regression analysis was used to estimate the combined and individual influence of selected explanatory variables on the adoption of energy-efficient technologies. The predictor variables included perceived cost savings, environmental benefits, stakeholder awareness, social benefits, institutional support, and identified implementation barriers. The regression model was evaluated using the coefficient of determination, standardised regression coefficients, significance levels, and relevant diagnostic statistics. Multiple regression is appropriate when the objective is to estimate the contribution of several predictors to variation in a continuous outcome while controlling for the effects of the other variables included in the model (Uyanık & Güler, 2013).

Prior to interpreting the regression results, the assumptions of linearity, independence of residuals, homoscedasticity, approximate normality of residuals, and absence of problematic multicollinearity were assessed. Variance inflation factors and tolerance statistics were examined to identify excessive correlations among the predictor variables. Statistical significance was evaluated at the 5% level, corresponding to $p < 0.05$. However, the interpretation of the findings considered the magnitude and direction of the coefficients in addition to statistical significance.

Qualitative responses obtained from the open-ended questionnaire items were analysed thematically. The analysis involved familiarisation with the responses, initial coding, comparison of related codes, development of preliminary themes, review of the themes against the original responses, and the preparation of concise thematic descriptions. Thematic analysis provides a flexible but systematic method for identifying and interpreting recurring patterns of meaning in qualitative data (Braun & Clarke, 2006). The resulting themes were organised under categories such as policy and regulatory constraints, financial limitations, implementation challenges, technical capacity, maintenance concerns, stakeholder awareness, and perceived technological reliability. Representative responses were used where appropriate to explain quantitative patterns, but identifying information was excluded. The qualitative findings were treated as supplementary evidence rather than as an independent qualitative dataset because they were obtained from brief open-ended survey questions. Their principal purpose was to contextualise the statistical results and provide deeper insight into the barriers and facilitators influencing technology adoption.

Ethical Considerations

Ethical approval was obtained from before questionnaire administration commenced. The study was conducted in accordance with the ethical principles of voluntary participation, informed consent, confidentiality, privacy, and responsible data management. Each prospective participant received information explaining the purpose of the study, the nature of the questions, the expected time required for participation, the intended academic use of the findings, and the absence of any penalty for declining to participate. Participants were informed that their involvement was voluntary and that they could discontinue the questionnaire before submission without providing a reason. Informed consent was obtained before respondents were permitted to proceed to the main questionnaire. Effective informed consent requires that participants receive understandable information and have sufficient opportunity to make a voluntary decision regarding participation (Pietrzykowski & Smilowska, 2021).

The questionnaire did not require respondents to provide names or unnecessary personally identifying information. Responses were reported in aggregate form, and qualitative statements were edited where necessary to prevent the identification of individuals, organisations, or projects. Access to the dataset was restricted to the research team, while electronic records were stored in password-protected files. The data were used solely for the stated research and academic purposes and were retained or disposed of in accordance with the applicable institutional data-management requirements. Confidentiality was distinguished from anonymity. Although respondents were permitted to complete the questionnaire without stating their names, complete anonymity could not be guaranteed where email distribution records or professional-network contacts were used to administer the survey. Therefore, any contact details used for questionnaire distribution were kept separately from the analytical dataset and were not used in reporting the findings.

Validity and Self-Report Limitations

Self-administered questionnaires are useful for collecting standardised information from geographically dispersed construction professionals, but they are subject to measurement limitations. The study relied substantially on respondents' accounts of technology adoption, sustainability outcomes, and organisational practices rather than direct energy audits, site inspections, utility records, or independently verified project-performance data. Consequently, some responses may reflect professional perceptions, incomplete recall, or personal interpretations rather than objective building performance. Social desirability bias may have encouraged respondents to overstate the extent to which their organisations adopted sustainable practices or complied with environmental requirements. Conversely, respondents may have understated implementation failures, maintenance problems, or institutional weaknesses that could reflect negatively on their organisations. Social desirability becomes problematic when respondents provide answers, they consider professionally acceptable rather than answers that accurately reflect actual behaviour or conditions (Larson, 2019).

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The use of data obtained from the same questionnaire and respondents may also create common method bias. This may inflate or suppress observed relationships where the predictors and dependent variables are measured using similar response formats at the same time. Procedural measures were therefore incorporated into the questionnaire design, including clear wording, separation of conceptually different sections, protection of respondent confidentiality, and the use of specific rather than excessively abstract items. Common method bias should nevertheless be considered when interpreting regression relationships derived entirely from self-reported measures (Kaltsonoudi et al., 2022). The questionnaire included fact-oriented and context-specific statements concerning observed technologies, project practices, costs, energy use, and implementation experiences. Open-ended questions also allowed respondents to clarify their ratings and describe conditions that might not have been captured by the closed-ended items. However, qualitative explanations from the same respondents should not be considered independent verification of the quantitative responses. They provide interpretive support but do not replace direct performance measurements or external documentary evidence.

Caution is therefore required when interpreting subjective variables such as perceived social benefits, reliability, affordability, stakeholder awareness, and ease of implementation. These assessments may differ according to respondents' professional responsibilities, project experience, organisational culture, access to information, and exposure to energy-efficient technologies. The cross-sectional design also prevents the study from determining whether the reported relationships are causal or whether perceived benefits changed over time. Future studies could strengthen the findings by combining professional surveys with energy-consumption records, lifecycle cost data, carbon calculations, building-performance simulations, physical inspections, or post-occupancy evaluations. Longitudinal analysis would also provide evidence regarding the durability, maintenance, and actual performance of the technologies after installation.

RESULTS AND DISCUSSION

Response Rate and Demographic Information

A total of 150 questionnaires were distributed, of which 123 were completed and considered usable, producing a response rate of 82%. This level of participation provided a substantial dataset for the planned descriptive and inferential analyses. Nevertheless, response rate alone is not a sufficient indicator of representativeness or freedom from non-response bias. The quality of survey findings also depends on whether respondents and non-respondents differ systematically in characteristics related to the study variables (Daikeler et al., 2023). The findings should therefore be interpreted in relation to the adopted sampling procedure and the characteristics of the participating professionals. As presented in Table 2, 70% of the respondents were male, while 30% were female. The predominance of male participants is broadly consistent

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with evidence that women remain underrepresented in professional and technical roles within the Nigerian construction industry. Previous Nigerian research has attributed this imbalance to gender stereotypes, workplace conditions, limited career progression, discriminatory practices, and insufficient institutional support for women entering and remaining in construction professions (Afolabi et al., 2017). However, the observed gender distribution relates specifically to the study sample and should not be interpreted as an exact estimate of the gender composition of the entire Nigerian construction workforce.

The professional-experience profile indicates that 40% of respondents had worked in the industry for more than 20 years. This suggests that a considerable proportion of the responses was obtained from experienced practitioners with prolonged exposure to construction planning, project delivery, technology selection, and building-performance issues. Their experience may strengthen the practical relevance of the findings, particularly regarding implementation barriers and industry practices. Nevertheless, length of service does not automatically guarantee accurate knowledge of all energy-efficient technologies, especially newer systems such as smart controls, advanced glazing, building-integrated photovoltaics, and automated energy-management platforms. The demographic composition should consequently be interpreted as contextual information rather than direct evidence of data validity. The diversity of respondents across professional roles, experience levels, and project categories is more informative when assessing whether the study captured a range of perspectives relevant to energy-efficient technology adoption.

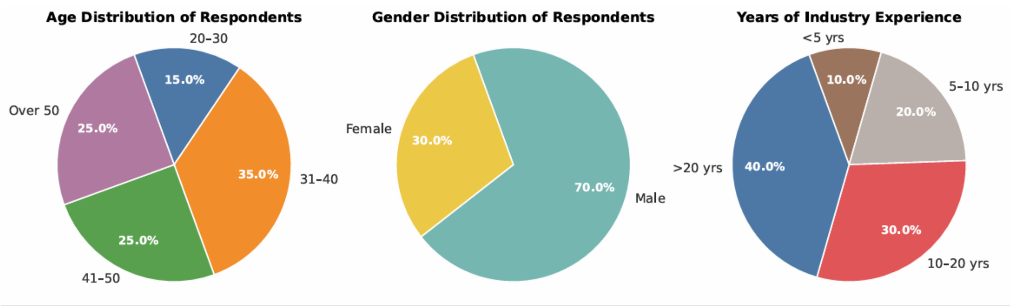

Figure 1. Demographic Characteristics of Respondents

Descriptive Statistics and Insights

The descriptive statistics derived from the survey provide critical insights into the perceptions of construction professionals regarding the adoption and impacts of energy-efficient technologies in the Nigerian construction sector (Table 2). The results highlight a generally positive outlook on these technologies, though certain areas exhibit more varied perceptions.

The mean scores for energy-consumption reduction and long-term cost savings were 4.20 and 4.00, respectively. Both values are above the scale midpoint of 3.00 and indicate broad agreement among respondents that energy-efficient technologies can

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reduce operational energy demand and generate financial benefits over the lifecycle of a building. The energy-consumption result received the second-highest mean score among the assessed dimensions, suggesting that reduced energy use is one of the most readily recognised outcomes of technology adoption. The comparatively low standard deviations indicate that respondents' assessments were clustered relatively close to the mean. This suggests a reasonable degree of consistency among the participating professionals, although the standard deviations should not be interpreted as proof that all respondents held identical views. Evidence from large-scale residential retrofit programmes similarly demonstrates that energy-efficiency interventions can reduce actual energy consumption, although realised savings may differ according to building characteristics, technology type, installation quality, and occupant behaviour (Coyne & Denny, 2021).

Table 2. Descriptive Statistics of Survey Responses

SN	Question	Mean	Standard Deviation
1	Energy Consumption Reduction	4.2	0.83
2	Long-term Cost Savings	4	0.92
3	Environmental Impact Reduction	4.3	0.68
4	Improvement in Social Benefits	3.7	0.75
5	Adoption of Sustainable Practices	3.9	0.8
6	Stakeholder Awareness of Benefits	3.5	0.88
7	Perceived Reliability of Technologies	3.8	0.77
8	Financial Incentives Influence	4.1	0.79
9	Ease of Implementation	3.6	0.85
10	Job Creation	3.9	0.81

The mean score of 4.00 for long-term cost savings indicates that respondents generally recognised the economic value of reduced energy expenditure. However, this result reflects perceived financial benefits rather than independently verified lifecycle-cost data. The economic outcome of any technology ultimately depends on its initial price, maintenance requirements, service life, energy tariffs, replacement costs, financing conditions, and actual operating performance. Consequently, the finding should be interpreted as evidence of positive professional perception rather than direct proof of a specific monetary return.

Environmental Impact

Environmental impact recorded the highest mean score of 4.30. This result indicates strong agreement that energy-efficient technologies can improve environmental performance by reducing electricity demand, dependence on fossil-fuel generation, and associated emissions. The result is particularly relevant in Nigeria, where unreliable grid electricity may require buildings to depend partly on petrol or diesel generators. The high rating suggests that environmental benefits are more visible to respondents than several of the social and institutional outcomes examined in the study. Commercial-building retrofit research has shown that properly selected interventions can improve energy performance while also supporting indoor environmental conditions, although poorly integrated measures may produce trade-offs between energy savings and air quality (Alazazmeh & Asif, 2021). The present finding therefore supports an integrated approach in which reductions in energy demand are assessed alongside ventilation, occupant comfort, and indoor environmental quality.

Social Benefits and Stakeholder Awareness

Social benefits and stakeholder awareness recorded lower mean scores of 3.70 and 3.50, respectively. Both scores remain above the neutral midpoint, showing that respondents generally acknowledged these dimensions. However, the lower ratings indicate that the social implications of energy-efficient construction and the level of stakeholder knowledge were less strongly recognised than energy, economic, and environmental benefits. Social outcomes may include improved thermal comfort, better indoor air quality, reduced exposure to generator noise and emissions, lower household energy expenditure, improved productivity, and healthier indoor environments. These outcomes are often more difficult to measure because they may emerge gradually and depend on occupant characteristics, building operation, and behavioural responses. Empirical evidence indicates that residential energy retrofits can improve comfort and some health-related outcomes, but the nature and magnitude of these benefits vary considerably across buildings and interventions (Fisk et al., 2020).

The stakeholder-awareness mean of 3.50 suggests that knowledge of available technologies, costs, benefits, maintenance requirements, and performance standards remains uneven. Recent Nigerian research has similarly identified a gap between awareness of green construction policies and their practical implementation. This indicates that general familiarity with sustainability does not necessarily lead to project-level adoption (Oke et al., 2025).

Reliability and Implementation

The mean score of 3.80 for perceived reliability indicates moderately positive but less uniform confidence in the performance of energy-efficient technologies. This variation may reflect differences in respondents' direct experience with particular products, project types, installation conditions, maintenance arrangements, and technical support. Concerns about reliability may arise where imported technologies are not adequately adapted to local climatic conditions, spare parts are difficult to obtain, installers lack specialised training, or building operators are unable to maintain complex systems. The finding suggests that adoption decisions are influenced not only by expected energy savings but also by confidence that technologies will continue to function throughout their expected service lives. Evidence on smart and green construction materials similarly shows that architects and engineers can influence adoption by providing technical information, engaging clients in decision-making, and

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communicating the long-term performance of new solutions (Rajendra & Mohanasundaram, 2024).

ANOVA Results

A one-way Analysis of Variance was conducted to determine whether perceptions of energy-efficient technologies differed across professional roles. The independent variable was job role, comprising architects, engineers, project managers, and other construction professionals. The dependent variable was the composite perception score calculated from the relevant Likert-scale items measuring the perceived effectiveness and benefits of energy-efficient technologies. As shown in Table 3, the between-group sum of squares was 15.36, with three degrees of freedom, producing a mean square of 5.12. The within-group sum of squares was 117.44, with 119 degrees of freedom, producing a mean square of approximately 0.987. Based on these values, the recalculated result was statistically significant, $F(3,119)=5.19$, $p=0.002$.

This result indicates that at least one professional group had a mean perception score that differed significantly from another group. The finding does not mean that professional role explained all differences in respondents' perceptions. Rather, it shows that the observed between-group variation was sufficiently large relative to the variation within the groups to reject the null hypothesis of equal group means at the 5% significance level.

Table 3. ANOVA Results for Job Role Impact on Perceptions of Energy Efficiency

SN	Source of Variation	Sum of Squares	DF (Degrees of Freedom)	Mean Square	F Value	p-Value	Significance
1	Between Groups	15.36	3	5.12	5.24	0.002	Yes
2	Within Groups	117.44	119	0.99			
	Total	**132.8**	**122**				

Post-hoc comparisons using Tukey's Honestly Significant Difference test reportedly showed that architects had significantly higher composite perception scores than engineers and professionals classified under the "other" category at $p < 0.05$. Project managers recorded intermediate scores, with no statistically significant difference reported between them and the other groups. This result may reflect differences in professional responsibilities. Architects are commonly involved during project conception, spatial planning, material selection, envelope design, daylighting, shading, and the specification of passive and active energy systems. These responsibilities may provide greater exposure to the expected benefits of energy-efficient technologies. Engineers and site-based professionals may place comparatively greater emphasis on constructability, system reliability, installation difficulties, capital costs, maintenance, and compliance with project schedules.

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Nevertheless, professional explanations should be treated as interpretations rather than direct statistical findings. The Tukey test establishes where mean differences occurred but does not explain why they occurred. The post-hoc table, including group means, mean differences, confidence intervals, and adjusted p-values, should therefore be included in the manuscript or supplementary material to support the reported comparisons. The significant professional variation indicates that general awareness programmes may be insufficient. Training and communication strategies should respond to the different responsibilities of architects, engineers, project managers, contractors, and other construction personnel. Architects may require more advanced design and simulation tools, while engineers and field personnel may benefit from practical guidance on installation, testing, commissioning, maintenance, and performance verification.

Regression Analysis

A multiple regression analysis was conducted to examine the influence of four independent variables perceived cost savings, environmental benefits, social benefits, and stakeholder awareness on the dependent variable: the adoption of energy-efficient technologies**.** The regression model is expressed as::

$$Adoption\ Rate = \beta_0 + \beta_1\ (Cost\ Savings) + \beta_2 (Environmental\ Impact) + \beta_3 (Social\ Benefits) + \beta_4 (Stakeholder\ Awareness) + \varepsilon \quad \text{.....................................}(1)$$

Where:
Adoption Rate is the dependent variable representing the adoption of energy-efficient technologies.
β_0 is the intercept.
β_1, β_2, β_3, and β_4 are the coefficients for cost savings, environmental impact, social benefits, and stakeholder awareness, respectively.
ε is the error term.

The estimated regression equation based on the study's findings is as follows:

$$Adoption\ Rate = 0.65 + 0.34 (Cost\ Savings) + 0.29 (Environmental\ Impact) + 0.15 (Social\ Benefits) + 0.22 (Stakeholder\ Awareness)$$

The model produced an (R^2) value of 0.76, indicating that the four predictors collectively explained 76% of the observed variance in the reported adoption measure. This represents substantial explanatory capacity. However, the adjusted (R^2), overall regression F-statistic, degrees of freedom, and model probability value should be reported before the statement that the overall model was statistically significant can be fully verified. All four predictors had positive and statistically significant coefficients. Holding the other variables constant, a one-unit increase in perceived cost savings was

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associated with an estimated 0.34-unit increase in the adoption score. A one-unit increase in perceived environmental benefits was associated with a 0.29-unit increase, while equivalent increases in stakeholder awareness and social benefits were associated with increases of 0.22 and 0.15 units, respectively. The unstandardised coefficients should be used to construct the regression equation. The standardised beta coefficients should be used to compare the relative influence of predictors measured on different scales. Based on the standardised coefficients, cost savings was the strongest predictor (β=0.40), followed by environmental impact (β=0.35), stakeholder awareness (β=0.25), and social benefits (β=0.18).

Table 4. Results of Regression Analysis

SN	Predictor	B	Standard Error	β	t-Statistic	p-Value
1	Constant	0.65	0.21		3.1	0.002
2	Cost Savings	0.34	0.05	0.4	6.8	<0.001
3	Environmental Impact	0.29	0.04	0.35	7.25	<0.001
4	Social Benefits	0.15	0.05	0.18	3	0.003
5	Stakeholder Awareness	0.22	0.04	0.25	5.5	<0.001

Figure 2 provides a visual summary of the standardized beta coefficients. It clearly illustrates the relative strength of each predictor**,** emphasizing the dominant influence of economic and environmental considerations over social and awareness-based factors in determining technology adoption rates. This visual distinction complements the numerical findings without redundancy, aiding in stakeholder interpretation and strategic priority-setting.

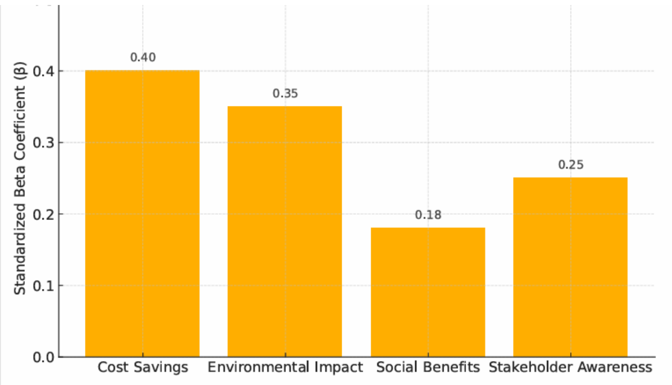

Figure 2. Standardized Regression Coefficients Predicting Technology Adoption

Discussion of Findings

The findings show that respondents strongly associated energy-efficient technologies with reduced energy consumption and long-term financial savings. These perceptions are understandable within the Nigerian construction context, where electricity costs, generator fuel, maintenance expenditure, and unreliable supply can impose substantial operational burdens on building owners and users. Energy-efficient technologies may therefore be viewed not only as environmental interventions but also as mechanisms for reducing recurrent expenditure and improving building resilience. The cost-savings result was further supported by the regression analysis, in which perceived economic benefit produced the strongest standardised coefficient. This suggests that construction stakeholders may be more willing to adopt energy-efficient systems when they can clearly understand the financial return. Research on green-building finance similarly identifies anticipated economic returns, clear regulatory conditions, and improved awareness as important drivers of investment in environmentally responsible buildings (Akomea-Frimpong et al., 2022).

Environmental impact received the highest descriptive mean and was the second-strongest regression predictor. This indicates that respondents recognised the potential of energy-efficient technologies to reduce energy demand, emissions, and environmental pressure. However, a high perception score does not necessarily demonstrate that measured emissions have been reduced across the sampled projects. Such a conclusion would require energy records, emission factors, system-performance data, or comparative building assessments. The lower ratings for social benefits and stakeholder awareness indicate that these dimensions have not received the same level of recognition as direct economic and environmental outcomes. Social benefits may be less visible because they include outcomes such as comfort, health, satisfaction, productivity, and affordability, which are more difficult to convert into conventional financial measures. The finding demonstrates the need to expand sustainability evaluation beyond energy and cost indicators.

The ANOVA result shows that perceptions differed significantly according to professional role. Architects reported more favourable assessments than some other groups, potentially because design-stage professionals are directly involved in decisions concerning building orientation, envelope performance, glazing, shading, material selection, and technology specification. Site engineers and field personnel may encounter different realities, including installation complexity, defective products, limited technical support, programme pressures, and maintenance concerns.

This professional variation supports the development of role-specific interventions rather than uniform training for all participants. Studies of sustainable building processes have shown that inadequate education, unfamiliarity with green technologies, and high initial costs weaken the readiness of project teams, while early sustainability planning and the engagement of personnel with appropriate expertise can improve implementation (Li et al., 2022). The regression findings further indicate that all four predictors were relevant, but their relative influence differed. Cost savings and environmental benefits had the strongest effects, while awareness and social benefits made smaller but still significant contributions. This means that financial and environmental arguments may generate initial interest, but knowledge, institutional

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learning, and appreciation of wider social value remain necessary for sustained adoption.

Stakeholder awareness should therefore not be treated as a secondary issue simply because its standardised coefficient was lower. An organisation may recognise that a technology is potentially profitable but remain unable to select, install, commission, operate, or maintain it properly. Awareness must include practical knowledge of available products, lifecycle costs, performance standards, procurement requirements, maintenance obligations, and local technical support.

Policy Implications and Practical Recommendations

The findings have several implications for government institutions, professional bodies, educational institutions, construction organisations, financial institutions, and clients. Government agencies should develop coordinated financial and regulatory measures that reduce the initial burden of adopting energy-efficient technologies. Relevant measures may include targeted tax relief, concessional green loans, loan guarantees, performance-based grants, accelerated planning approval, and incentives linked to verified energy performance. International evidence identifies financial incentives, reliable information on costs and benefits, mandatory regulations, and green rating systems as important strategies for promoting green-building technologies (Chan et al., 2017).

Professional bodies, including the Nigerian Institute of Architects, the Nigerian Society of Engineers, the Nigerian Institute of Building, the Nigerian Institute of Quantity Surveyors, and COREN, should strengthen continuing professional development on energy-efficient design and construction. Training should be tailored to professional responsibilities and should combine theoretical instruction with demonstrations, case studies, simulation, installation, commissioning, performance measurement, and maintenance. Construction firms should strengthen organisational capacity by assigning responsibility for sustainability performance, introducing lifecycle-cost analysis, establishing internal benchmarks, and documenting project energy outcomes. Sustainability requirements should be incorporated from project conception rather than added after major design and procurement decisions have been completed.

Universities and other tertiary institutions should integrate energy modelling, passive design, lifecycle assessment, renewable-energy systems, smart-building controls, post-occupancy evaluation, and sustainable procurement throughout architecture, engineering, building, quantity-surveying, and project-management curricula. Sustainability education is most effective when it is embedded across built-environment programmes rather than treated as an isolated elective subject (Opoku, 2018). Public-awareness programmes should also target developers, clients, facility managers, occupants, and communities. These programmes should explain not only environmental benefits but also operating-cost savings, thermal comfort, indoor air quality, resilience, maintenance, and property performance. Nigerian evidence showing a disconnect between policy awareness and practical implementation demonstrates that information campaigns should be linked to enforcement, financing, technical guidance, and demonstrable projects.

Contribution to Knowledge

This study contributes Nigeria-specific empirical evidence on the perceived environmental, economic, and social effects of energy-efficient technologies. Its principal contribution lies in combining descriptive assessment with professional-group comparison and multivariable analysis. The ANOVA results show that professional background is associated with significant variation in perceptions, demonstrating that the construction workforce should not be treated as a single homogeneous stakeholder group. The regression results further quantify the relative influence of economic, environmental, social, and awareness-related factors on adoption. The study therefore extends existing discourse by showing that adoption is influenced by both measurable project considerations and less tangible institutional and social factors. It also provides a framework that may be adapted for studies in other Sub-Saharan African construction markets, subject to appropriate contextual and measurement modifications.

Study Limitations and Directions for Future Research

The cross-sectional design captured professional perceptions during a single period and cannot establish how adoption or attitudes changed over time. It also limits causal interpretation because the direction of the identified relationships cannot be confirmed from simultaneous measurements. The sample was restricted to projects with some exposure to energy-efficient technologies. This may have produced selection bias because professionals working entirely on conventional projects may hold different levels of knowledge or acceptance. Geographical imbalance, particularly the possible underrepresentation of rural areas and some northern states, may further limit national generalisability.

The reliance on self-reported data creates the possibility of recall error, social desirability bias, common-method bias, and differences in respondents' interpretation of questionnaire items. The reported benefits should therefore not be treated as substitutes for measured energy consumption, audited lifecycle costs, emissions records, indoor environmental monitoring, or post-occupancy evaluations. Future studies should employ longitudinal designs and monitor buildings before and after the installation of energy-efficient systems. Comparative research across Nigeria's climatic zones would clarify whether technologies perform consistently under different temperature, humidity, solar, and occupancy conditions. Further studies should also integrate professional surveys with utility records, energy simulation, lifecycle-cost calculations, indoor environmental measurements, and occupant interviews. Comparative research across ECOWAS countries could establish whether financial, technical, institutional, and behavioural barriers are shared regionally or require country-specific responses.

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Finally, greater attention should be given to building users and clients. Research involving occupant comfort, health, satisfaction, energy behaviour, willingness to pay, and maintenance practices would provide a more complete assessment of whether energy-efficient technologies achieve their intended outcomes after construction.

CONCLUSION

This study conducted a comprehensive evaluation of the impact of advanced energy-efficient technologies within the Nigerian construction sector, utilizing a quantitative methodology that engaged a diverse range of construction professionals across various roles. The research aimed to uncover the multifaceted benefits and perceptual barriers associated with adopting these technologies. The findings clearly demonstrate that energy-efficient technologies significantly reduce energy consumption and operational costs, aligning with both national and global sustainability goals. Statistical analyses, including regression and ANOVA, identified cost savings and environmental benefits as the primary drivers of technology adoption. The environmental impact of these technologies is particularly noteworthy, reflecting substantial reductions in carbon emissions and enhanced environmental stewardship within the sector.

However, the study also revealed that the social benefits and stakeholder awareness of these technologies are not as well recognized. These aspects received lower mean scores, indicating a critical gap in the appreciation of the broader advantages that energy-efficient technologies can offer. This gap highlights the need for the construction industry to move beyond focusing solely on economic and environmental impacts and to fully embrace the social and community benefits that these technologies can bring.

The implications of these findings are far-reaching. They affirm that energy-efficient construction practices are not only technically viable but also strategically important for Nigeria's path toward achieving the Sustainable Development Goals (particularly SDGs 7, 11, and 13). While economic and environmental considerations are well integrated into the decision-making processes of construction professionals, there is a considerable need to elevate the understanding and valuation of social benefits. To address this gap, it is recommended that targeted awareness campaigns and educational initiatives be developed to articulate the holistic advantages of energy-efficient technologies. These efforts should emphasize the social and community benefits, ensuring that stakeholders understand the full spectrum of impacts. Additionally, improving communication and engagement strategies could substantially increase the adoption of sustainable practices. Policymakers, industry leaders, and educational institutions should collaborate to create comprehensive curricula and continuous professional development programs that cover the entire spectrum of sustainability in construction. Furthermore, policymakers should consider implementing policies that not only incentivize the adoption of energy-efficient technologies but also promote awareness of their social benefits, potentially integrating social impact assessments into the planning and implementation phases of construction projects.

While this study provides valuable and context-specific insights, it is important to acknowledge its limitations. The cross-sectional design offers only a snapshot in time, limiting insights into longitudinal trends. Additionally, the reliance on self-reported data introduces potential bias, and geographic underrepresentation from some regions may affect generalizability. These limitations suggest the need for broader, multi-method, and multi-regional studies. Future research should expand on this study by exploring the long-term performance of energy-efficient technologies in diverse climatic and socio-economic settings across Nigeria and West Africa. Longitudinal research, combined with qualitative insights from end-users, could yield a richer understanding of how technologies are adopted, maintained, and perceived over time. Comparative studies across regions or sectors such as health, education, or public infrastructure may also uncover sector-specific dynamics and opportunities for scaling up sustainable construction practices.

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