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Building Energy Efficiency and Internet of Things: Exploring Barriers and Integrating Factors from an African Variant

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ABSTRACT

This study examines the barriers to adopting Internet of Things technologies to improve building energy efficiency in Ghana. The study addresses the increasing energy demand in the built environment and the need for intelligent, data-driven systems that support real-time monitoring, energy optimisation and sustainable building performance. A quantitative cross-sectional survey design was adopted, targeting building managers, facility managers, energy managers and technical professionals involved in building energy management. Data were collected from 150 respondents using a structured questionnaire and analysed using descriptive statistics, including frequencies, mean scores, standard deviations, and rankings. The findings revealed that all identified barriers recorded mean scores above 4.00, indicating strong agreement that they significantly constrain IoT adoption in buildings. The most critical barriers were high initial implementation costs, stakeholder unawareness, and inadequately skilled professionals. Other important barriers included insufficient financial incentives, limited qualified suppliers or manufacturers, weak legal and institutional support, lack of expertise, slow return on investment, compatibility issues and limitations in existing building designs. The study concludes that IoT adoption in Ghana's building sector depends not only on technological availability but also on financial support, stakeholder education, professional capacity building, regulatory clarity, supplier development and smart-ready building design. The findings provide evidence for policymakers, building owners, and industry practitioners seeking to advance intelligent and energy-efficient buildings in developing-country contexts.

Keywords: Building, Energy Efficiency, Internet of Things, Ghana.

INTRODUCTION

The world faces an unprecedented energy challenge. As cities grow and economies develop, our buildings consume more energy than ever before. This is not just a number on a utility bill; it's a crisis that touches every aspect of our lives. Buildings worldwide consume approximately 32% of all energy produced and contribute to approximately 34% of global greenhouse gas emissions (United Nations Environment Programme, 2025). For developing nations like Ghana, this challenge feels particularly acute.

Walking through Accra or Kumasi today, you'll witness a country in rapid transformation. New buildings rise from the ground daily, air conditioners hum in offices that never needed them before, and families who once relied on natural ventilation now depend on electric fans and cooling systems. Ghana's energy story reflects this rapid change. In 2024, the country consumed 24,688 GWh of electricity, a 4.8% jump from the previous year (Energy Commission of Ghana, 2024). Residential customers alone accounted for 34.8% of this consumption, closely trailing industrial users at 35.6%.

Traditionally, Ghanaian builders have relied on time-tested methods passed down through generations. Thick laterite walls that keep interiors cool, raised floors that promote airflow, and strategic building orientation that harnesses natural breezes. These approaches worked well for centuries. However, modern lifestyles and rapid urbanisation have outpaced these traditional solutions. Today's buildings often prioritise speed and cost over climate-responsive design, resulting in structures that rely heavily on mechanical cooling and artificial lighting (Afful et al., 2025).

This is where the Internet of Things (IoT) enters the picture as a potential game-changer. IoT is not just another technology buzzword; it represents a fundamental shift in how buildings can manage energy. Research shows that IoT technologies can reduce energy consumption by up to 30% while reducing operating costs by 20% (Poyyamozhi et al., 2024). More specifically, IoT-enabled systems have demonstrated average energy reductions of 24.23% in applications like water heater optimisation (Islam et al., 2025). Furthermore, research indicates that smart energy management systems that leverage IoT concepts can significantly enhance energy efficiency and reduce waste in buildings (Hakawati et al., 2024).

This study seeks to unravel these complexities by examining how IoT technologies can transform building energy efficiency in Ghana. We explore not just the technical possibilities, but the human and organisational factors that determine success or failure. Our research addresses six key issues: How do current energy consumption patterns shape the need for IoT solutions? What specific benefits can IoT technologies deliver? What barriers prevent widespread adoption? Which factors facilitate successful integration? How do these elements interact with each other? And most importantly, what can policymakers, building managers, and technology providers do to promote the effective adoption of IoT?

The remainder of the study is structured as follows: Section 2 reviews the relevant literature on IoT in the built environment. Section 3 discusses the study area and the methodology used to identify and categorise barriers. Section 4 presents the study's findings and ensuing discussion. Section 5 puts forward policy and practice recommendations, while Section 6 concludes the study.

LITERATURE REVIEW

The Global Energy Challenge in Buildings

Buildings are energy gluttons. Across the globe, they consume more energy than any other sector, accounting for roughly 40% of total energy use and 30% of CO_2 emissions (Chaudhry et al., 2024; Nejat et al., 2015). This massive appetite for energy reflects the complex needs of modern buildings, including heating and cooling systems that maintain comfortable temperatures year-round, lighting that extends productive hours into the night, elevators that move people efficiently between floors, and numerous appliances that support contemporary lifestyles (Chaudhry et al., 2024).

The pattern varies dramatically between developed and developing nations. The International Energy Agency projects that energy demand in buildings in developing countries will surge by 50% by 2040, making efficiency improvements in these regions critical to global climate goals (IEA, 2021; Bouckaert et al., 2021).

The 2023 National Energy Statistics reveal Ghana's total final energy consumption increased from 5,470 ktoe in 2000 to 8,537 ktoe in 2022, representing significant average annual growth (Energy Commission of Ghana, 2023). The residential sector's contribution is particularly noteworthy, accounting for 41% of total final energy consumed in 2019 and 47% of total electricity generation by 2023. These figures underscore the immense pressure on Ghana's energy infrastructure from the building sector, which directly impacts national energy security, economic stability, and environmental sustainability (Energy Commission of Ghana, 2023).

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Recent research confirms this trend, with studies showing that Ghana's residential electricity consumption has risen to 47% of total generation, while household age-dependency ratios have worsened (Amoako et al., 2023; Santos et al., 2023). The residential sector accounts for approximately 46% of electricity consumption, with the country relying on a diversified energy mix (International Energy Agency, 2023). This escalating demand necessitates effective energy management strategies, both as an environmental concern and a fundamental aspect of national development.

Contemporary research on building energy consumption in developing countries reveals significant challenges and opportunities. Developing countries face unique challenges in collecting and analysing energy data (Li et al., 2025; Debnath & Mourshed, 2018). Similarly, Berardi (2017) emphasised the need for context-specific approaches in developing country settings, given the unique challenges these countries face.

Studies focusing specifically on African contexts reveal additional complexities. Hafez et al. (2023) investigated energy efficiency measures in the building sector across sub-Saharan Africa, identifying significant gaps in implementation and monitoring. Their research emphasises the importance of cost-effective design approaches that consider local climatic conditions and resource constraints. Furthermore, in most residential buildings in Ghana, studies have shown that traditional building practices, although culturally appropriate, often fail to integrate modern energy-efficiency technologies (Chan et al., 2018; Twerefou & Abeney, 2020).

Research on building materials and energy efficiency in African contexts provides additional insights. Okanta (2023) investigated the impact of building materials on energy efficiency in warm, humid climates, finding that local materials can contribute significantly to passive cooling when properly integrated with modern design principles. This emphasises the potential for combining traditional knowledge with contemporary energy management approaches.

Traditional Approaches to Building Energy Efficiency; IoT Revolution in Building Energy Management.

Historically, energy efficiency in buildings, particularly in regions with limited access to advanced technologies, has relied heavily on passive design strategies and conventional construction practices. These methods minimise energy consumption by leveraging natural elements and inherent material properties, often rooted in vernacular architecture and local climatic understanding (Perera et al., 2025).

In the Ghanaian context, traditional practices have been integral to building for generations, shaped by the tropical climate characterised by high temperatures and humidity (Agyekum et al., 2020). Key practices include the judicious use of local materials, such as laterite and timber, which possess inherent thermal properties that contribute to passive cooling and insulation (Okanta, 2023; Jegede & Taki, 2022). Architectural features promoting natural airflow, such as large windows, strategically placed openings, and high ceilings, are common. Building orientation is often optimised to minimise direct sunlight exposure and maximise exposure to prevailing breezes (Okanta, 2023; Perera et al., 2025).

Recent research by Umana et al. (2024) examined traditional building practices across West Africa, finding that indigenous knowledge systems contain a sophisticated understanding of passive energy management principles. Their study demonstrates that traditional techniques, including the strategic use of courtyards, overhangs, and natural ventilation systems, effectively reduce energy consumption without mechanical intervention.

Contemporary studies on passive design strategies in tropical climates provide additional validation for traditional approaches. According to Amos-Abanyie et al. (2009), the traditional vernacular building techniques in Ghana achieve thermal comfort through passive means. Traditional buildings often outperform modern constructions in terms of natural cooling and ventilation effectiveness.

However, research also reveals limitations of traditional approaches in contemporary contexts. Agyekum et al. (2020) examined the effectiveness of traditional energy-efficiency measures in modern Ghanaian buildings, finding that while these approaches remain valuable, they are insufficient to meet the energy demands of contemporary lifestyles and building functions. Their study emphasises the need for hybrid approaches that combine traditional wisdom with modern technologies.

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While these traditional methods are effective to a certain extent, their impact is often limited by increasing energy demands, rapid urbanisation, and the proliferation of energy-intensive modern lifestyles. The lack of standardised building codes and enforcement mechanisms for energy efficiency highlights the need for more advanced, data-driven approaches that complement and enhance traditional practices (Global Alliance for Buildings and Construction, 2024).

IoT represents a paradigm shift in how physical objects interconnect and interact, enabling seamless data collection and exchange over networks. In building energy management, IoT offers unprecedented levels of granular data collection, real-time monitoring, and intelligent control, moving beyond static, rule-based systems to dynamic, data-driven optimisation (Poyyamozhi et al., 2024).

Recent research demonstrates the transformative potential of IoT in building energy management. A comprehensive review published in 2024 identifies IoT as a promising solution for energy management in smart buildings, while noting significant obstacles, including substantial upfront costs (Poyyamozhi et al., 2024). Studies show that IoT-enabled systems can achieve substantial energy savings through applications including real-time energy monitoring, smart lighting systems, HVAC optimisation, occupancy management, predictive maintenance, and integrated building management systems.

Also, smart energy management utilising IoT concepts can enhance energy efficiency and reduce waste in structures. IoTs provide actionable insights and enable automated control, empowering building managers and occupants to make informed decisions and actively participate in energy conservation efforts (Hakawati et al., 2024).

Contemporary systematic reviews provide comprehensive insights into IoT applications in smart buildings. Taboada-Orozco et al. (2024) conducted a systematic literature review on data-driven building management systems, identifying key trends and challenges associated with IoT implementation. Their research highlights the importance of data quality, system integration, and user acceptance in successful IoT deployments.

Advanced IoT applications in building energy management continue to evolve. Islam et al. (2025) developed and tested an IoT platform with smart algorithms for building energy management, demonstrating significant improvements in energy efficiency through cloud-based systems with intuitive user interfaces. Their research indicates that modern IoT platforms can achieve energy savings of 25-30% when properly implemented and maintained.

Research on AI-enabled smart building management systems reveals additional opportunities. According to Bajwa et al. (2024), the use of AI-enabled smart building management plays a transformative role in optimising building operations through predictive analytics, automated control, and intelligent decision-making systems.

Understanding Technology Adoption Through Theoretical Lenses

Several theoretical frameworks underpin IoT adoption in buildings, providing lenses for understanding the factors influencing user acceptance, organisational readiness, and the impact of technological innovation. Key frameworks include the Technology Acceptance Model (TAM), Diffusion of Innovation Theory (DOI), and Technology-Organisation-Environment (TOE) Framework, each offering unique perspectives on technology adoption processes (Venkatesh et al., 2023).

Technology Acceptance Model (TAM): Originally proposed by Davis (1989), the TAM explains how users accept and use technology through Perceived Usefulness (PU) and Perceived Ease of Use (PEOU), which are key determinants of their attitude toward technology use and influence their behavioural intention. Recent extensions of TAM for IoT contexts have incorporated additional constructs such as trust, privacy concerns, and social influence.

Contemporary research has extended TAM for IoT applications in building management. Brar et al. (2022) developed a modified TAM specifically for IoT adoption in indoor disaster management systems, incorporating constructs such as environmental concern, perceived trust, and social media influence on technology adoption.

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Their research found that traditional TAM constructs remain relevant but require adaptation to IoT-specific contexts, with environmental concern serving as a significant moderator of the relationships among perceived ease of use, perceived usefulness, and intention to use IoT-based systems.

Research on IoT acceptance using TAM reveals important insights. Norouzzadeh et al. (2025) investigated factors influencing IoT adoption in smart homes using an extended TAM framework, finding that perceived usefulness and ease of use remain primary determinants. Still, trust and privacy significantly moderate these relationships. Their study emphasises the importance of addressing security concerns in IoT adoption strategies.

Diffusion of Innovation Theory (DOI): Rogers' (2003) theory explains how innovations spread through social systems over time, identifying five adopter categories and characteristics of innovation that affect adoption rates. Recent applications of DOI to IoT adoption have emphasised the importance of relative advantage, compatibility, complexity, trialability, and observability in determining adoption success (Patel et al., 2024).

Contemporary research applying DOI to IoT adoption in buildings provides valuable insights into the diffusion process. Early adopters are typically organisations with greater technical resources and risk tolerance (Parra-Sánchez, 2025). This highlights the importance of demonstration projects and peer influence in accelerating IoT adoption across different organisational contexts.

Studies on the innovative characteristics of IoT adoption reveal specific factors that affect success. According to Kronlid et al. (2024), relative advantage and compatibility are the most important determinants, while complexity represents the primary barrier to adoption. This emphasises the need for simplified IoT solutions that integrate well with existing building systems.

Technology-Organisation-Environment (TOE) Framework: Tornatzky and Fleischer's (1990) framework examines the adoption of technological innovation through technological, organisational, and environmental contexts. Research applying the TOE framework to IoT adoption in developing countries reveals context-specific factors that influence technology acceptance. In developing countries, environmental factors, particularly regulatory uncertainty and infrastructure limitations, play a more significant role than in developed countries (Salleh et al., 2024). This emphasises the need for supportive policy environments and infrastructure development to facilitate IoT adoption.

In examining IoT adoption in manufacturing contexts, each framework contributes unique insights; however, integration provides a more comprehensive understanding of adoption processes (Ahmetoglu et al., 2023). This demonstrates the value of multi-theoretical approaches in complex contexts of technology adoption. These frameworks offer structured approaches for understanding the complexities of IoT adoption in building energy management contexts, providing both theoretical insights and practical guidance for implementation strategies.

Benefits and Barriers of IoT Adoption: Integration Factors

Research identifies numerous benefits of IoT adoption in building energy management, with energy efficiency improvements consistently emerging as the primary advantage. Studies show that energy savings are a significant benefit of adopting smart building technology in developing countries, with potential reductions of 20-30% in overall energy consumption (Sharma et al., 2023). Benefits include enhanced energy efficiency, cost savings, improved occupant comfort, better space utilisation, and enhanced building security and safety.

Additionally, performance expectancy and perceived usefulness are the strongest predictors of IoT adoption intention (Norouzzadeh et al. 2025). As such, benefits vary significantly by building type and user context, with residential applications exhibiting different adoption patterns than commercial implementations. According to Irshad et al. (2020), in challenging climatic conditions typical of developing countries, IoT-enabled climate control can reduce HVAC energy consumption by 35% while improving occupant comfort scores by 25%.

According to Kulkarni et al. (2024, occupant satisfaction and productivity improve in IoT-enabled buildings. The outcomes of this comfort and productivity translate into improved occupant health and economic growth (Awada et al., 2021; Lawal & Rafsanjani, 2022).

However, significant barriers hinder the adoption of IoT, particularly in developing countries. Key barriers, including lack of standardisation, organisational resistance, data quality issues, and legal challenges, are dominant (Poyyamozhi et al., 2024). Studies focusing on developing countries highlight barriers such as complex frameworks, the affordability of IoT, poor IT infrastructure, legal regulations, a lack of knowledge and skilled personnel, and trust issues (Khan et al., 2023).

IoT adoption barriers continue to evolve, especially in developing economies. According to Kumar et al. (2024), financial constraints, technical complexity, and skills gaps collectively constitute the primary impediments. These barriers are often interconnected, requiring comprehensive approaches to address multiple challenges simultaneously (Satyro et al. 2024).

Specific challenges in African contexts include high initial investment costs, inadequate power supply, poor maintenance culture, and lack of well-trained personnel (Kuaban et al., 2024; Waiganjo et al., 2024). These infrastructure and capacity limitations significantly impact the successful deployment and sustainability of IoT systems across the continent. Language barriers and connectivity issues also impact IoT adoption in developing countries (Loriot, 2024). These challenges are particularly pronounced in regions where local languages are not well-supported by IoT interfaces and where internet infrastructure remains unreliable or expensive (Kuaban et al. 2024).

Research on cybersecurity concerns reveals the growing importance of security considerations. Dritsa & Trigka (2025) conducted a comprehensive survey examining cybersecurity barriers to IoT adoption and found that security concerns significantly influence adoption decisions, particularly in sectors handling sensitive data. Their research emphasises the need for robust security frameworks, advanced threat detection mechanisms, and comprehensive user education to address the evolving cybersecurity landscape in IoT ecosystems.

Studies on organisational barriers provide insights into internal challenges. Westergren et al. (2024) investigated the organisational implementation of IoT technologies, finding that change management challenges, staff concerns about technological displacement, and a lack of technical expertise constitute significant internal barriers. Their research emphasises the importance of comprehensive organisational readiness assessment and strategic change management approaches in IoT implementation. The study revealed that successful IoT adoption requires proactive leadership that identifies and accounts for both technological capabilities and diverse stakeholder perspectives, particularly in addressing resistance from workers who may perceive IoT as a threat to their established work practices (Massoud et al., 2025).

Successful IoT integration in building energy management requires consideration of multiple factors spanning technological, organisational, and environmental dimensions. Research emphasises the importance of addressing technological, organisational, and environmental factors simultaneously to achieve successful implementation outcomes (Poyyamozhi et al., 2024).

Contemporary research on integration factors reveals critical success elements. Kitcharoen (2024) examined factors influencing successful IoT integration across manufacturing and distribution companies, identifying management support, technical infrastructure readiness, and staff training as the most critical factors. Their research found that projects addressing all three factors achieved significantly higher success rates than those addressing only one or two factors (Khan et al. 2024).

Technical infrastructure readiness emerges as a fundamental requirement for successful IoT integration. Tondro et al. (2025) investigated the infrastructure requirements for IoT implementation in emerging economies, finding that reliable internet connectivity, a stable power supply, and existing technological capabilities significantly influence the success of integration. Their research emphasises the need for infrastructure assessments and capability maturity evaluations before IoT implementation.

Studies on organisational factors reveal the importance of human elements in the success of integration. Kitcharoen (2024) examined organisational factors affecting IoT integration, finding that management support, staff training, and change management processes are critical determinants of success. Their research emphasises that technical solutions alone are insufficient without appropriate organisational support.

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Research on vendor support and partnerships reveals external factors that influence the success of integration. Poyyamozhi et al. (2024) investigated the role of vendor relationships in IoT integration, finding that ongoing support, training provision, and local presence significantly influence implementation outcomes. Their research emphasises the importance of strategic vendor selection based on support capabilities rather than just technical features.

Studies on phased implementation approaches reveal effective strategies for managing the complexity of integration. Waiganjo et al. (2024) examined phased IoT implementation strategies in African contexts, finding that gradual, pilot-based approaches achieve higher success rates than comprehensive implementations. Their research provides frameworks for structuring phased approaches that minimise risks while demonstrating value (Khan et al. 2024).

Key integration factors include technical infrastructure readiness, organisational support, user training and education, data security and privacy measures, and regulatory compliance. Studies highlight the need for comprehensive approaches that address both technical and non-technical factors (Chen et al., 2025). Successful integration requires stakeholder engagement, phased implementation strategies, and continuous monitoring and evaluation to ensure optimal performance and user satisfaction (Poyyamozhi et al., 2024).

To ensure successful integration, monitoring and evaluation frameworks are crucial. Chen et al. (2025) developed comprehensive frameworks for monitoring the progress of IoT integration, including technical performance metrics, user satisfaction measures, and organisational readiness indicators. This emphasises the importance of continuous assessment and adaptation throughout integration processes.

IoT Implementation Challenges in Developing Countries

The implementation of IoT technologies in developing countries faces unique challenges that differ significantly from those encountered in developed nations. Research conducted across various developing countries reveals consistent barriers to successful IoT adoption, particularly in the building energy management sector (Kumar et al., 2024).

Infrastructure limitations are among the most significant challenges. Many developing countries, including Ghana, face issues with reliable internet connectivity, stable power supply, and adequate telecommunications infrastructure (Kumar et al., 2024). These foundational requirements are essential for IoT systems to function effectively, as they rely on continuous connectivity and power to collect, transmit, and process data. The intermittent nature of power supply in many African countries can disrupt IoT operations, resulting in data loss and system failures that compromise the reliability of energy management systems.

Recent research by Khan et al. (2024) examined infrastructure challenges across construction sites in developing regions, finding that power reliability and connectivity issues significantly affect the success of IoT implementation. Their study emphasises that infrastructure challenges often compound, creating cascading effects that significantly impact system performance and user confidence in IoT technologies.

Financial constraints constitute another major barrier to IoT adoption in developing countries. The high initial investment costs of IoT infrastructure, including sensors, networking equipment, and software platforms, often exceed the budgetary capacity of many organisations (Poyyamozhi et al., 2024). Additionally, the ongoing operational costs, including maintenance, software updates, and technical support, can strain limited financial resources. This economic challenge is particularly acute in the building sector, where return-on-investment periods may be longer than in other industries.

Studies on financial barriers reveal specific challenges in developing countries. Tondro et al. (2024) examined financing challenges for IoT adoption across sub-Saharan Africa, finding that limited access to capital, high interest rates, and currency volatility significantly impact investment decisions. Their research emphasises the need for innovative financing mechanisms tailored to developing country contexts.

Technical expertise and skills gaps represent critical barriers to successful IoT implementation. The complexity of IoT systems requires specialised knowledge in areas such as sensor technology, data analytics, cybersecurity,

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and system integration (Khan et al., 2024). Many developing countries face shortages of qualified technical personnel with the necessary skills to design, implement, and maintain IoT systems. This skills gap extends beyond technical competencies to include project management, change management, and strategic planning capabilities necessary for successful technology adoption.

Research on skills gaps in IoT implementation provides detailed insights. Kitcharoen (2024) conducted a comprehensive assessment of organisational capabilities that affect IoT implementation, identifying significant gaps in adaptive, absorptive, and innovative capabilities. Their research emphasises that capability development often represents the most significant long-term challenge to sustainable IoT adoption.

Regulatory and policy frameworks in many developing countries are often inadequate or outdated, failing to address the unique requirements of IoT technologies. Issues such as data privacy, cybersecurity standards, and cross-border data flows require comprehensive regulatory frameworks that many developing countries have yet to establish (Tondro et al., 2025). The absence of clear guidelines and standards can create uncertainty for organisations considering IoT investments and may hinder widespread adoption.

Studies on regulatory challenges reveal specific issues affecting IoT adoption. Tondro et al. (2025) examined regulatory frameworks in emerging economies, finding that many lack comprehensive IoT-specific regulations, while others have unclear guidelines for technology acquisition. Their research emphasises the need for balanced regulatory approaches that protect stakeholders while encouraging innovation and technology transfer.

Cultural and organisational factors also play significant roles in IoT adoption challenges. Resistance to change, particularly in traditional industries and organisations, can impede technology adoption efforts. The lack of awareness about the benefits and applications of IoT may result in limited support from senior management and stakeholders. Additionally, concerns about job displacement and changes to established work processes can create resistance among employees (Kitcharoen, 2024).

Critical Review and Research Gaps

Despite growing interest in IoT applications for building energy management, several research gaps persist, particularly in developing country contexts. Limited empirical studies examine the specific challenges and opportunities for IoT adoption in Ghana's building sector. Most existing research focuses on developed countries with different technological, economic, and regulatory environments (Chen et al., 2025).

Contemporary systematic reviews reveal significant gaps in research from developing countries. Kumar et al. (2024) conducted a comprehensive review of IoT adoption research, finding that fewer than 15% of studies focus on developing-country contexts, with even fewer examining sub-Saharan African settings. Their research emphasises the need for context-specific studies that address the unique challenges and opportunities in developing countries.

There is a lack of understanding of how traditional building practices in Ghana can be integrated with modern IoT technologies. Research by Afful et al. (2024) highlights the potential for combining indigenous knowledge with contemporary technologies, but empirical studies demonstrating successful integration remain limited. This gap represents a significant opportunity for research that bridges traditional and modern approaches (Poyyamozhi et al. 2024).

Additionally, limited research has examined the cost-effectiveness of IoT solutions in resource-constrained environments, which are typical of developing countries. Chen et al. (2024) note that most cost-benefit analyses focus on developed-country contexts, where labour costs, infrastructure conditions, and economic factors differ. Research specifically addressing economic viability in developing countries is critically needed.

Studies on policy and regulatory frameworks for IoT adoption in developing countries are limited. Tondro et al. (2024) identified significant gaps in understanding of how regulatory environments influence IoT adoption in developing countries, particularly regarding data privacy, cybersecurity, and cross-border data flows. This gap has important implications for policy development and implementation strategies.

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Research on cultural factors affecting IoT adoption in African contexts is particularly limited. Kitcharoen (2024) notes that most technology adoption studies assume Western cultural contexts, potentially missing important cultural factors that influence adoption in African settings. Understanding cultural dimensions of technology adoption represents an important research opportunity.

The lack of context-specific frameworks for evaluating the success of IoT adoption in Ghanaian buildings represents a significant gap that this study aims to address. Existing evaluation frameworks often assume infrastructure and resource conditions typical of developed countries, which can provide inappropriate guidance for implementation in developing countries.

METHODOLOGY

This study employed a quantitative research methodology to examine the barriers to adopting Internet of Things technologies to improve building energy efficiency in Ghana. The study was underpinned by a positivist research philosophy, which assumes that social and technical phenomena can be objectively measured through observable indicators and statistical procedures. This philosophical position was appropriate because the study sought to quantify professional perceptions of barriers to IoT adoption, including financial, technical, institutional, market-related, and human capacity constraints in the building energy management sector.

A cross-sectional survey design was employed because data were collected from respondents at a single point in time. This design was suitable for assessing current professional views on the barriers limiting IoT adoption in Ghanaian buildings. However, the study's cross-sectional design was a limitation, as it did not allow the researcher to examine changes in perceptions, adoption behaviour, or institutional readiness over time.

The target population comprised building managers, facility managers, energy managers, engineers, quantity surveyors, architects, technical officers, and other construction- and energy-related professionals with knowledge of building systems, energy performance, and digital technologies. A convenience sampling technique was used to select respondents who were accessible, willing to participate and professionally relevant to the study. This approach was justified by access, time and resource constraints, although it may limit the generalisability of the findings because respondents were not selected through random probability sampling.

The formula is reliable and has been used in numerous empirical studies across the social sciences, education, and construction management research. In this case, the total population was 240, and a 5% margin of error (0.05) was accepted. Thus, applying Yamane’s formula yields:

$n = 240 / (1 + 240(0.05)^2) = 240 / (1 + 240(0.0025) = 240 / 1.6 = 150$

Therefore, a statistically adequate sample size of **150 respondents** was determined. This approach, as noted by Stamatopoulos (2019), enables economical use of resources without compromising scientific accuracy when capturing the underlying population dynamics. The method also meets the dependability threshold for population-based research.

The collected data were analysed using SPSS. Descriptive statistics, including frequencies, percentages, mean scores, standard deviations, and rankings, were used to examine respondents’ perceptions of barriers to IoT adoption and factors influencing its integration. Since the study relied on self-reported responses, there was potential for social desirability bias, in which participants may have provided favourable responses regarding their knowledge, readiness, or institutional adoption of IoT technologies. Ethical considerations were observed through informed consent, voluntary participation, anonymity, confidentiality, and secure data handling

RESULTS AND DISCUSSION

Presentation of Results

Table 1 presents the results on the perceived barriers to adopting Internet of Things technologies in buildings. The analysis was based on responses from 150 respondents, with all items ranging from 1 to 5. This shows that respondents used the full range of the Likert scale in assessing the barriers. However, the mean scores for all the identified barriers were above 4.00, indicating that respondents generally agreed that the listed factors significantly hinder IoT adoption in buildings. The results therefore suggest that the implementation of IoT technologies for improving building energy efficiency is constrained by several interconnected financial, technical, institutional, market-related, and human-capacity challenges.

The highest-ranked barrier was the initial cost of implementing IoT, which recorded a mean score of 4.30 and a standard deviation of 0.530. This indicates that respondents strongly agreed that the financial requirement for IoT adoption remains a major challenge. IoT systems usually require sensors, controllers, communication devices, data platforms, software applications, and integration with existing mechanical, electrical, and plumbing systems. These requirements involve substantial upfront investment, especially where buildings were not originally designed to accommodate smart technologies. The result implies that although IoT systems may offer long-term benefits such as energy savings, predictive maintenance, improved monitoring, and operational efficiency, the immediate implementation costs continue to discourage many building owners, developers, contractors, and facility managers.

The second-ranked barrier was stakeholders' unawareness, with a mean score of 4.29 and a standard deviation of 0.573. This result indicates that a lack of awareness among key stakeholders is a major limitation to IoT adoption in buildings. Many stakeholders may have a limited understanding of how IoT technologies contribute to energy efficiency, indoor comfort, building performance, real-time monitoring, and data-driven decision-making. In some cases, IoT may be understood only as a general smart-building concept, without a clear appreciation of its practical and measurable benefits. This lack of awareness can reduce confidence in investing in IoT systems, particularly where stakeholders do not clearly understand the relationship between IoT adoption and long-term operational savings. The finding therefore highlights the need for awareness creation, stakeholder education, pilot projects, case studies, and practical demonstrations to improve understanding of IoT-enabled building solutions.

The third-ranked barrier was inadequately skilled professionals, which recorded a mean score of 4.27 and a standard deviation of 0.612. This suggests that respondents strongly agreed that the shortage of competent professionals affects the adoption of IoT technologies in buildings. IoT implementation requires multidisciplinary skills in construction technology, building services engineering, information technology, cybersecurity, data analytics, energy management, installation, operation, and maintenance. The lack of such skills may affect the entire implementation process, from design and planning to installation, commissioning, data interpretation, system maintenance, and performance optimisation. Without adequate numbers of skilled professionals, IoT systems may be poorly installed, underutilised, or improperly maintained, thereby limiting their expected benefits.

The results further show that insufficient financial incentives had a mean score of 4.12 and the lowest standard deviation (0.452). The low standard deviation suggests strong consistency in respondents' views on this barrier. This indicates that respondents generally agreed that the absence of financial support mechanisms, such as grants, subsidies, tax reliefs, rebates, low-interest loans, and energy-performance-based financing, discourages investment in IoT systems. This barrier is closely related to the high initial implementation cost, as financial incentives can help reduce the burden of upfront investment. Where such support is absent, stakeholders may prefer traditional building systems or delay investment in digital technologies.

Similarly, a few qualified suppliers or manufacturers also recorded a mean score of 4.12, with a standard deviation of 0.580. This indicates that the limited availability of reliable IoT suppliers and manufacturers is another significant barrier. Qualified suppliers are important because they provide appropriate devices, technical guidance, installation support, maintenance services, software solutions, and after-sales assistance. Where suppliers or manufacturers are few, stakeholders may face higher procurement costs, delays, uncertainty about product quality, limited technical support, and compatibility challenges. This result suggests that developing a stronger IoT supply chain is necessary to support wider adoption in the building sector.

The barrier related to the lack of legal and institutional support recorded the highest mean score, 4.11, and the highest standard deviation, 0.638. This shows that respondents considered weak legal and institutional frameworks a significant barrier, although their views were more varied than for other items. The variation may be due to differences in respondents' professional experience, organisational background, project type, or exposure to smart building policies. Legal and institutional support is important for addressing issues such as data privacy, cybersecurity, interoperability standards, smart building certification, procurement guidelines, and public sector support. Since IoT systems collect and process building-related data, unclear governance frameworks can create uncertainty and reduce stakeholder confidence.

The results also indicate that lack of expertise recorded a mean score of 4.08 and a standard deviation of 0.517. This finding reinforces the concern that many stakeholders may lack the specialised technical knowledge required to plan, integrate, and manage IoT systems effectively. In addition, slow return on investment recorded a mean score of 4.03 and a standard deviation of 0.538, suggesting that stakeholders may hesitate to adopt IoT because the financial benefits are often realised gradually through reduced energy consumption, lower maintenance costs, and improved operational efficiency.

Finally, IoT compatibility issues and limitations of building designs each recorded a mean score of 4.01, with standard deviations of 0.597. These results show that technical integration and building adaptability remain important concerns. Many existing buildings were not designed with smart technologies in mind and may lack adequate cabling routes, network capacity, equipment space, flexible service systems, or compatibility with modern IoT platforms. This makes retrofitting more costly and technically complex.

Overall, the results show that IoT adoption in buildings is affected by a combination of cost, awareness, skills, supplier capacity, legal support, technical compatibility, and design-related barriers. The three most critical barriers were initial implementation costs, stakeholder unawareness, and a shortage of skilled professionals. This suggests that wider adoption of IoT technologies in buildings will require financial support, stakeholder education, workforce upskilling, supplier development, regulatory clarity, open technical standards, and smart-ready building design. For countries such as Ghana, addressing these barriers is important for promoting energy efficiency, reducing operational waste, improving occupant comfort, and supporting the transition towards sustainable and intelligent built environments.

Table 1: Barriers to IoT technologies in buildings

Code	Statement	N	Min	Max	Mean	Sd	Rank
BR3	Initial costs of implementing IoT	150	1	5	4.30	0.530	1st
BR5	Stakeholders' unawareness	150	1	5	4.29	0.573	2nd
BR2	inadequate skilled professionals	150	1	5	4.27	0.612	3rd
BR7	Insufficient financial incentives	150	1	5	4.12	0.452	4th
BR9	Few qualified suppliers or manufacturers	150	1	5	4.12	0.580	5th
BR4	Lack of legal and institutional	150	1	5	4.11	0.638	7th
BR10	lack of expertise	150	1	5	4.08	0.517	6th
BR6	Slow return on investment	150	1	5	4.03	0.538	8th
BR8	IoT compatibility issues	150	1	5	4.01	0.597	9th
BR1	Limitation of Building designs	150	1	5	4.01	0.597	10th

Source: Field Data, 2026

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DISCUSSION

Table 1 provides an empirical explanation for why IoT adoption in buildings remains difficult despite its potential to improve energy efficiency and building performance. All mean scores were above 4.00, indicating that the 150 respondents generally agreed that the listed issues are serious barriers. This is important because buildings account for about 40% of global energy consumption and 30% of CO2 emissions (Chaudhry et al., 2024; Nejat et al., 2015). In Ghana, rising residential electricity consumption also makes intelligent energy management increasingly necessary (Energy Commission of Ghana, 2023; Amoako et al., 2023). The results therefore suggest that the challenge is not the usefulness of IoT, but the financial, technical, institutional, and human capacity required for adoption.

The highest-ranked barrier was the initial cost of implementing IoT, with a mean of 4.30 and a standard deviation of 0.530. This shows strong agreement that cost remains the most immediate constraint. IoT systems require sensors, smart meters, controllers, communication networks, software platforms and integration with building services. These components create high upfront investment, especially in existing buildings not designed for smart technologies. This aligns with Poyyamozhi et al. (2024), who identify substantial upfront costs as a major obstacle to the adoption of smart building IoT. It also supports Tondro et al. (2024), who report that limited access to capital and high interest rates affect IoT investment in sub-Saharan Africa. Although IoT can generate long-term savings, immediate affordability remains a decisive concern.

Stakeholders' unawareness ranked second, with a mean of 4.29. This indicates that limited understanding among owners, consultants, contractors, occupants and facility managers affects adoption decisions. The finding is consistent with the Technology Acceptance Model, which argues that perceived usefulness and perceived ease of use influence technology acceptance (Davis, 1989; Venkatesh et al., 2023). If stakeholders do not understand how IoT supports real-time monitoring, energy reduction, and operational efficiency, they may be reluctant to invest. The finding also reflects Diffusion of Innovation Theory, which emphasises relative advantage, compatibility and observability as conditions for innovation uptake (Rogers, 2003; Patel et al., 2024). This supports the need for pilot projects, local case studies and practical demonstrations.

Inadequately skilled professionals ranked third, with a mean of 4.27 and a standard deviation of 0.612. This confirms that IoT adoption is not only a technological issue but also a competence issue. Effective implementation requires skills in construction technology, building services engineering, information technology, cybersecurity, data analytics, installation and maintenance. This agrees with Khan et al. (2023) and Kumar et al. (2024), who identify skills gaps and limited technical knowledge as major barriers in developing countries. Without these competencies, IoT systems may be poorly designed, wrongly installed, underutilised or poorly maintained.

Insufficient financial incentives recorded a mean of 4.12 and the lowest standard deviation of 0.452, indicating strong consistency in respondents' views. This suggests that the absence of grants, subsidies, tax reliefs, rebates, low-interest loans and performance-based financing discourages adoption. The finding extends the cost barrier because incentives can reduce upfront investment. It also aligns with the Technology Organisation Environment framework, which explains adoption through technological, organisational and environmental conditions, including external support and regulation (Tornatzky & Fleischer, 1990; Salleh et al., 2024).

Few qualified suppliers or manufacturers also recorded a mean of 4.12, showing that weak supply chain capacity affects adoption. Reliable suppliers are needed for devices, installation support, software updates, maintenance, and after-sales services. Poyyamozhi et al. (2024) and Waiganjo et al. (2024) emphasise that vendor support and local presence are important for sustainable IoT integration. Where supplier capacity is weak, adopters may face higher costs, delays and compatibility problems.

Legal and institutional support recorded a mean of 4.11 and the highest standard deviation of 0.638. This shows that respondents considered it important, although their views varied more widely. The finding aligns with Tondro et al. (2025) and Chen et al. (2025), who note that data privacy, cybersecurity, interoperability standards, and unclear regulatory guidelines can create uncertainty regarding IoT adoption. Although the table ranks this item seventh, its mean is higher than that of lack of expertise, suggesting that the ranking may require minor adjustment.

The remaining barriers, including a lack of expertise, slow return on investment, compatibility issues, and limitations in building design, show that interconnected factors constrain adoption. Existing buildings may lack cabling routes, network capacity and smart-ready service systems, making retrofitting costly and complex. This supports Kronlid et al. (2024), who argue that compatibility and complexity strongly influence the diffusion of innovation.

Overall, IoT adoption in buildings requires financial support, stakeholder education, workforce upskilling, supplier development, regulatory clarity, and smart-ready building design. For Ghana, addressing these barriers is essential for improving energy efficiency and advancing sustainable intelligent buildings.

The identified barriers also indicate that IoT adoption in buildings can be strengthened through deliberate integration factors that directly address the financial, technical, institutional, and human-capacity constraints reported in Table 1. First, phased implementation should be encouraged, with building owners starting with low-cost pilot applications such as smart metering, occupancy sensors, or energy monitoring before progressing to more complex automation systems. This can reduce the burden of high initial costs and allow stakeholders to observe measurable energy savings before committing to large-scale investment. Second, stakeholder awareness and user training are essential to improving perceived usefulness, ease of use, and confidence in IoT-enabled building systems. Practical demonstrations, local case studies, workshops, and facility-manager training can help address unawareness, lack of expertise, and inadequate professional skills. Third, technical integration can be improved through open standards, interoperable devices, and vendor-supported platforms that enable IoT systems to connect seamlessly with existing mechanical, electrical, and building management systems. This is particularly important for reducing compatibility issues and overcoming limitations in existing building designs. Fourth, institutional support through building codes, smart-building guidelines, cybersecurity protocols, data privacy rules, and procurement standards can reduce uncertainty and improve trust in IoT investments. Finally, financial incentives such as subsidies, tax reliefs, green financing, low-interest loans, and energy-performance-based funding can mitigate cost and slow-return concerns. These integration factors suggest that the practical adoption of IoT in Ghanaian buildings requires not only technology acquisition but also a coordinated ecosystem of finance, policy, capacity building, supplier development, and smart-ready design. This aligns with the manuscript’s argument that successful IoT adoption depends on financial support, stakeholder education, workforce upskilling, regulatory clarity, vendor support, and technically adaptable building systems.

Theoretical Interpretation of the Empirical Barriers

The empirical findings are strengthened when interpreted through the Technology Acceptance Model, Diffusion of Innovation Theory, and the Technology-Organisation-Environment framework. The Technology Acceptance Model explains the human-related barriers, particularly stakeholder unawareness, lack of expertise, and inadequately skilled professionals. Since TAM argues that adoption depends on perceived usefulness and perceived ease of use, limited awareness reduces stakeholders’ understanding of how IoT can support real-time energy monitoring, operational savings, predictive maintenance, and improved building performance. Similarly, inadequate professional skills make IoT systems appear complex, risky, and difficult to use, thereby weakening confidence in adoption.

Diffusion of Innovation Theory explains why IoT adoption remains slow despite its potential benefits. The barriers of high initial cost, slow return on investment, compatibility issues, and limitations in existing building designs reflect weak diffusion conditions. Although IoT offers clear relative advantages, these benefits may not be immediately observable to building owners and managers. Compatibility problems also suggest that many existing buildings are not designed to accommodate smart technologies, making adoption appear technically difficult and financially demanding.

The Technology Organisation Environment framework provides a broader explanation of the technological, organisational, and external barriers. Technological barriers include compatibility issues and building design limitations, while organisational barriers include weak internal capacity and a shortage of skilled professionals.

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Environmental barriers include insufficient financial incentives, a limited number of qualified suppliers, and weak legal and institutional support. Together, the three frameworks show that IoT adoption in Ghanaian buildings is constrained by perception, innovation complexity, organisational readiness, and the wider institutional environment.

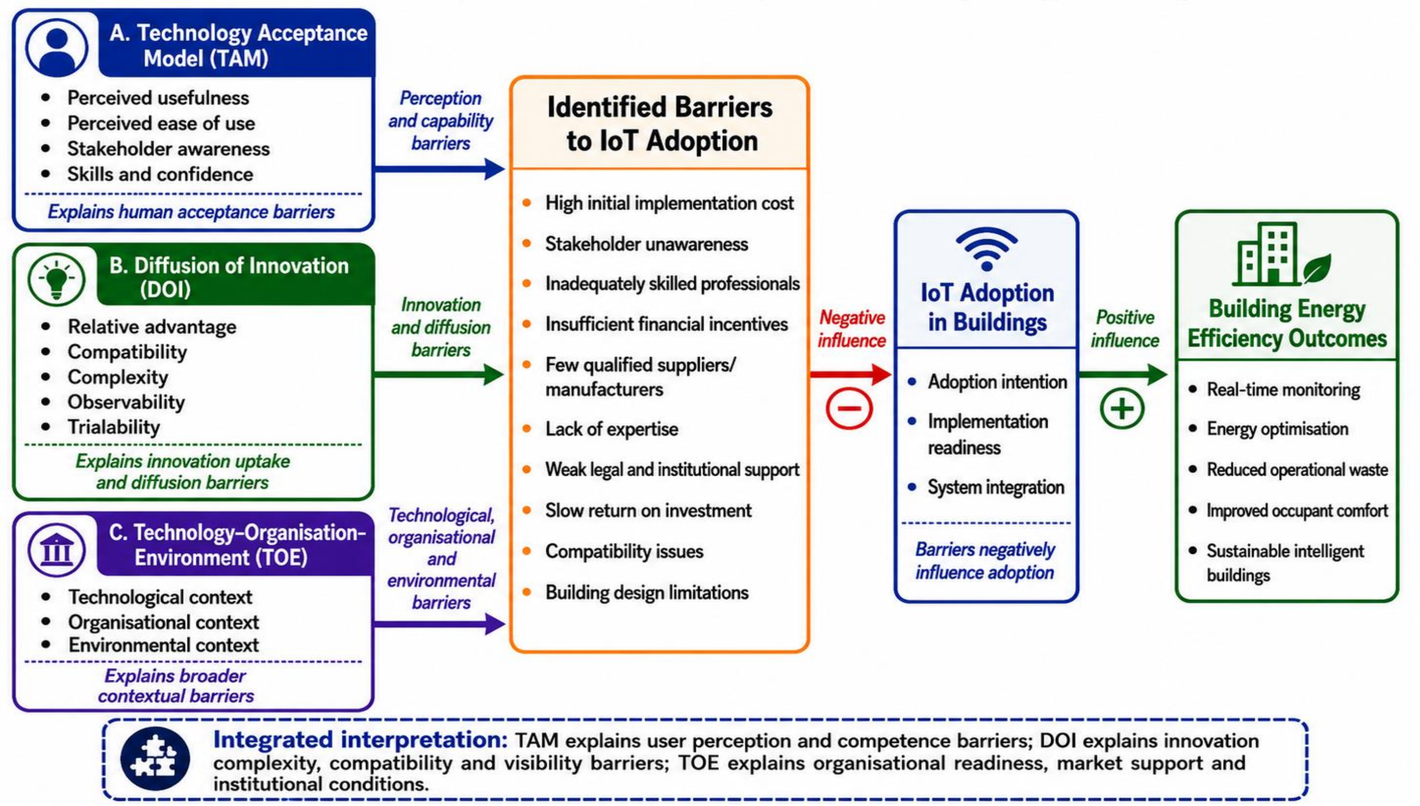

Figure 1: Theoretical Framework for IoT Adoption Barriers in Building Energy Efficiency. Source: Authors Construct, 2026.

IMPLICATIONS AND RECOMMENDATIONS

The strong relationship between IoT typologies and benefits provides compelling justification for government investment in IoT adoption incentives. Policymakers should implement targeted financial incentives, such as tax breaks, subsidies, or low-interest loans, to address high upfront investment costs. The complex paradox suggests that incentive programs should provide proportionally greater support for more sophisticated implementations.

The evidence from this study suggests that government intervention can play a crucial role in accelerating the adoption of IoT for building energy efficiency. Given the substantial energy savings potential demonstrated by IoT technologies, up to a 30% reduction in energy consumption, public investment in adoption incentives is likely to generate significant returns through reduced energy demand, lower greenhouse gas emissions, and improved energy security.

Incentive programs should be designed to address the specific barriers identified in this research. Financial incentives should be structured to reduce the burden of high upfront investment costs while encouraging comprehensive implementation that maximises benefits. Performance-based incentives that tie payments to demonstrated energy savings can help ensure that public investments achieve intended outcomes while encouraging effective implementation.

Regulatory frameworks must address integration challenges identified in the study. This includes establishing technical standards for IoT devices, promoting open communication protocols, and explicitly updating building codes to address the integration of IoT technologies. The lack of direct relationship between technological characteristics and integration success suggests that regulatory support for implementation processes is as important as technical standards.

Building codes should be updated to include provisions for IoT infrastructure in new construction and guidelines for retrofitting existing buildings with IoT systems. These codes should address technical requirements, safety standards, data security protocols, and interoperability specifications. Regular updates should be planned to keep pace with technological developments while maintaining stability for market participants.

Investment in national capacity building is crucial, given the positive relationship between IoT sophistication and the associated barriers. Collaboration with educational institutions to develop specialised training programs can help address the skills gap that currently limits IoT adoption. Public-private partnerships can ensure that training programs meet industry needs while building national technical capacity.

Capacity-building initiatives should address a range of skill levels, from basic technical skills for installation and maintenance to advanced skills for system design and data analytics. Training programs should be developed for different stakeholder groups, including building managers, facility technicians, engineers, and policymakers. Certification programs can help ensure quality and provide career pathways for professionals in the growing IoT industry.

Public awareness campaigns should educate building owners and managers about IoT benefits for energy efficiency, emphasising long-term cost savings and environmental benefits. These campaigns should address common misconceptions about IoT technologies and provide practical information about implementation processes and available support.

Research and development support can help create locally appropriate IoT solutions that address specific challenges and opportunities in Ghana and similar developing countries. Government funding for research institutions and technology development programs can help create cost-effective solutions tailored to local infrastructure and economic conditions.

The non-linear path to integration success emphasises the importance of comprehensive implementation strategies that address organisational, technical, and human factors beyond technology selection. Building managers should develop explicit integration strategies that include change management, staff training, and ongoing support arrangements.

The strong benefits-technology relationship suggests that organisations should consider comprehensive IoT strategies rather than single-purpose solutions. However, the complexity paradox suggests that more sophisticated systems require a proportionally greater focus on barrier mitigation and implementation support.

Phased implementation approaches can help organisations manage complexity while building capabilities over time. Starting with pilot projects allows testing of both technical functionality and organisational processes before committing to building-wide implementations.

The integration challenges identified in the study highlight market demand for interoperable solutions. Developers should prioritise creating IoT devices and platforms that adhere to open standards and enable seamless integration with existing systems. The complex paradox suggests that sophisticated systems must be designed with user-friendly interfaces to minimise barriers to adoption. Investment in user experience design and comprehensive support services can help address the skills gap that limits adoption.

Context-specific product development is important for success in developing country markets. This includes considering local infrastructure limitations, economic constraints, and technical capabilities when designing products.

CONCLUSION

This study concludes that the adoption of Internet of Things technologies has significant potential to improve building energy efficiency in Ghana, particularly through real-time monitoring, intelligent control, energy optimisation, and improved operational performance. However, the findings show that several interconnected barriers constrain IoT adoption in buildings. The most critical barriers identified were high initial implementation costs, limited stakeholder awareness, and an insufficient number of skilled professionals. These were followed by insufficient financial incentives, limited qualified suppliers, weak legal and institutional support, lack of expertise, slow return on investment, compatibility issues, and limitations in existing building designs. The study therefore demonstrates that the successful integration of IoT in Ghana's building sector cannot depend solely on technological availability. Rather, it requires a supportive ecosystem that combines financial mechanisms, stakeholder education, professional capacity building, regulatory clarity, supplier development, and smart-ready building design. The findings further suggest that government, industry actors, building owners, and technology providers must collaborate to reduce adoption risks and improve confidence in IoT-enabled building solutions. Overall, the study contributes context-specific evidence to the discourse on sustainable building energy management in developing countries and provides a practical basis for advancing intelligent, energy-efficient, and resilient buildings in Ghana.

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