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IOT IMPLEMENTATION FOR ENERGY MANAGEMENT WITHIN RESIDENTIAL BUILDINGS IN SRI LANKA: DRIVERS AND BARRIERS

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ABSTRACT

Effective energy management is essential to address the growing energy demand and sustainability challenges in Sri Lanka. The Internet of Things (IoT) offers promising solutions by enabling real-time monitoring, automation, and data-driven decision-making to enhance energy efficiency. While IoT adoption has advanced in many developed countries, its application within Sri Lanka's residential building sector remains limited. Existing literature lacks a focused examination of the contextual drivers and barriers influencing IoT adoption in this domain. This study aims to bridge this gap by identifying and analysing the key factors affecting IoT implementation for energy management in Sri Lankan households. Adopting a qualitative research approach, semi-structured interviews were conducted with fifteen industry experts, each possessing over ten years of experience in construction and at least five years in energy management with IoT knowledge. The findings highlight eleven key drivers, including cost efficiency, ease of control, and government support, and ten significant barriers, such as high initial costs, data privacy concerns, and low-quality devices. The study contributes to the academic literature by offering an understanding of IoT adoption in residential building for energy management. Future research should focus on addressing specific technical integration challenges, exploring infrastructure limitations and the integration of renewable energy sources.

Keywords: *Barriers; Enablers; Energy Management; Internet of Things; Residential Buildings.*

1. INTRODUCTION

The increasing demand for energy and the growing concerns for sustainability have led to a global shift towards smarter and more efficient energy management strategies (Mir, 2024). As populations grow and industries expand, the need for reliable, cost-effective, and environmentally sustainable energy systems has become more critical (Ehsanifar et al., 2023). One of the most significant strategies to address these challenges is the integration of the Internet of Things (IoT) into energy systems. IoT technologies enable

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real-time monitoring, automation, and optimisation of energy consumption, leading to more efficient energy management (Bedi et al., 2018). Through the integration of smart devices, sensors, and analytics into energy systems, IoT can transform how energy is produced, distributed, and consumed, resulting in a significant enhancement of energy management (Jia et al., 2024).

IoT-driven energy management solutions have proven to be effective in reducing energy consumption across various sectors by providing real-time insights into energy usage patterns and offering tools for better decision-making (Ehsanifar et al., 2023). These systems offer several benefits, including the ability to track energy usage at the individual device level, automate energy-saving actions, and predict maintenance needs before problems occur (Jia et al., 2024). The widespread adoption of IoT technologies in developed countries has demonstrated substantial improvements in energy efficiency, cost reduction, and the achievement of sustainability goals (Singh et al., 2022). These advancements, however, have not been equally realised in Sri Lanka, where energy management practices in residential buildings are still evolving.

Despite the global momentum in integrating IoT technologies into energy management systems, Sri Lanka remains in the early stages of adopting these solutions, particularly within the residential sector. While numerous studies have explored the potential of IoT in energy management across various construction domains (Kumar et al., 2021; Zhang et al., 2021), residential energy consumption in Sri Lanka continues to rely heavily on traditional, unoptimized practices (Liyanage et al., 2023). This is especially concerning given the rising national energy demand and the urgency for sustainable and efficient energy use (Caldera et al., 2023). Although there is growing interest in smart technologies, academic and practical investigations into IoT implementation specifically within Sri Lankan residential buildings remain scarce. This lack of context-specific research presents a critical gap in understanding the feasibility, challenges, and opportunities of adopting IoT-driven energy solutions in this sector.

To address this gap, this paper aims to identify and analyse the key drivers and barriers influencing IoT adoption for energy management in Sri Lanka's residential buildings. By examining these factors through qualitative research, the study aims to generate insights into the enablers of successful implementation of IoT for energy management, as well as the challenges that may hinder progress. Ultimately, the research also provides targeted strategies to enhance the adoption of IoT technologies in Sri Lankan households, thereby contributing to national energy efficiency and sustainability goals.

2. LITERATURE REVIEW

2.1 IOT IN ENERGY MANAGEMENT

IoT refers to a network of interconnected physical devices that communicate and exchange data through the internet, enabling intelligent monitoring, control, and automation of various processes (Wortmann & Flüchter, 2015). It has transformed energy management by enabling real-time data collection, automation, and predictive analytics (Mudaliar & Sivakumar, 2020). Smart meters, intelligent sensors, and cloud-based platforms facilitate accurate energy monitoring and control, improving efficiency (Bolla et al., 2011). Studies indicate that IoT-based energy management systems can reduce energy consumption by up to 30% in residential buildings (Al-Ali et al., 2017). Recent advancements in IoT technologies, including edge computing, blockchain integration for energy transactions, and machine learning algorithms for predictive energy management, have significantly improved efficiency and security in energy consumption (Ehsanifar et al., 2023; Jia et al., 2024). These developments allow for better load balancing, real-time fault detection, and seamless integration with distributed energy resources. Smart home systems, embedded with IoT solutions, are gaining popularity globally, as they enable automatic appliance control and provide consumers with real-time feedback on their energy usage, fostering behavioural changes that contribute to energy savings (Yar et al., 2021).

2.2 ENERGY MANAGEMENT PRACTICES IN SRI LANKA

Sri Lanka's energy consumption patterns show a high dependency on non-renewable energy sources, with residential demand accounting for a significant portion of the total electricity usage (Murshed et al., 2020). The government has implemented various initiatives, such as net metering for solar energy, energy-efficient lighting programs, and tiered tariff structures, to promote conservation (De Alwis & Bekchanov, 2020). However, these initiatives primarily target large-scale consumers, leaving a gap in residential energy management. Studies highlight that the lack of smart infrastructure, the absence of policy frameworks, and resistance to new technologies hinder the adoption of advanced energy management solutions (Yahya et al., 2023). Comparative studies with countries such as India and Malaysia reveal that government incentives and public awareness campaigns play a crucial role in encouraging IoT adoption in residential energy management (Zhang et al., 2021).

The adoption of IoT in Sri Lanka's residential sector has been slow, primarily due to affordability concerns and the absence of nationwide digital infrastructure. The energy sector in Sri Lanka heavily depends on centralised electricity distribution, with minimal integration of smart grid technologies (Kumar et al., 2021). Many developed countries have moved towards decentralised energy models, where IoT enables consumers to produce, store, and distribute their own energy efficiently. Lessons from these international case studies suggest that Sri Lanka must adopt a more proactive approach to digital transformation in the energy sector, including investment in IoT-ready infrastructure and smart metering solutions at the household level (De Alwis & Bekchanov, 2020).

2.3 DRIVERS AND BARRIERS FOR IOT IMPLEMENTATION IN RESIDENTIAL BUILDINGS

Studies have identified several key drivers and barriers to the implementation of IoT in energy management. Among these, the most commonly cited drivers are cost efficiency, energy efficiency, real-time monitoring, predictive maintenance, and sustainability goals. Cost efficiency is a major motivator, as IoT systems can reduce long-term energy consumption and operational costs (Bedi et al., 2018; Mishra & Singh, 2023). Energy efficiency is another critical driver, with IoT enabling better management of energy consumption, leading to significant savings (Ahmad & Zhang, 2021; Hossein Motlagh et al., 2020). Real-time monitoring and predictive maintenance offer increased visibility into energy usage, allowing for timely adjustments and improved system performance (Saleem et al., 2022). Additionally, achieving sustainability goals is a significant driver, as IoT technologies contribute to reducing environmental impact through optimised energy use (Mishra & Singh, 2023).

On the other hand, several barriers hinder the adoption of IoT for energy management. High initial investment is a significant obstacle, as the upfront cost of IoT systems can be prohibitive for many residential consumers. Data security and privacy concerns are also critical challenges, as IoT systems require the collection and transmission of sensitive data, raising potential vulnerabilities (Bedi et al., 2018). Integration complexity and lack of standardisation further complicate the implementation process, as IoT solutions often need to integrate with existing systems and adhere to industry standards. Other barriers include reliability and connectivity issues, which can disrupt IoT operations, and the lack of skilled professionals, which hinders the effective deployment and maintenance of IoT systems. Lastly, the lack of awareness among both consumers and policymakers about the benefits and functionalities of IoT technologies poses a significant challenge to their widespread adoption. These barriers must be addressed for IoT to achieve its full potential in residential energy management. The drivers and barriers identified by the various literature have been provided in Table 1.

Table 1: Drivers and barriers for IoT implementation for energy management

Code	Drivers	Sources
D1	Cost efficiency	(Bedi et al., 2018; Mishra & Singh, 2023)
D2	Energy efficiency	(Ahmad & Zhang, 2021; Hossein Motlagh et al., 2020)
D3	Real-time monitoring	(Mudaliar & Sivakumar, 2020; Saleem et al., 2022)
D4	Predictive maintenance	(Han et al., 2021a; Mudaliar & Sivakumar, 2020; Saleem et al., 2022) (Han et al., 2021a; Mudaliar & Sivakumar, 2020; Saleem et al., 2022)
D5	Sustainability goals	(Mishra & Singh, 2023)
D6	Time saving	(Han et al., 2021; Yahya et al., 2023)
D7	Easy control	(Mudaliar & Sivakumar, 2020; Sabit & Tun, 2024)
Code	**Barriers**	**Sources**
B1	High initial investment	(Jia et al., 2024; Khafiso et al., 2024)
B2	Data security and privacy concerns	(Bedi et al., 2018; Jia et al., 2024; Khafiso et al., 2024; Mishra & Singh, 2023)
B3	Integration complexity	(Kumar et al., 2021; Sabit & Tun, 2024)
B4	Lack of standardisation	(Al-Obaidi et al., 2022; Sabit & Tun, 2024; Zhang et al., 2021)
B5	Reliability and connectivity issues	(Al-Obaidi et al., 2022; Kumar et al., 2021; Sabit & Tun, 2024)
B6	Lack of skilled professionals	(Al-Obaidi et al., 2022; Kumar et al., 2021; Marinakis & Doukas, 2018)
B7	Lack of awareness	(Kumar et al., 2021; Sabit & Tun, 2024; Zhang et al., 2021)

3. METHODOLOGY

This study aims to identify the drivers and barriers to the utilisation of IoT in energy management within Sri Lankan residential buildings. Understanding these factors is essential for assessing the feasibility of IoT adoption and its potential impact on energy efficiency in the residential sector. Expert perspectives are critical in developing a comprehensive understanding of the opportunities and challenges related to IoT implementation. Professionals with experience in energy management, construction, and IoT can provide valuable insights into how these technologies can be effectively integrated into Sri Lanka's residential energy landscape. In-depth discussions based on professionals' field experience are necessary to explore the subject comprehensively (Saunders et al., 2023).

A qualitative research approach was adopted to capture detailed insights into the real-world drivers and barriers associated with IoT-based energy management in Sri Lanka. The study is structured around several key components: a literature review to examine global and local trends in energy management and IoT applications, data collection through semi-structured expert interviews, thematic analysis to identify emerging drivers and barriers, and synthesis of findings to propose actionable recommendations for IoT adoption in residential buildings.

According to Guest et al. (2006), data saturation in qualitative research is generally achieved within 6 to 12 interviews, with more than 80% of thematic codes typically emerging in the early stages. In the present study, thematic saturation was observed after the eleventh interview, with four additional interviews conducted to validate the absence of new emerging themes and to ensure robustness in the findings. A total of fifteen (15) semi-structured interviews were conducted with industry experts who possessed more than ten years of experience in the construction sector and at least five years of involvement in energy management, alongside demonstrated knowledge of IoT technologies.

Participants were selected through purposive sampling to ensure the inclusion of individuals with adequate professional or academic expertise relevant to the study's objectives. The experts were selected from the construction industry such that they represent key stakeholders within different stages of the building lifecycle, including both construction and operational phases. As the aim of the study was to examine the key drivers and barriers influencing the IoT adoption for energy management in Sri Lanka's residential buildings, three selection criteria were used to choose the professionals being interviewed, namely, experience in the construction industry, energy management and knowledge and understanding of IoT. For this study, experts such as Engineers, Chief executive officers, quantity surveyors, and assistant operation managers who fulfilled the three selection criteria were selected. These experts offered valuable insights into the real-world challenges associated with IoT adoption in residential energy management, including issues related to infrastructure limitations, regulatory constraints, and technological integration. Through this, the study addressed a significant research gap concerning the practical implementation of IoT-based energy management systems in Sri Lankan residential buildings. A summary of the experts' profiles is presented in Table 2.

Table 2: Profile of interview experts

Expert	Designation	Experience in the construction industry (more than 10 years)	Experience in Energy Management (more than 5 years)	Knowledge regarding IoT
R1	Senior Engineer	✓	✓	✓
R2	Chief Executive Officer	✓	✓	✓
R3	Chief Executive Officer	✓	✓	✓
R4	Lead Consultant	✓	✓	✓
R5	Charted Quantity Surveyor	✓	✓	✓
R6	Chief Executive Officer	✓	✓	✓
R7	Assistant Operations Manager	✓	✓	✓
R8	Senior Engineer	✓	✓	✓
R9	Chief Executive Officer	✓	✓	✓
R10	Charted Quantity Surveyor	✓	✓	✓
R11	Senior Engineer	✓	✓	✓
R12	Senior Engineer	✓	✓	✓
R13	Charted Quantity Surveyor	✓	✓	✓
R14	Chief Executive Officer	✓	✓	✓
R15	Chief Executive Officer	✓	✓	✓

The interviews were conducted in person, each lasting between 30 to 45 minutes. The collected data was analysed using manual content analysis, following a three-stage process. First, all interviews were transcribed to ensure accuracy. Second, the transcriptions were critically reviewed to identify key themes and patterns. Finally, the data were standardised and classified according to both deductive and inductive coding approaches. By following this structured methodology, the study ensures a thorough exploration of IoT's role in energy efficiency, backed by industry expertise and best practices. The insights gained will contribute to developing practical recommendations for implementing IoT-based energy management solutions in Sri Lankan residential buildings.

4. RESULTS AND DISCUSSION

4.1 DRIVERS OF IOT IMPLEMENTATION FOR ENERGY MANAGEMENT

The literature review identified five key drivers for IoT implementation in energy management, including cost efficiency, energy efficiency, real-time monitoring, predictive maintenance, and sustainability goals. Through the expert interviews, six additional drivers were identified, further expanding the understanding of the factors influencing IoT adoption in Sri Lanka's residential energy management sector. Table 3 presents the outcomes of these expert interviews, highlighting the drivers of IoT for energy management in residential buildings.

Among the eleven drivers of IoT for energy management in residential buildings, the cost efficiency, time saving, easy control, and government support emerged as the most frequently mentioned drivers. These factors were highlighted by nearly all of the participants as key drivers that influence the adoption of IoT solutions in residential buildings.

Cost efficiency was identified as a critical driver within the literature (Bedi et al., 2018; Mishra & Singh, 2023), similarly, experts emphasised that IoT systems may seem expensive at the initial stage, but they can lead to long-term savings through energy optimisation and reduction in utility costs. Timesaving was another frequently mentioned driver, as IoT-based systems allow for the automation of energy-consuming devices, reducing the need for manual monitoring and control. The ability to easily control devices remotely via IoT interfaces was also cited as a significant factor, providing convenience to homeowners and improving user engagement with energy management practices. Finally, government support, particularly in the form of incentives and regulatory frameworks, was highlighted as an essential factor in driving the adoption of IoT in residential buildings.

4.2 BARRIERS TO IOT IMPLEMENTATION FOR ENERGY MANAGEMENT

Further, the experts were questioned about the significant barriers that impact the implementation of IoT in energy management. Initially, seven barriers to IoT implementation for energy management were identified through the literature review. However, the interviews revealed three additional barriers, expanding the understanding of the challenges faced in adopting IoT for residential energy management in Sri Lanka. The identified ten barriers are listed in Table 4. Among them, the most frequently highlighted barriers include high initial investment, data security and privacy concerns, lack of awareness, and the use of low-quality devices. These barriers were emphasised by the majority of experts as significant obstacles that hinder the widespread adoption of IoT-based energy management solutions in residential buildings. However, factors such as cost and accessibility of IoT depend on different socio-economic groups. Although is was considered a significant barrier among the majority of the participants, it should be analysed in detail across various socio-economic groups.

4.3 STRATEGIES TO OVERCOME BARRIERS TO IOT IMPLEMENTATION

The expert interviews provided valuable insights into various strategies for overcoming the barriers to IoT implementation in residential energy management. These strategies, proposed by the respondents, addressed the challenges related to cost, awareness, security concerns, and regulatory frameworks. Table 5 presents the strategies identified by the experts, along with the respondents who suggested each solution. These strategies reflect a comprehensive approach that includes government support, developer responsibility, public awareness, expert guidance, and business planning.

Table 3: Drivers of IoT implementation for energy management

	Code	Drivers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
Drivers as per the Literature	D1	Cost efficiency	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	D2	Energy efficiency	✓	✓			✓	✓	✓	✓	✓	✓	✓			✓	✓
	D3	Real-time monitoring	✓		✓	✓			✓	✓	✓		✓	✓		✓	✓
	D4	Predictive maintenance	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓
	D5	Sustainability goals	✓	✓				✓	✓	✓	✓	✓			✓	✓	✓
	D6	Time saving	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
	D7	Easy control	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Additional Drivers	D8	People's interest	✓	✓		✓		✓	✓		✓			✓	✓	✓	✓
	D9	Growing population			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
	D10	Support from the Government	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
	D11	Promotions from service providers	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓

Table 4: Barriers to IoT implementation for energy management

	Code	Drivers	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
Barriers as per the literature	B1	High initial investment	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
	B2	Data security and privacy concerns	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
	B3	Integration complexity	✓			✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
	B4	Lack of standards and regulations	✓	✓	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓
	B5	Reliability and connectivity issues	✓	✓				✓	✓	✓	✓	✓			✓	✓	✓
	B6	Lack of skilled professionals	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
	B7	Lack of awareness	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Additional Barriers	B8	Architectural issues	✓	✓		✓		✓	✓		✓			✓	✓		
	B9	Lack of cost planning	✓	✓	✓					✓	✓	✓		✓	✓		
	B10	Low-quality devices	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 5: Strategies to overcome the barriers to IoT implementation

Code	Strategies to Bridge the Gap	Experts	Related Barriers
S1	Government intervention to reduce the cost of devices	R8	B1, B9, B10
S2	Developers should demonstrate the results of IoT systems to justify the initial investment	R4, R5, R13	B1, B6, B7
S3	Public awareness campaigns by both the government and developers to educate the public about IoT technologies and their benefits	R1, R2, R3. R9. R10	B2, B7
S4	Government-imposed standards for IoT technologies to ensure secure and efficient integration	R1, R6, R7, R12, R15	B2, B3, B4, B5
S5	Providing energy guarantees for energy-consuming equipment to build consumer confidence	R1, R15	B1, B3
S6	Seeking expert guidance before adopting IoT systems to ensure proper implementation	R3, R4, R5, R7	B3, B5, B6, B7
S7	Encouraging collaborative initiatives among stakeholders in the IoT ecosystem	R5, R12	B3, B6, B9
S8	Developing a comprehensive business plan before adopting IoT to ensure alignment with business goals	R14, R15	B3, B9

These strategies indicate a combined approach to overcome the barriers to IoT adoption in residential energy management. The suggestions from the respondents highlight the importance of collaboration between the government, developers, and other stakeholders to reduce the identified barriers, such as cost, lack of awareness, and knowledge regarding IoT for energy management. Tax reductions and cost reduction strategies, such as providing energy guarantees for equipment, aim to tackle the financial barriers identified in the study. Public awareness campaigns and the implementation of IoT standards are crucial to addressing knowledge gaps and ensuring a secure and efficient ecosystem. Furthermore, expert guidance and a well-structured business plan are seen as essential for ensuring proper IoT system implementation and long-term success. These strategies emphasise the need for coordinated efforts to overcome the challenges and unlock the potential of IoT in residential energy management. The outcomes of this study specifically focus on the residential building sector within Sri Lanka and can be generalised for the residential building sector of similar developing countries.

5. CONCLUSION

This study explored the drivers and barriers to the implementation of IoT in energy management within Sri Lankan residential buildings. The findings revealed that key drivers such as cost efficiency, timesaving, ease of control, and government support were the most significant drivers encouraging the IoT adoption. These factors reflect the economic motivations for adopting smart technologies. On the other hand, high initial investment, data security and privacy concerns, lack of awareness, and the prevalence of low-quality devices were identified as the most significant barriers. To address these challenges, the study identified several strategies, including government interventions in terms of tax reduction and financial aid, public awareness campaigns, standardisation of IoT technologies, and the promotion of expert guidance. These strategies aim to reduce financial and technical gaps that currently impact the IoT adoption. According to the outcomes of the research, it was identified that IoT can significantly enhance energy management practices in residential buildings. This study can be further developed focusing on the specific technical challenges associated with IoT implementation in Sri Lankan residential buildings, such as infrastructure limitations and the integration of renewable energy sources.

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