

FACTORS INFLUENCING ENERGY EFFICIENCY SYSTEM IMPLEMENTATION AND MAINTENANCE IN RESIDENTIAL GREEN BUILDINGS

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Abstract — Green residential buildings offer long-term environmental, economic, and social benefits, yet the effectiveness of their energy efficiency systems heavily depends on proper implementation and maintenance. This study investigates the key factors contributing to ineffective maintenance of energy-efficient systems in certified green residential buildings in Klang Valley, Malaysia. A structured questionnaire was distributed to residents and maintenance staff across three certified Green Building Index (GBI) developments. Despite a smaller-than-ideal sample size ($n = 60$), respondent diversity was maintained. Descriptive analysis revealed that financial limitations, inadequate maintenance planning, and weak management were primary barriers to maintaining energy efficiency. Additionally, the study incorporated perception-based findings, showing that most respondents recognized energy-efficient systems' health, environmental, and societal benefits. The results highlight the importance of proactive maintenance strategies and training, and the role of perception in shaping energy practices. These insights support the development of integrated, perception-informed maintenance models to improve system performance and sustainability in green housing.

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Keywords: energy efficiency, green building maintenance, stakeholder perception, green building index, sustainable residential development

1.0 INTRODUCTION

Green building in Malaysia focuses on developing sustainable and environmentally friendly buildings that reduce environmental impact while maximising energy efficiency. The country has seen a growing interest in green building practices due to increasing concerns about climate change, rising energy costs, and the need for better resource management [1]. According to a study by Tokbaevich et.al. [2], green building design reduces the impact on the environment, surrounding communities, and their inhabitants. This happens by using resources like water and energy efficiently. Green buildings are also designed to retain and take advantage of existing trees and transportation options. Moreover, they use materials that are recycled, recyclable, and non-toxic. A building maintenance management plan is crucial to guaranteeing optimal building performance and condition. Across most nations, maintenance activities are executed through fundamental management concepts encompassing planning, monitoring, and control [3]. As stated by Azmy et. al. [4], maintaining a building is crucial for ensuring its proper functionality, ultimately enhancing the living experience of those who reside within. It's critical to find a balance between providing affordable housing options and providing high-quality maintenance. Adequate facility maintenance guarantees a dependable building that can operate seamlessly without any disruptions.

However, adopting green buildings is not widespread and immediate due to several issues that hinder their development. One of the main challenges is the need for more expertise in keeping track of technology. This makes the system unreliable and outdated. The current technology available for green buildings is also not up to the mark, and it is not reliable enough to ensure that the buildings are energy-efficient and environmentally friendly [5]. He also stated that another challenge is the prolonged investment recovery periods, which are a significant concern for homeowners. The high initial cost of green building residential construction and installation requires longer to recover the investment, making it less attractive to investors. In construction projects, maintenance expenditures

have traditionally been viewed as a burden and a frequent problem [6]. However, earlier research suggests that using green concepts from the beginning, such as design and planning, is essential to maximising the performance of green buildings [7].

This issue further slows down the adoption rate of green residential buildings. Lastly, poor information dissemination is another core issue in the sustainable development of green residential buildings. The public is not fully aware of the benefits of residential green buildings, and there is a lack of education and awareness regarding their features and advantages. This further reduces the adoption rate of green residential buildings as a novel form of architecture.

1.1. Green Building Residential in Malaysia

Green building refers to sustainable or high-performance construction practices prioritizing energy efficiency and environmental consciousness throughout a building's life cycle. This includes the planning stage and construction, operation, maintenance, remodelling, and eventual demolition. Green building is essential for promoting sustainable development and safeguarding our planet while enhancing the quality of life for all [8].

Green buildings support the construction sector in meeting energy and water efficiency standards, minimising the use of natural resources, and improving the environment and public health. Building Research Establishment Environmental Assessment Method (BREEAM), Green Mark, and Leadership in Energy and Environmental Design (LEED) are just a few examples of the various green building rating systems that assess and identify structures that meet specific green requirements. Nonetheless, in Malaysia, GBI is the accepted standard for green construction. The prerequisites include water efficiency, indoor environmental quality, energy efficiency, sustainable site planning and management, and innovation [9].

Green building residential in Malaysia is a growing trend, with increasing green residential properties being developed in the main cities. Environmental concerns, social benefits, and economic considerations are some of the factors that influence people's decisions to buy green residential properties [10]. As stated by [11], green building residential was created to lessen its detrimental effects on both the environment and people. The selling price of green housing, which is greater than that of conventional buildings due to their higher cost, is further boosted by the growing demand in the housing market for green buildings.

The government of Malaysia has implemented various initiatives to promote green buildings in the residential sector. These initiatives include incentives such as investment tax allowances and income tax exemptions for using green technology services and systems [12]. However, the implementation of green building concepts still faces barriers and challenges. These include financial constraints, limited tax exemptions, and legislative challenges [13]. To overcome these barriers, it is essential to raise awareness and provide support for green building initiatives within the construction industry [14]. Additionally, the government should consider implementing proper guidelines and regulations for green building construction and provide incentives for using green building practices in government and private projects [15]. By implementing these strategies, Malaysia can work towards achieving sustainable residential construction and reducing carbon emissions in the building sector [15].

However, implementing green buildings in Malaysia faces economic, technological, knowledge, financial, and political barriers [16–18]. The primary elements influencing the buying decisions of green residential properties in Malaysia include neighbourhood and housing qualities, financial considerations, and geographical aspects of green construction [10]. Chuweni et. al., [9, 19] support time consumption as another barrier to green building resident development. Construction stakeholders are worried about the development of green buildings because these projects can take a long time during the planning stage, as time is needed to create the green concept during the design stage. Furthermore, as their time is equivalent to money, the longer the preparation before the project takes place, the lower their earnings. Because of that, construction stakeholders prefer not to work on a project for an extended time.

Malaysia is dedicated to achieving low-carbon development to restructure the economic landscape into a more sustainable one. The National Energy Transition Roadmap (NETR) has been created to accelerate energy transition and improve climate resilience by changing how energy is generated [20]. The construction industry has made significant strides towards sustainable building practices through various initiatives such as green building ratings, industrialised building systems, sustainable building designs, environmentally friendly construction materials, and directories of green products [21–23]. The government must adopt green procurement criteria and evaluate all aspects of its operations for opportunities to integrate green technology-based practices, systems, and products.

However, there are insufficient sustainability performance standards for building materials, a lack of research in sustainable building materials, and a need for a more skilled workforce in the construction industry [24].

Growing awareness of the advantages of green buildings has led to a rising preference for environmentally friendly residential developments. This consumer demand shift encourages the construction industry to integrate sustainable practices into mainstream projects [25]. As adoption increases, the cost of constructing green buildings will decline, improving affordability and accessibility for a broader population.

Green building involves sustainable construction practices prioritising energy efficiency and environmental consciousness throughout a building's life cycle. Buildings that fulfil specific green standards are evaluated and rated by green building rating systems like LEED, BREEAM, and GBI. In Malaysia, green building residential development is growing and is driven by environmental concerns, social benefits, and economic considerations.

Although challenges remain, the push toward eco-conscious living continues to reshape construction practices. Green buildings have been identified as an effective solution for mitigating the environmental impact of human activities, particularly in the built environment. These include reduced water and energy consumption, improved indoor air quality, lower greenhouse gas emissions, enhanced occupant comfort and health, and reduced maintenance and operational costs [26–29].

1.2. Operation and Maintenance

According to Salaheldine et. al. [30], Khalid et. al. [31] and Kadhim et. al. [32] building maintenance management involves overseeing and regulating building usage by considering technical, social, legal, and financial factors. Meanwhile, Verma et. al. [33] and Pedro et. al. [34] describe maintenance as a structured program encompassing technical and administrative activities to preserve or restore a facility to its intended functional condition.

Maintenance stakeholders, such as building managers, owners, and users, allocate the necessary maintenance costs to perform good maintenance work. This is crucial for sustaining the required standard of quality in buildings. Appropriate resources, including staffing and finance, are essential for practical maintenance activities. By emphasising the importance of allocating maintenance costs, stakeholders can ensure sufficient resources are available to support maintenance efforts. This will enable the implementation of regular maintenance activities, which can help prolong the lifespan of buildings, enhance safety and comfort for users, and reduce the frequency of repairs and damages [35].

Sustaining a safe and functional environment for green buildings requires routine inspections and repairs. This involves maintaining the facility's cleanliness, painting, equipment repair, and other maintenance duties. The objective is to spot problems early on and take prompt action to solve them before they worsen. This calls for routine cleaning of offices and communal areas to keep everyone safe and in a clean atmosphere. This involves vacuuming, dusting, and sanitising surfaces to stop the spread of bacteria. As mentioned by Au-Yong et. al. [6], proper maintenance management will enhance maintenance planning, and implementation with the right tools and materials will reduce the total life cycle cost and need to rectify building defects in line with a statement by Lu et. al. [36].

Energy efficiency components in green buildings include thermal comfort, energy performance, indoor air quality, HVAC systems, daylighting, and creatively coupled energy-saving measures [23]. Liu et. al. [23] also stated that green buildings have the potential to mitigate greenhouse gas emissions and lower building energy consumption through sustainable energy performance. However, obstacles must be overcome, including installation, operation, and maintenance expenses.

Lu et. al. [36] and Asmone et. al. [37] stated that it is essential to implement proper maintenance measures to uphold the various functions of green buildings following their installation. These measures sustain the ecosystem services green buildings provide and maintain their monetary value. The incorporation of green spaces into building projects and the challenges posed by rising urban density are further compounded by insufficient resource allocation for maintenance. Therefore, prioritising the maintenance of green buildings is crucial for their continued benefits.

By incorporating sustainable and efficient practices into a range of strategies, one can reduce adverse effects on the environment, address environmental issues, improve the safety of maintenance crews and building occupants, and facilitate effective maintenance practices that satisfy effectiveness standards like functional and quality. Effective and sustainable building maintenance methods must be used simultaneously since they both help create a built

environment that is safer and cleaner. While effective maintenance achieves low energy intensity levels, poor maintenance practices of heating, ventilation, and air conditioning (HVAC) systems, for instance, contribute to energy consumption, which is accompanied by rising carbon dioxide (CO₂) emissions [38].

1.3. Perception Toward Energy Efficiency System

Perception is crucial in successfully implementing and maintaining energy efficiency systems in green buildings. Various stakeholders, including residents, developers, and maintenance personnel, form opinions based on their experiences, knowledge, and perceived benefits. Huang, [39] emphasised that residents' positive perception of indoor comfort and utility savings significantly influences their acceptance of energy-efficient technologies. Similarly, Oyewole et. al. [40] found that developers' perception of long-term return on investment strongly affects their decision to adopt green systems. Moreover, perceiving maintenance complexity or required technical expertise often hinders proper upkeep [41]. Therefore, understanding perception helps identify behavioural or attitudinal barriers to implementation and contributes to shaping more effective policy and educational interventions.

2.0 METHOD

This study was conducted in the Klang Valley area. Three residential green buildings were selected as the case study, which were certified as green buildings by the Green Building Index (GBI). The case study is in Bandar Rimbayu, Mont Kiara, and Ken Rimba, Shah Alam. The questionnaire was distributed to respondents within the case study area, targeting the residents and maintenance staff. This study aims to identify the factors contributing to ineffective maintenance of energy efficiency systems in residential green buildings. The target population comprised residents and maintenance staff of GBI-certified residential buildings in Klang Valley. Using the [42] table for a population of ~500, the recommended sample size was 217. However, due to accessibility constraints, 75 questionnaires were distributed, with 60 completed (80% response rate). While this sample is smaller than ideal, it aligns with similar studies on niche populations, e.g., [9], N=50; [17], N=65. Non-response bias was mitigated by ensuring respondent diversity Table 1. SPSS version is used to analyse the data.

Table 1 Respondents' Composition

Respondents	Frequency	Percentage (%)
Gender		
Male	33	55
Female	27	45
Race		
Malay	55	91.7
Chinese	4	6.7
Indian	0	0
Iban	1	1
Age		
Below 21	6	10
22-25	44	73.3
26-30	4	6.7
30 and above	6	10
Marital Status		
Married	54	90
Single	6	10

3.0 RESULTS AND DISCUSSION

As shown in Table 2, 78.3% of respondents reported residing in green residential buildings and utilising energy-efficient systems. Additionally, 15% of those surveyed were maintenance workers well-versed in their buildings' energy-efficient systems. Notably, all participants in this survey were users of energy-efficient systems, either as residents or as management and maintenance staff members. This establishes the credibility of the data collected, as it is based on their personal experiences with the system.

Table 2 Respondents' Composition

Status	Frequency	Percentage (%)
Resident	47	78.3
Maintenance worker	9	15
JMB Staff	3	5
Building Manager	1	1.7

3.1. Perception of People on The Implementation of Energy Efficiency System

The survey results revealed strong agreement among respondents that energy efficiency systems positively impact societal, economic, and environmental outcomes, as evidenced by the data in Table 3.

Table 3 Perception of Implementation of Energy Efficiency System

Question	Strongly Disagree	Disagree	Mixed Feeling	Agree	Strongly Agree	Mean Score
Enhance health and be eco-friendly	0	0	4	18	38	4.57
Reduce social, economic, and environmental impact	0	0	5	20	35	4.5

The data collected through questionnaires was analysed and tabulated to determine the mean score of respondents' perceptions regarding implementing an energy efficiency system to reduce social, economic, and environmental impact in a green residential building. The mean score of perceptions was 4.5 out of 5, indicating that most participants felt that implementing such a system was necessary and highly beneficial. This promising result suggests that people are becoming increasingly aware of the positive impact of energy-efficient systems on the environment, society, and the economy.

The findings indicate strong positive perceptions among respondents regarding the benefits of energy conservation. For the statement "Enhance health and eco-friendliness," none of the respondents disagreed, with 4 expressing mixed feelings, 18 agreeing, and 38 strongly agreeing. The mean score of 4.57 suggests a significant consensus that energy conservation practices contribute to improving health and promoting environmentally friendly outcomes. Similarly, for the statement "Reduce social, economic, and environmental impact," no respondents disagreed. The mean score of 4.5 reflects a strong belief that energy conservation can help mitigate negative social, economic, and environmental impacts. These findings highlight a consensus on the positive effects of energy conservation in both health and broader societal aspects.

3.2. Factors of Ineffective Maintenance of Energy Efficiency Systems in Residential Green Buildings

As presented in Table 4, financial constraints have been identified as the most significant factor influencing the ineffectiveness of energy efficiency systems in residential green buildings, with a mean score of 4.37. This suggests that financial limitations constitute a significant barrier to implementing and maintaining these systems. The high score of this factor indicates that many stakeholders strongly agree that financial issues play a critical role in determining the success of energy efficiency initiatives [16–18].

One of the primary financial concerns is the upfront cost of installing energy-efficient technologies, such as solar panels, energy-efficient windows, and advanced HVAC systems [17]. These systems often require a high initial investment that can be difficult for developers and homeowners, especially in residential green buildings targeting middle- or low-income groups. Additionally, there is often a lack of financial incentives or government subsidies to support adopting energy-efficient technologies, further exacerbating the financial burden on stakeholders.

Moreover, the long-term financial benefits of energy efficiency systems, such as reduced energy bills and lower maintenance costs, may not be immediately visible, leading to hesitancy among building owners and developers to invest in these systems. Studies have shown that when financial support is provided through subsidies or low-interest loans, the adoption of energy efficiency systems increases significantly [13]. Therefore, to overcome

financial barriers, policymakers and industry stakeholders must collaborate to provide financial assistance and create a conducive environment for implementing energy-efficient technologies.

Table 4 Factors of Ineffective Maintenance of Energy Efficiency Systems in Residential Green Buildings

Factors of an ineffective energy efficiency system	Strongly Disagree	Disagree	Mixed Feeling	Agree	Strongly Agree	Mean Score
Financial	0	1	6	23	30	4.37
Poor maintenance plan	0	1	3	32	24	4.32
Management problems	0	0	12	26	22	4.17
Cost too high	0	3	13	20	24	4.08
Inexperience workers	1	4	12	20	23	4.00
Poor maintenance	0	0	20	25	15	3.92

Poor maintenance plans are the second highest-scoring factor, with a mean score 4.32. Maintenance is critical to ensuring energy-efficient systems' long-term efficiency and functionality [23]. However, the lack of proper maintenance planning is a common issue in residential green buildings, leading to the degradation of energy-efficient technologies over time.

A well-structured maintenance plan is essential for identifying potential system failures, scheduling regular inspections, and ensuring energy-efficient equipment operates optimally [36]. When maintenance is neglected or improperly managed, systems may fail to deliver the expected energy savings. For example, air filters in HVAC systems may become clogged, reducing airflow and increasing energy consumption, while solar panels may lose efficiency due to dust or dirt accumulation.

The lack of skilled maintenance personnel further compounds the problem, as inexperienced workers may be unable to identify or address issues related to the energy efficiency system. Building owners and managers must invest in developing and implementing comprehensive maintenance plans, including regular monitoring, inspections, and repairs. Furthermore, investing in training programs for maintenance staff can help mitigate the impact of poor maintenance planning on the performance of energy efficiency systems [38].

Management problems are in third, with a mean score of 4.17. Effective management is crucial in ensuring the successful implementation and ongoing operation of energy efficiency systems in residential green buildings. Management issues may arise from a lack of communication between building owners, managers, and maintenance personnel, resulting in inefficient decision-making and coordination.

One common management problem is the lack of accountability for energy efficiency goals. When management does not prioritise energy efficiency, staff are not motivated to follow through with energy-saving initiatives or maintenance tasks. This issue can be particularly challenging in larger residential complexes, where multiple stakeholders manage the building. Additionally, management may lack the technical expertise required to oversee energy-efficient systems effectively, leading to poor decision-making and a lack of focus on sustainability.

Addressing management problems requires a shift in organisational culture, where energy efficiency is a priority and a shared responsibility among all stakeholders. Regular training and workshops for management personnel can enhance their understanding of energy-efficient technologies and practices, enabling them to make informed decisions and lead by example [43].

Another factor influencing the ineffectiveness of energy efficiency systems is the perception that costs are too high, with a mean score of 4.08. Like financial constraints, this factor reflects concerns about the cost of implementing and maintaining energy-efficient technologies. While initial costs are a significant hurdle, the ongoing maintenance and repair of these systems can also be expensive, particularly if specialised equipment or expertise is required.

For many residential green building owners, the perceived high costs of energy efficiency systems can discourage investment. However, while upfront costs may be substantial, energy-efficient systems typically result in long-term savings through reduced energy consumption and lower utility bills. Furthermore, implementing energy efficiency systems can enhance the overall value of residential properties, making them more attractive to environmentally conscious buyers [44].

Workers' inexperience is also a notable factor, with a mean score of 4.00. The effectiveness of energy efficiency systems relies heavily on the workers' expertise and skills responsible for their installation, maintenance, and repair. Inexperienced workers may lack the technical knowledge to operate and maintain these systems effectively, leading to inefficiencies and system failures.

The lack of training and professional development opportunities for maintenance personnel is a significant challenge in the green building sector. To address this issue, building owners and managers must invest in training programs to ensure workers have the skills and knowledge required to maintain energy-efficient systems [45]. Additionally, collaboration with industry experts and technology providers can help bridge the gap between workers' current skill levels and the technical requirements of modern energy-efficient systems.

Lastly, poor maintenance was identified as a factor with a mean score of 3.92. Although it scores lower than the other factors, it remains an important issue. Inadequate maintenance can significantly reduce the efficiency of energy systems, leading to higher energy consumption and increased operational costs.

One primary reason for poor maintenance is the lack of regular inspections and preventive maintenance. Maintenance is often only carried out when a system fails, leading to costly repairs and energy inefficiencies. Proactive maintenance, including regular inspections and early detection of potential issues, can significantly improve the performance of energy-efficient systems and extend their lifespan [46].

Half of the respondents also agreed that applying housekeeping to maintenance can improve maintenance practices on energy-efficient systems. This approach involves maintaining cleanliness and orderliness in the working environment to ensure optimal performance and energy efficiency. They also agreed that applying advanced condition monitoring in maintenance could enhance maintenance practices for energy-efficient systems. This approach involves using advanced sensors and monitoring systems to detect potential faults or issues before they occur.

Overall, the study findings suggest that most respondents believe in adopting maintenance practices that can improve energy efficiency in their residences. The results reflect a growing awareness and interest in reducing energy consumption and promoting sustainable living practices.

The survey results suggest several ways to improve maintenance practices and promote sustainability for residential green buildings. One way is to enhance training and education by implementing programs for maintenance staff and homeowners on properly maintaining energy-efficient systems [47]. This can improve awareness and skills in managing green building technologies effectively. Since technology constantly evolves, staying informed about all systems contributing to energy efficiency is essential. Systems may not be adequately maintained or updated without the proper knowledge.

In green buildings, condition-based maintenance strategies, such as routine inspections, monitoring, and predictive maintenance methods, can help find problems early and stop system breakdowns. Expert evaluation may be required regularly, depending on the requirements and system requirements. Owners and maintenance teams must also adopt proactive maintenance management to prevent energy waste, cut operating costs, and improve the general sustainability of green buildings. This can all be achieved by implementing proactive management techniques to handle maintenance concerns quickly and effectively [48].

Investing in maintenance resources entails setting aside enough funds for maintenance tasks, including workers with the necessary training, equipment, and tools. Maintaining the functionality and lifespan of energy-efficient systems in environmentally friendly residential structures is essential. Residents in the green building area could have their neighbourhood. Involving the community will raise awareness of the value of upkeep for green buildings, promote a sustainable culture, and motivate locals to actively contribute to maintaining energy efficiency and environmental consciousness actively [8].

The residents benefited from the ongoing improvement, not only the maintenance team. Stressing the importance of continuing maintenance procedures, such as performance reviews, feedback channels, and routine evaluations, can help maximise energy-saving technologies and guarantee the long-term viability of green residential buildings.

4.0 CONCLUSION

This study identified critical challenges affecting the maintenance and performance of energy-efficient systems in residential green buildings, with financial constraints, poor maintenance planning, and weak management emerging as dominant factors. Beyond technical and financial concerns, the study also emphasized the influence of user and stakeholder perception, confirming that positive beliefs about environmental and health benefits drive greater acceptance of energy-efficient technologies.

The findings suggest that overcoming maintenance-related inefficiencies requires more than technical upgrades — it demands strategic investment in workforce training, structured maintenance plans, and stakeholder engagement. Moreover, promoting a culture of sustainability through education and community involvement can reinforce the value of maintenance and energy conservation.

This research contributes actionable recommendations for developers, property managers, and policymakers to strengthen maintenance practices through perception-sensitive and resource-conscious frameworks. Green residential buildings can achieve longer system lifespans, reduced energy use, and higher occupant satisfaction by adopting proactive and condition-based maintenance strategies. The insights gained from this study lay the groundwork for future research into behavioural and operational dynamics in sustainable housing management.

Furthermore, this study emphasizes integrating perception-driven strategies into energy efficiency planning. Stakeholders' attitudes and awareness influence the success of maintenance practices, suggesting that behavioural insights should inform policy design, training programs, and communication campaigns targeting energy conservation in green buildings.

Looking ahead, future research can build on these findings by employing mixed-method approaches or longitudinal designs to assess how perceptions and maintenance strategies evolve. Expanding the scope beyond Klang Valley to include diverse geographic areas and building types could also provide broader generalisability and deeper insights into nationwide energy efficiency practices.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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