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FACILITIES OF GREEN RESIDENTIAL BUILDING ELEMENTS AND THEIR IMPACT ON LIFE CYCLE COSTS IN HOUSING PROJECT DESIGN

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Abstract

Green buildings are designed to promote environmental stewardship and resource conservation throughout their life cycle, from construction to demolition. In response to global warming and growing urban populations, the adoption of green features in residential buildings has become an essential practice to conserve the natural environment, reduce resource consumption, and protect human health. This study investigates the utilisation of green features in certified green residential buildings and examines their impact on life cycle costs. A qualitative research design was adopted, involving multiple case studies of five GBI-awarded green residential projects. Data were collected through semi-structured interviews with developers and document analysis of project records to capture real descriptive perspectives and prevailing cost trends in the industry. The analysis reveals that, from a cost-effectiveness perspective, building orientation, window design, and rainwater harvesting systems are the most commonly applied green features across all projects, contributing to improved energy and water efficiency. The findings also indicate that the highest cost implications occur during the design and construction phase of the life cycle, while reduced operational costs over time help offset the higher initial investment. This study contributes to the body of knowledge by providing empirical insights into how specific green residential building features influence life cycle cost components in the Malaysian context, thereby informing developers and policymakers on cost-effective strategies for sustainable housing. Future research should further explore the constraints in implementing green building features and assess the level of awareness of life cycle costing among construction stakeholders to support more effective sustainable construction practices.

Keywords: Residential Building Facilities, Green Building, Green Features, Life Cycle Cost, Life Cycle Cost Analysis

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INTRODUCTION

Green building implementation has emerged as an important strategy to minimise environmental degradation caused by human activities while promoting sustainable development. Green buildings are recognised for balancing the three pillars of sustainability—environmental, social and economic sustainability (Ha et al., 2023). Although green buildings generally require higher initial investment, numerous studies have demonstrated that this additional cost can be offset through lower operational and maintenance expenses over the building's life cycle, resulting in improved long-term economic performance (Weerasinghe et al., 2022).

In Malaysia, the promotion of green buildings has gained increasing attention in support of the United Nations 2030 Agenda for Sustainable Development. The introduction of the Green Building Index (GBI) in 2009 as the national green building rating tool reflects the country's commitment to sustainable construction and environmentally responsible development (Zakaria et al., 2024). Within the residential sector, the adoption of green features has become increasingly important due to growing concerns over climate change and carbon emissions. The building sector is a major consumer of energy and contributor to greenhouse gas emissions, making residential buildings a key area for sustainable intervention (Min et al., 2022). Green features, including passive and active building systems, are therefore introduced to improve energy efficiency, conserve resources and enhance indoor environmental quality (Mazli & Fauzi, 2022; Simpeh et al., 2024).

Despite these benefits, the implementation of green residential buildings in Malaysia remains relatively limited. One of the major barriers is the perception of higher construction costs, with green buildings reported to cost approximately 10.77% more than conventional buildings (Husin et al., 2024). This additional cost discourages developers and contractors from adopting green features due to concerns over project profitability (Ahmad et al., 2024). Therefore, this paper reviews the utilisation of green features in residential buildings and examines their implications on life cycle cost, focusing on design and construction cost, operational and maintenance cost, and end-of-life cost.

LITERATURE REVIEW

Green Features and Life Cycle Cost

Green features refer to building characteristics and technologies incorporated to minimise environmental impacts while improving resource efficiency, occupant well-being and overall building performance (Goh et al., 2022; Mazli & Fauzi, 2022). These features include both passive and active design strategies that contribute to sustainable building development. In contrast, life cycle cost (LCC) refers to the total cost incurred throughout a building's life cycle, encompassing

design and construction, operation and maintenance, and end-of-life activities such as demolition, recycling and disposal (Dwaikat & Ali, 2018). Since green buildings require additional initial investment, evaluating their economic performance using LCC provides a more comprehensive assessment than considering construction cost alone.

Malaysia Green Building Index

The Green Building Index (GBI), introduced in 2009 by the Pertubuhan Akitek Malaysia (PAM) and the Association of Consulting Engineers Malaysia (ACEM), is Malaysia's primary green building rating system. GBI evaluates building sustainability based on six criteria: energy efficiency (EE), indoor environmental quality (EQ), sustainable site planning and management (SM), materials and resources (MR), water efficiency (WE), and innovation (IN). These criteria provide guidance for integrating sustainable practices throughout the design, construction and operational stages of buildings.

Building Life Cycle Cost Analysis

Life cycle cost analysis (LCCA) is widely recognised as an effective decision-making tool for evaluating the long-term economic performance of buildings. In line with ISO 15686-5:2017, LCC consists of design and construction cost, operational cost, maintenance cost and end-of-life cost, together with considerations of service life, analysis period and discount rate (Dwaikat & Ali, 2018; Zakaria et al., 2024; Ayob et al., 2026). Rather than focusing solely on initial construction expenditure, LCCA enables decision-makers to assess future cost savings arising from improved building performance, making it particularly suitable for evaluating green building investments.

Utilization of Green Features in Green Residential Buildings

The incorporation of green features into residential buildings has become an important strategy for achieving sustainable development through reduced energy consumption, efficient resource utilisation and improved indoor environmental quality (GBI, 2013). Based on previous studies, this research focuses on six commonly adopted green features in Malaysian residential buildings, namely building orientation, window, ventilation and daylight design, green and cool roofs, low volatile organic compound (VOC) materials, rainwater harvesting systems and renewable energy systems. These features represent a combination of passive and active design strategies that enhance environmental performance while supporting long-term economic sustainability.

Building orientation is a passive design strategy that minimises solar heat gain and maximises natural daylight, thereby reducing cooling and lighting energy demand (Sivadasan & Basiruddin, 2019; Ha et al., 2023). Similarly,

appropriate window design, natural ventilation and daylight optimisation improve thermal comfort and indoor environmental quality while reducing dependence on artificial lighting and mechanical ventilation (Goh et al., 2022). Green roofs and cool roofs improve thermal performance by reducing heat transfer through the building envelope. Green roofs absorb solar radiation through vegetation, whereas cool roofs utilise reflective materials to reduce roof surface temperature and mitigate the urban heat island effect (Goh et al., 2022; Lawin & Zakaria, 2023).

Low VOC materials are increasingly adopted to improve indoor air quality by reducing harmful emissions from construction materials. Products such as low VOC paints, adhesives and sustainable materials, including bamboo, contribute to healthier indoor environments while promoting the use of renewable resources (Ha et al., 2023; Isukuru et al., 2023).

Rainwater harvesting systems improve water efficiency by collecting and reusing rainwater for non-potable purposes such as toilet flushing and landscape irrigation. The system consists of storage tanks, pumps and distribution pipes that reduce dependence on treated water supplies (Goh et al., 2022). Renewable energy systems, particularly solar photovoltaic (PV) technology, further improve building sustainability by generating clean electricity from renewable resources and reducing reliance on conventional energy sources (Goh et al., 2022).

Overall, the selected green features are expected to influence the life cycle cost performance of residential buildings differently. While some features primarily reduce energy and water consumption during the operational stage, others contribute to improved building durability, lower maintenance requirements or higher residual value at the end of the building's service life. Therefore, understanding the utilisation of these green features provides an important basis for evaluating their implications on life cycle cost in green residential buildings.

Implications of Green Features on Life Cycle Cost of Residential Buildings

Green features are widely recognised as important determinants of the life cycle cost (LCC) performance of green residential buildings. Although the incorporation of green features may require additional investment during the design and construction stage, previous studies have shown that these features can generate long-term economic benefits through lower operational expenditure, reduced maintenance requirements and higher residual value at the end of the building's service life (Dwaikat & Ali, 2018; Weerasinghe et al., 2022). Therefore, the economic performance of green buildings should be evaluated based on the entire building life cycle rather than the initial construction cost alone.

In this study, green features represent the independent variable, while life cycle cost is the dependent variable. The selected green features comprise building orientation, window, ventilation and daylight design, green and cool roof, low VOC materials, rainwater harvesting system and renewable energy system. These features are expected to influence the three main LCC components, namely design and construction cost, operational and maintenance cost, and end-of-life cost. Since each green feature contributes differently throughout the building life cycle, a comprehensive investigation is required to understand their individual impacts on the overall life cycle cost performance of green residential buildings.

Implications of Green Features on Design and Construction Cost

According to Dwaikat and Ali (2016), they revealed that the green building construction cost is higher as compared to the conventional building and range between 0% to 21%, depending on the type of residential buildings such as terraced house, bungalow and apartment buildings. According to Husin et al. (2024), they explained that passive design strategies such as building orientation, walls insulation and low-emissivity windows will result in relatively lower cost implications in terms of design and construction.

Different green features contribute differently to the initial project cost. Passive design features such as building orientation and natural daylight optimisation generally require greater design consideration with minimal additional construction cost, whereas active systems such as rainwater harvesting and renewable energy installations involve higher expenditure due to additional equipment, materials and installation works. Likewise, the use of low VOC materials and green roofing systems may increase material procurement costs but are expected to provide long-term economic benefits through improved durability and resource efficiency. Therefore, the impact of each green feature on design and construction cost should be evaluated individually rather than generalising the cost implication of green buildings.

Implications of Green Features on Operational and Maintenance Cost

A comparative study between three green buildings and one conventional building by Weerasinghe et al. (2022) shown that the ratio of the overall operational to maintenance cost is approximately 80:20 in both green and conventional buildings. Based on the research outcomes from Weerasinghe et al. (2022), the utilities cost is the main contributor to the operational costs. Nevertheless, there was a significant savings in utilities cost for green buildings over conventional buildings due to the integrated green building features. Similarly, the maintenance cost for internal services is significantly contribute to the total maintenance cost. However, there was also showing a huge savings in

maintenance cost for green buildings over conventional buildings due to the availability of green technologies to control the building environment quality.

The operational and maintenance cost savings also vary according to the type of green feature implemented. Passive features, including building orientation, window design and green roofs, primarily reduce electricity consumption by lowering cooling and lighting demands. Meanwhile, active systems such as rainwater harvesting and renewable energy systems directly reduce water and electricity utility costs. Material-related features, including low VOC materials, may also reduce maintenance frequency due to improved durability and building performance. Hence, understanding the contribution of each green feature provides a more comprehensive evaluation of operational and maintenance cost throughout the building life cycle.

Implications of Green Features on End-of-Life Cost

In the pursue of sustainable practices, the industry is expected to apply deconstruction technique as the option to carefully demolish, dismantle and recycle the building materials (Dwaikat & Ali, 2018). Due to the application of material recycling, the residual value of the green building would be higher than the building that applying mechanical technique for demolition (Weerasinghe et al., 2022). Also, some of the green building features such as photovoltaic panels or the bamboo-made materials could be removed from the building for recycle operations to enhance more residual value.

The influence of green features extends beyond the operational stage to the end-of-life phase of the building. Green materials and building systems that are designed for reuse, recycling or deconstruction can reduce demolition waste and disposal costs while increasing the residual value of recoverable materials and components. For example, photovoltaic panels, recyclable roofing materials and certain sustainable building products may retain salvage value after the building reaches the end of its service life. Therefore, evaluating the contribution of individual green features to end-of-life cost is essential to capture their overall economic benefits within the life cycle cost assessment.

RESEARCH METHODOLOGY

This study used a qualitative multiple-case study approach to explore how green features are used in residential buildings and how they affect life cycle costs (LCC). Data came from semi-structured interviews and document analysis, providing detailed insights from industry practitioners (Creswell & Creswell, 2018). Five residential projects certified by the Green Building Index (GBI) were chosen as case studies. Selection was based on their certification, project completion, available documents, and the willingness of developers or property managers to take part. Respondents included property developers, property

managers, and facilities managers, each with at least five years of experience in green building implementation, operation, or maintenance. The interview questions were developed from a literature review and checked by experts before data collection to make sure they were clear and relevant.

Document analysis was used to support and check the interview results. The documents reviewed included GBI assessment reports, project specifications, cost plans, Bills of Quantities, and records of operation and maintenance. The analysis looked at six main green building features found in the literature: building orientation, window, ventilation and daylighting design, green and cool roofs, low VOC materials, rainwater harvesting systems, and renewable energy systems. The study examined how these features affected four parts of life cycle cost: design and construction, operation, maintenance, and end-of-life costs. Data from interviews and documents were analysed using qualitative content analysis and cross-case comparison to find common patterns and differences among the five case studies.

FINDINGS AND DISCUSSION

Data analysis is carried out through content analysis method to identify the utilization of green features and to analyse the implications of green features on life cycle cost of the green residential buildings.

Green Residential Projects

In this research, there are five GBI-awarded green residential projects being studied. Table 1.0 shows the list of GBI-awarded green residential projects that have involved in this study. The projects are named as Project A, B, C, D and E respectively.

Table 1.0: List of Projects

Project	Project Name
A	Construction and Completion of 37-Storey Luxury Apartment at Jalan Molek 1/27, Taman Molek, 81100 Mukim Plentong, Daerah Johor Bahru, Johor Darul Takzim
B	Construction and Completion of 28-Storey and 6-Storey Luxury Apartment at Jalan Molek 1/27, Taman Molek, 81100 Mukim Plentong, Daerah Johor Bahru, Johor Darul Takzim
C	Construction and Completion of 16-Storey Luxury Apartment at Persiaran Ponderosa Utama, Zon 2A, Taman Ponderosa, 81100 Mukim Plentong, Daerah Johor Bahru, Johor Darul Takzim
D	Construction and Completion of 35-Storey Condominium at Jalan Laksamana 1, Persiaran Puteri Selatan, Puteri Harbour, Iskandar Puteri, 79100 Mukim Pulau, Daerah Johor Bahru, Johor Darul Takzim

Project	Project Name
E	Construction and Completion of 44-Storey and 43-Storey Condominium at Jalan Jalil Perkasa 1, Bukit Jalil, 57000 Mukim Petaling, Daerah Kuala Lumpur, Wilayah Persekutuan Kuala Lumpur.

Utilization of Green Features in Green Residential Buildings

Based on the data from five GBI-awarded projects, the current prevalent green features that have applied in the green residential buildings are identified. Table 2.0 shows the summary of green features that are utilized in five GBI-awarded green residential projects. These green features are divided into two different design approaches, namely passive design and active design. Based on the summary, passive design approach results in higher rate of utilization as compared to active design approach.

Passive design approach such as building orientation as well as window, ventilation and daylighting design are applied in all of the five projects. These green features typically involve lower initial and operational cost as well as minimal maintenance requirements. Thus, developers of all projects tend to apply passive green features from the perspective of cost effectiveness. However, green and cool roof are the least preferred passive green features due to their higher initial cost and maintenance challenges. There are three projects only to apply green and cool roof. Whereas, the remaining two projects are choosing other passive green features like landscaped garden or green vertical wall as the alternatives to prevent heat.

Table 2.0: Utilization of Green Features in Green Residential Projects

Green Features		Project A	Project B	Project C	Project D	Project E	Total Project Applied
Passive Design	Building Orientation	√	√	√	√	√	5
	Window, Ventilation & Daylight	√	√	√	√	√	5
	Green & Cool Roof	√	√	√	X	X	3
Active Design	Low VOC Materials	√	√	√	X	X	3
	Rainwater Harvesting System	√	√	√	√	√	5
	Renewable Energy System	√	√	X	X	X	2

Among the six green features, the rainwater harvesting system was implemented in all five projects, making it the most widely adopted active design strategy. Developers considered it particularly suitable for high-rise residential buildings due to its ability to collect and reuse rainwater for non-potable purposes such as landscape irrigation and cleaning of common areas, thereby improving water efficiency. In contrast, low VOC materials and renewable energy systems were less frequently adopted. Only three projects utilised low VOC paints, adhesives, sealants and finishes, as these materials generally incur higher costs while offering limited direct energy-saving benefits. One project instead prioritised reducing transportation emissions during material procurement. Renewable energy systems, particularly solar photovoltaic panels, were the least adopted green feature, with only two projects incorporating them. Their limited implementation was mainly attributed to high initial investment costs and licensing requirements despite their potential to promote cleaner energy use.

Implications of Green Features on Life Cycle Cost of Residential Buildings

Based on the cost data obtained from the five case study projects, the implications of green features on the life cycle cost (LCC) of green residential buildings were analysed. Table 3.0 summarises the LCC breakdown into four components: design and construction cost, operational cost, maintenance cost and end-of-life cost. This classification provides a comprehensive understanding of cost allocation throughout the building life cycle and identifies the key sources of cost implications associated with green building implementation.

The findings show that the life cycle cost per square metre (LCC/m²) ranges from RM3,369.21/m² to RM4,280.77/m², with an average of RM3,789.68/m². The variation reflects differences in building size, design complexity, selection of green features, construction practices, long-term maintenance strategies and occupancy rates. These factors demonstrate that the economic performance of green residential buildings is influenced not only by the adoption of green features but also by project-specific characteristics.

Among the four cost components, design and construction cost accounts for the largest proportion of the total LCC, averaging 65.05%. This reflects the substantial upfront investment required to integrate green features during the development stage. Projects A and E recorded the highest design and construction costs due to extensive green feature adoption and greater structural complexity, while Projects B, C and D incurred relatively lower costs because of their smaller development scale.

Maintenance cost represents the second largest component, contributing an average of 19.22% of the LCC. The findings indicate that projects with greater utilisation of green technologies, such as rainwater harvesting and renewable energy systems, require more regular maintenance to sustain building

performance. Projects B, C and D recorded higher maintenance costs, mainly due to higher occupancy rates and greater utilisation of green systems. In contrast, Projects A and E incurred relatively lower maintenance costs, partly because lower occupancy resulted in reduced system usage and maintenance demand.

Operational cost contributes an average of 15.42% of the LCC, demonstrating the long-term economic benefits of green building implementation. The lower operational expenditure is largely attributed to reduced energy and water consumption achieved through the integration of green features. Projects B, C and D recorded relatively higher operational costs due to higher occupancy rates, whereas Projects A and E achieved lower operational costs through more effective integration of green features and lower building occupancy.

End-of-life cost constitutes only 0.31% of the total LCC, indicating minimal expenditure for deconstruction and disposal activities. Larger developments, including Projects A, B, D and E, incurred relatively higher deconstruction costs due to their building size, while Project C recorded the lowest end-of-life cost. In addition, Projects A and B demonstrated higher residual values through the recovery of recyclable materials, particularly solar photovoltaic systems, highlighting the potential economic benefits of sustainable material recovery at the end of the building life cycle.

Table 3.0: Life Cycle Cost Breakdown for Green Residential Projects

	Components	Project A		Project B		Project C		Project D		Project E		Average	
		Cost (RM)	%	Cost (RM)	%	Cost (RM)	%	Cost (RM)	%	Cost (RM)	%	Cost (RM)	%
DESIGN & CONSTRUCTION COST	Building Works	150,000,000.00	59.68	102,000,000.00	53.75	31,400,000.00	56.05	100,000,000.00	55.17	140,000,000.00	60.85	104,680,000.00	57.10
	GBI Certification	100,000.00	0.04	100,000.00	0.05	50,000.00	0.09	100,000.00	0.06	100,000.00	0.04	90,000.00	0.06
	Other Costs (Site & Soft Costs)	10,500,000.00	4.18	7,140,000.00	3.76	1,884,000.00	3.36	8,000,000.00	4.41	11,200,000.00	4.87	7,744,800.00	4.12
	Professional Fees	10,500,000.00	4.18	7,140,000.00	3.76	1,570,000.00	2.80	7,000,000.00	3.86	9,800,000.00	4.26	7,202,000.00	3.77
	Subtotal	171,100,000.00	68.08	116,380,000.00	61.32	34,904,000.00	62.30	115,100,000.00	63.50	161,100,000.00	70.02	119,716,800.00	65.05
OPERATIONAL COST	Utilities Cost	13,711,163.20	5.45	11,415,902.40	6.02	4,004,626.08	7.15	9,362,248.00	5.16	11,748,111.20	5.11	10,048,410.18	5.77
	- Energy Cost	9,966,264.00	3.96	10,570,280.00	5.57	3,741,879.12	6.69	7,248,192.00	3.99	9,060,240.00	3.94	8,117,371.02	4.83
	- Water Cost	3,442,891.20	1.37	604,016.00	0.32	187,244.96	0.33	1,812,048.00	1.00	2,416,064.00	1.05	1,692,452.83	0.81
	- Sewerage Cost	302,008.00	0.12	241,606.40	0.13	75,502.00	0.13	302,008.00	0.17	271,807.20	0.12	238,586.32	0.13
	Administrative Cost	16,006,424.00	6.37	15,100,400.00	7.96	4,644,883.04	8.29	14,496,384.00	8.00	15,493,010.40	6.73	13,148,220.29	7.47
	Other Costs (Ins. & Taxes)	4,530,120.00	1.80	4,107,308.80	2.16	1,268,433.60	2.26	5,405,943.20	2.98	3,926,104.00	1.71	3,847,581.92	2.18
	Subtotal	34,247,707.20	13.62	30,623,611.20	16.14	9,917,942.72	17.70	29,264,575.20	16.14	31,167,225.60	13.55	27,044,212.38	15.42
MAINTENANCE COST	Services	13,590,360.00	5.41	13,590,360.00	7.16	4,530,120.00	8.09	9,060,240.00	5.00	13,590,360.00	5.91	10,872,288.00	6.31
	Fabric & Decoration	9,060,240.00	3.60	7,550,200.00	3.98	1,661,044.00	2.96	9,060,240.00	5.00	5,436,144.00	2.36	6,553,573.60	3.58
	Cleaning & Ext. Works	13,590,360.00	5.41	13,590,360.00	7.16	1,812,048.00	3.23	9,060,240.00	5.00	6,040,160.00	2.63	8,818,633.60	4.69
	Repairs & Replacement	9,060,240.00	3.60	7,550,200.00	3.98	3,020,080.00	5.39	9,060,240.00	5.00	12,080,320.00	5.25	8,154,216.00	4.64
	Subtotal	45,301,200.00	18.02	42,281,120.00	22.28	11,023,292.00	19.67	36,240,960.00	20.00	37,146,984.00	16.15	34,398,711.20	19.22
END OF LIFE COST	Deconstructing Cost	1,410,000.00	0.56	958,800.00	0.51	236,128.00	0.42	940,000.00	0.52	1,316,000.00	0.57	972,185.60	0.52
	Residual Value	(705,000.00)	-0.28	(479,400.00)	-0.25	(59,032.00)	-0.09	(282,000.00)	-0.16	(658,000.00)	-0.29	(436,686.40)	-0.21
	Subtotal	705,000.00	0.28	479,400.00	0.26	177,096.00	0.33	658,000.00	0.36	658,000.00	0.28	535,499.20	0.31
	Total LCC (RM)	251,353,907.20	100	189,764,131.20	100	56,022,330.72	100	181,263,535.20	100	230,072,209.60	100	181,695,222.78	100
	Gross Floor Area (m2)	58,717		52,800		15,465		53,800		56,364		-	
	Total LCC/m2 (RM)	4,280.77		3,594.02		3,622.52		3,369.21		4,081.90		3,789.68	

CONCLUSION

This study successfully accomplished two primary research objectives. Regarding the utilization of green features, data from the five GBI-awarded residential projects revealed that developers strongly prefer passive design approaches over active ones. Specifically, building orientation, optimized window design, and rainwater harvesting systems were universally implemented across all five projects. In contrast, only three projects utilized green or cool roofs and low-VOC materials, while just two integrated renewable energy systems.

In terms of life cycle cost (LCC) implications, the findings indicated that the financial impact is heavily concentrated in the initial phases. The design and construction stage carried the highest cost implication at 65.05%, followed by maintenance costs at 19.22%, operational costs at 15.42%, and end-of-life costs at a negligible 0.31%. A closer look at the individual projects revealed that two projects incurred higher cost implications during the design and construction phase, while the remaining three experienced lower impacts. Conversely, for both the operational and maintenance phases, three projects faced higher cost implications compared to two with lower impacts. In the final deconstruction phase, four projects saw higher cost implications, leaving only one with a lower financial impact.

Several limitations were encountered during the research process, most notably the difficulty of recruiting qualified interviewees and accessing sensitive cost data due to strict privacy and confidentiality constraints. To build upon these insights, future studies should pursue more rigorous research into the broader scope of green building features and life cycle costing, ultimately producing more comprehensive benchmarks to guide future sustainable construction.

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