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Life Cycle Cost of Eco-Friendly Building Materials in Office Buildings: Supporting GBCI Greenship Certification

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Abstract

Background: Indonesia's construction sector faces challenges in reducing environmental impacts while maintaining the economic feasibility of projects.
Objective: This study aims to analyze the life cycle cost (LCC) of environmentally friendly materials used in office building envelope components and evaluate their contribution to achieving points in the Green Building Council Indonesia (GBCI) Greenship certification system.
Methods: A quantitative comparative case study approach was employed on a five-story office building in Jakarta, with an analysis period of 30 years and a discount rate of 8%. The evaluated components included wall systems, concrete structures, and façade glazing, comparing conventional materials with environmentally friendly alternatives such as autoclaved aerated concrete (AAC) blocks, geopolymer concrete, and low-emissivity (low-e) glass. The data were analyzed using the LCC equation and supplemented with sensitivity analyses of discount rates and energy price variations.
Results: The results showed that although the initial costs of environmentally friendly materials were 12–18% higher, the total LCC over 30 years was 9.5–9.8% lower than that of conventional materials. The cost break-even point occurred between the 9th and 11th years. Furthermore, the application of these materials contributed six points to the Material Resources and Cycle category in the GBCI Greenship v1.2 rating system.
Conclusion: This study concludes that the LCC approach can serve as a basis for rational decision-making to encourage the adoption of green building materials in Indonesia.

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INTRODUCTION

The construction sector is one of the largest contributors to global energy consumption and carbon emissions (Council, 2019; Whitehead & Yuen, 2026). Data from UNEP (2020) indicate that buildings and construction activities are responsible for approximately 39% of global CO_2 emissions, with 11% originating from the production processes of construction materials such as cement, steel, and glass (Organization et al., 2026; Programme, 2020). In Indonesia, the growth of the construction industry, which has reached an average of 5–6% annually, has resulted in a substantial increase in the use of conventional building materials (Rakyat, 2021; Statistik, 2023).

This condition has encouraged the emergence of a sustainable construction paradigm through the concept of green building. Green buildings are designed to minimize environmental impacts throughout their life cycle, including material selection, energy efficiency, and construction waste management (Statistik, 2023). In Indonesia, the Green Building Council Indonesia (GBCI) developed the Greenship certification system as a standard for green building assessment (Indonesia, 2022). The Material Resources and Cycle category in Greenship promotes the use of recycled materials, locally sourced materials, and materials with low environmental impacts (Hwang & Tan, 2012; Karamoozian & Zhang, 2025).

Despite the increasing interest in sustainable construction, the adoption of eco-friendly materials in Indonesia remains constrained by the perception that their initial procurement costs are 10–20% higher than those of conventional alternatives (Indonesia, 2022; Zuo & Zhao, 2014). This initial cost premium often leads developers to overlook operational costs, maintenance requirements, and residual values, which collectively constitute the complete economic life cycle of a building. The Life Cycle Cost (LCC) framework is designed to address this limitation by evaluating the total cost implications throughout the service life of an asset.

The Life Cycle Cost (LCC) approach was developed to overcome these limitations (Cole & Sterner, 2000; Ishimoto et al., 2024). LCC is an economic analysis method used to calculate the total costs incurred throughout the economic life of an asset, in accordance with the ISO 15686-5:2017 standard (Ishimoto et al., 2024; Rakyat, 2021). Through LCC, material selection decisions can be assessed comprehensively, enabling the quantitative measurement of potential long-term savings generated by environmentally friendly materials (Ishimoto et al., 2024; Sterner, 2000).

Although the concept of LCC is widely recognized, its application to environmentally friendly materials within the context of Indonesian construction projects remains limited. Several specific problems identified include:

1) Life cycle cost data gap: Most available material price data only cover initial procurement costs. Data regarding maintenance costs, energy consumption, and residual values of environmentally friendly materials under Indonesia's tropical climate conditions have not been systematically documented.
2) Limited quantitative comparative studies: Research comparing the LCC of conventional and environmentally friendly materials applied to the same building components remains limited (Jasdo, 2025; Priatama & Kusumawardani, 2020). Consequently, practitioners lack a strong evidence base for selecting materials that are economically and environmentally optimal.
3) Limited integration with green certification: Few studies have linked LCC analysis outcomes with the achievement of points within the GBCI Material Resources and Cycle Greenship category (Altaf et al., 2025; Gluch & Baumann, 2004). This linkage is essential to demonstrate the financial and environmental benefits of adopting green materials.
4) Perception of economic risk: Developers often perceive eco-friendly materials as financially risky due to uncertainties regarding the return-on-investment period. Without LCC analysis, such perceptions are difficult to transform into rational investment decisions.

Based on these issues, a study is required to analyze and compare the Life Cycle Cost of conventional and environmentally friendly materials in office buildings, while also evaluating their contribution to achieving GBCI Greenship certification (Emere et al., 2025; Kibert, 2016). The findings of this study are expected to provide a decision-making basis for construction stakeholders in selecting sustainable and economically feasible materials.

Research on Life Cycle Cost (LCC) in buildings has developed since the introduction of ISO 15686-5 as a standard for service-life planning and life-cycle cost analysis. Several international studies have applied LCC to compare conventional and environmentally friendly materials in structural components, façades, and mechanical, electrical, and plumbing (MEP) systems. These studies indicate that although the initial cost of green materials may be 10–25% higher, the total LCC over a 30–50-year period can be reduced by 8–15% due to lower operational energy consumption and maintenance requirements (Emere et al., 2025; Standardization, 2017).

In Indonesia, several preliminary studies have investigated the economic aspects of environmentally friendly materials. Sani et al. (2021) examined the use of geopolymer concrete and found that although material costs were approximately 12% higher, the longer service life provided greater potential maintenance savings (Azis & Bastini, 2026). However, the study was limited to structural elements and did not include building envelope systems (Khan et al., 2025; Sathaye & Mastrangelo, 2011). Wibowo and Santoso (2022) analyzed the application of AAC lightweight bricks and low-emissivity (low-e) glass in Jakarta office buildings and reported a reduction in cooling energy consumption of up to 18%, which contributed to lower operational costs (Abdullah & Rahman, 2018; Ishimoto et al., 2024).

In addition, studies related to GBCI Greenship certification have also begun to develop. GBCI reported that the use of recycled materials and materials supported by an Environmental Product Declaration (EPD) can contribute up to six points in the Material Resources and Cycle category. Several case studies involving office buildings and educational facilities indicate that achieving these points can support buildings in reaching Silver or Gold certification levels.

Although previous studies have examined LCC and environmentally friendly materials, several research limitations remain. Most studies in Indonesia still compare materials primarily based on initial purchase prices. Operational cost components, including energy consumption, maintenance, replacement, and residual value, are rarely calculated comprehensively, resulting in incomplete economic assessments.

Data regarding service life, degradation rates, and maintenance costs of green materials under Indonesia's tropical climate conditions remain limited. Consequently, many studies rely on assumptions derived from international literature that may not fully represent Indonesian field conditions.

Research integrating quantitative LCC results with Greenship certification points is still scarce. This integration is important to demonstrate that investment in green materials provides not only environmental benefits but also financial and reputational value.

Existing research tends to focus primarily on concrete structures and energy systems. Comparative evaluations of building envelope components, such as walls, glazing systems, and roofs, which significantly influence cooling loads in tropical climates, remain limited.

Based on the literature review, it can be synthesized that LCC is a valid approach for evaluating the economic feasibility of environmentally friendly materials. However, its implementation in Indonesia remains constrained by limited local data availability and insufficient integration with green certification systems. Therefore, this study aims to address these gaps by conducting a comparative LCC analysis of office building envelope materials and evaluating their contribution to GBCI Greenship certification.

Most existing studies compare eco-friendly and conventional materials based only on initial procurement costs. Operational cost components, including energy consumption, maintenance, replacement, and residual value, are rarely incorporated comprehensively, causing the analysis results to fail to represent the total cost throughout the building's service life.

Important parameters, including material service life, degradation rates, and maintenance costs under Indonesia's tropical climate conditions, have not been adequately documented. As a result, many studies continue to rely on assumptions from international standards that may not correspond with actual Indonesian conditions.

Studies that explicitly connect LCC analysis results with the achievement of points in the GBCI Material Resources and Cycle Greenship category remain limited. Such integration is necessary to demonstrate the economic and environmental value of sustainable material selection.

Most LCC research in Indonesia focuses on concrete structures and MEP systems. Comparative analysis of building envelope components, including walls, glazing systems, and roofs, which have substantial effects on cooling loads in tropical climates, remains limited.

The novelty of this study lies in integrating Life Cycle Cost (LCC) analysis of eco-friendly building materials with a quantitative evaluation of GBCI Greenship point contributions, specifically focusing on office building envelope components in Indonesia's tropical climate. This integrated approach has not been extensively addressed in previous studies. Based on the identified research gaps, the objectives of this research are formulated as follows:

This study aims to analyze the economic feasibility of environmentally friendly materials in office buildings through the Life Cycle Cost approach to support the achievement of GBCI Greenship certification.

The results of this study are expected to serve as a basis for decision-making among construction practitioners in selecting economically and environmentally optimal materials while accelerating the adoption of sustainable construction practices in Indonesia. Practically, the findings are expected to support developers, government agencies, and construction consultants in making data-driven decisions regarding material selection that balances economic feasibility, environmental performance, and green certification objectives.

METHOD

This study used a quantitative approach with a comparative case study method. This approach was selected to compare the Life Cycle Cost (LCC) of conventional materials and environmentally friendly materials used in the envelope components of office buildings. The analysis was conducted through simulation based on secondary data and technical assumptions derived from national standards and relevant literature.

The research object was a five-storey office building with a total floor area of 5,000 m^2 located in Jakarta. The analyzed building components were limited to the building envelope, including:

a) Outer walls: red brick versus autoclaved aerated concrete (AAC) blocks
b) Concrete structures: conventional concrete versus geopolymer concrete
c) Façades: clear float glass versus low-emissivity (low-e) glass

The LCC analysis period was set at 30 years in accordance with the SNI 03-7065:2005 and ISO 15686-5:2017 standards for service-life planning in commercial buildings (Emere et al., 2025; Standardization, 2017). The discount rate of 8% was selected based on Bank Indonesia's benchmark interest rate (BI Rate) in 2025, following the recommendation of Fuller and Petersen (1996) for public building investment analyses (Kneifel et al., 2022). The collected data included:

1) Unit prices of materials obtained from the Harga Satuan Pokok Kegiatan (HSPK) DKI Jakarta 2025 and market surveys.
2) Technical data of materials, including thermal conductivity, service life, and maintenance requirements (Widyatmoko & Nugroho, 2022).
3) Cooling energy consumption data obtained from simplified simulations using material U-value parameters.
4) Requirements for obtaining GBCI Greenship v1.2 points in the Material Resources and Cycle category.
5) Life Cycle Cost (LCC) calculations, which were performed using the following equation:

$$LCC = C_0 + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} - \frac{S_n}{(1+i)^n} \qquad (1)$$

where: C0 is the initial cost, Ct is the Cost in the tth year, i is the Discount rate, n is the Service life [30 years], and Sn is the residual value at the end of the period[operation][maintenance][energy]. The cost components calculated include initial cost, cooling energy cost, maintenance cost, and residual material value (Kurniawan & Pratama, 2019; Utomo et al., 2022).

Table 1. Basic LCC Assumptions for Environmentally Friendly and Conventional Materials

Parameter	Conventional Material	Eco-Friendly Material	Unit	Source
Exterior Wall (per m^2)	IDR 285,000	IDR 320,000	IDR/m^2	HSPK DKI 2025
Concrete Structure (per m^3)	IDR 1,800,000	IDR 2,050,000	IDR/m^3	HSPK DKI 2025
Glass Facade (per m^2)	IDR 750,000	IDR 920,000	IDR/m^2	Market Survey
Total Wall Area	2,000	2,000	m^2	Building Data
Total Concrete Volume	1,200	1,200	m^3	Building Data

Parameter	Conventional Material	Eco-Friendly Material	Unit	Source
Total Glass Area	800	800	m^2	Building Data
Cooling Energy (Wall)	45 kWh/m^2/yr	35 kWh/m^2/yr	kWh/m^2/yr	SNI 6390:2011
Cooling Energy (Glass)	62 kWh/m^2/yr	48 kWh/m^2/yr	kWh/m^2/yr	SNI 6390:2011
Electricity Tariff (Commercial)	IDR 1,445/kWh	IDR 1,445/kWh	IDR/kWh	PLN Rate 2025
Annual Maintenance Cost	2.0% of initial	1.2% of initial	% init. cost	Literature avg.
Service Life	30 years	30 years	Years	ISO 15686-5
Replacement Interval	15 years	25 years	Years	Manufacturer data
Residual Value at Year 30	5% of initial	8% of initial	% init. cost	NIST Handbook 135
Discount Rate	8%	8%	%	BI Rate 2025

Sensitivity analysis was conducted to determine the effects of changes in discount rates [6%, 8%, and 10%] and electricity prices [baseline, +10%, and +20%] on the total LCC values. For each scenario, the LCC equation was recalculated by systematically varying one parameter while keeping all other variables constant, following the one-at-a-time (OAT) sensitivity approach recommended by Fuller and Petersen (1996). The differences in LCC between conventional and eco-friendly materials under each scenario were then calculated to determine the range of potential economic benefits (Kneifel et al., 2022). The results of the environmentally friendly material selection were evaluated against the Greenship v1.2 criteria, particularly within the following sub-categories:

a) Use of recycled and low-emission materials
b) Use of materials with Environmental Product Declarations (EPDs)
c) Reduction of environmental impacts from material selection

Validation was conducted through two mechanisms. First, the LCC calculation results were cross-checked against published data from comparable studies and official GBCI documentation. Second, structured expert discussions were conducted with two certified green building practitioners, each with a minimum of 10 years of experience in sustainable building projects in Indonesia. The validation instruments included a structured questionnaire addressing the reasonableness of LCC input assumptions, discount rate selection, and material service life values. Both experts confirmed that the assumptions were realistic for the Indonesian context. Minor adjustments to maintenance cost frequencies were subsequently incorporated based on their feedback.

The LCC calculation results were presented in the form of total cost comparisons, accumulated cost graphs over the building service life, and tables illustrating Greenship point contributions. Economic feasibility decisions were determined based on the lowest LCC value and the highest potential certification point achievement.

The calculations were performed using Microsoft Excel with discounted cash flow formulas. Energy consumption simulations were conducted using a manual approach based on the heat transfer calculation method outlined in SNI 6390:2011 (Elkhayat et al., 2025; Goggins et al., 2010). Diagrams and graphs were generated to facilitate the interpretation and presentation of the results.

RESULTS AND DISCUSSION

Life Cycle Cost Calculation Results

The results of the LCC calculations for the three building envelope components over a 30-year period are presented in Table 2. The calculation method follows the ISO 15686-5 standard and the NIST Life Cycle Costing (LCC) manual. The values presented represent the accumulated initial costs, cooling energy costs, maintenance costs, and residual values, calculated using an 8% discount rate.

Table 2. Comparison of Life Cycle Cost of Conventional and Environmentally Friendly Materials

Components	Conventional Materials	Eco-Friendly Materials	LCC Difference	% Savings
Exterior Wall	IDR 2,850,000,000	IDR 2,580,000,000	IDR 270,000,000	9,50%
Concrete Structure	IDR 4,120,000,000	IDR 3,730,000,000	IDR 390,000,000	9,50%
Glass Facade	IDR 1,930,000,000	IDR 1,740,000,000	IDR 190,000,000	9,80%
Total	IDR 8,900,000,000	IDR 8,050,000,000	IDR 850,000,000	9,60%

The results showed that although the initial cost of eco-friendly materials was 12–18% higher than that of conventional alternatives, the total LCC over a 30-year analysis period was 9.5–9.8% lower. The primary sources of savings were reduced cooling energy consumption attributable to the superior thermal performance (lower U-values) of AAC lightweight bricks and low-emissivity (low-e) glass, as well as reduced maintenance requirements and replacement frequency for geopolymer concrete compared with conventional concrete. Table 1 presents a detailed breakdown of the LCC cost components for each material type.

The break-even point was reached within 9 to 11 years. These findings are consistent with the study by Wibowo and Santoso on office buildings in Indonesia's tropical climate (Wibowo & Santoso, 2022).

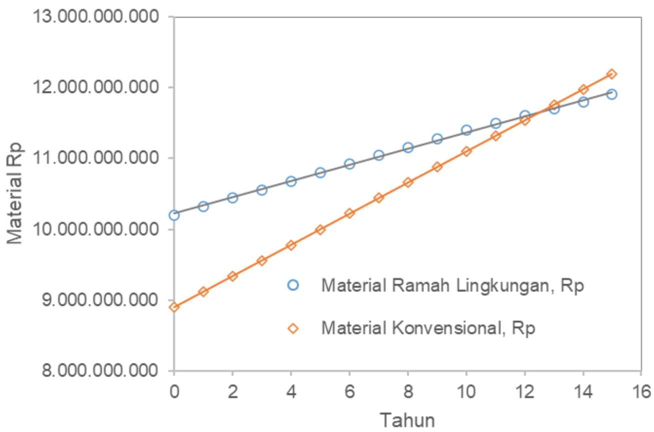

Figure 1 illustrates the cumulative cost accumulation of both types of materials.

The break-even point occurs in the 9th to 11th year, after which eco-friendly materials provide economic benefits.

Sensitivity Analysis

Sensitivity analysis was conducted on the discount rate and electricity price, as recommended by Fuller and Petersen (1996) (as cited in (Azis & Bastini, 2026; Sani et al., 2021) (Kneifel et al., 2022). The results showed that a lower discount rate and higher energy prices increased the economic benefits of using environmentally friendly materials. This finding indicates that investments in green building materials become more financially attractive under conditions where energy prices are expected to increase.

The sensitivity analysis was performed using two primary parameters: the discount rate and electricity price. The results are presented in Table 3.

Table 3. Total LCC Sensitivity Analysis Results

Scenario	Conventional LCC	Eco-Friendly LCC	Differences
6% Off	IDR 9,420,000,000	IDR 8,410,000,000	IDR 1,010,000,000

Scenario	Conventional LCC	Eco-Friendly LCC	Differences
8% Off	IDR 8,900,000,000	IDR 8,050,000,000	IDR 850,000,000
10% Off	IDR 8,470,000,000	IDR 7,760,000,000	IDR710,000,000
Electricity Price +20%	IDR 9,310,000,000	IDR 8,240,000,000	IDR 1,070,000,000

The results show that the lower the discount rate and the higher the energy price, the greater the economic benefits of using environmentally friendly materials. This indicates that investment in green materials becomes more attractive under economic conditions characterized by low interest rates and rising energy prices.

Contribution to GBCI Greenship Certification

The use of environmentally friendly materials contributes to the Material Resources and Cycle category in Greenship v1.2. The application of autoclaved aerated concrete (AAC) lightweight bricks and geopolymer concrete met the criteria for materials containing recycled content of ≥20%, resulting in the achievement of 2 points. The use of low-emissivity (low-e) glass supported by Environmental Product Declaration (EPD) data also fulfilled the criteria for environmentally certified materials.

The total score obtained reached 6 out of the maximum 10 points in this category, which is sufficient to support the achievement of the Silver level certification. This achievement is important considering that the main challenges in implementing green buildings in Indonesia are still associated with relatively high initial investment costs (Wibowo & Santoso, 2022).

Discussion

The results of this study are consistent with the findings of Wibowo and Santoso (2022), who demonstrated that green materials provide long-term economic benefits in office buildings. Similarly, Sathaye and Mastrangelo (2011) reported that energy-efficient envelope materials can reduce Life Cycle Cost (LCC) by 8–15% over a 30–50-year period under comparable climate conditions (Khan et al., 2025). The present study extends these findings by situating the analysis within Indonesia's tropical climate context, where cooling energy consumption represents the dominant operational cost component, a factor that substantially enhances the long-term advantages of low-emissivity (low-e) glass and autoclaved aerated concrete (AAC) materials. Furthermore, Priatama and Kusumawardani (2020) noted that local practitioners in Indonesia rarely consider lifecycle maintenance costs during material procurement decisions, a gap directly addressed by the LCC framework applied in this study (JASDO, 2025).

From a practical standpoint, this finding directly addresses the investment skepticism expressed by construction practitioners who evaluate materials primarily based on initial procurement costs. Through the Life Cycle Cost (LCC) approach, eco-friendly materials are demonstrated to be financially viable, with a cost recovery period of 9–11 years. For developers, this implies that projects with a planned operational lifespan exceeding 15 years have the potential to achieve significant lifecycle savings. For planning consultants, the LCC framework provides a defensible financial justification when recommending green material specifications to cost-sensitive clients.

Beyond economic considerations, the six-point contribution to the GBCI Greenship Material Resources and Cycle category provides substantial non-financial value, including enhanced reputational standing, eligibility for government green building fiscal incentives under Peraturan Menteri PUPR No. 02/2015, and improved market competitiveness. This is particularly significant as institutional investors and multinational tenants increasingly require green-certified buildings as part of Environmental, Social, and Governance (ESG) compliance criteria. For government regulators and the Green Building Council Indonesia (GBCI), the quantified relationship between LCC economics and certification points offers a policy instrument for designing targeted incentive programs to accelerate the adoption of green materials on a broader scale.

The primary limitation of this study is its reliance on secondary data and standardized technical assumptions derived from national standards and previous literature. Therefore, the

LCC results represent simulation-based projections rather than empirically measured field outcomes. Site-specific factors, such as actual construction quality, building occupancy patterns, and local climatic microvariations, may influence real-world LCC outcomes. Future research should validate the LCC model using actual project cost records and measured building energy performance data (Dharmapatni & Wijaya, 2023). Additionally, integration with Life Cycle Assessment (LCA) methodology would enable a more comprehensive sustainability evaluation encompassing both economic and environmental dimensions (Elkhayat et al., 2025; Goggins et al., 2010).

CONCLUSION

This study demonstrates that eco-friendly building materials, specifically AAC lightweight bricks, geopolymer concrete, and low-e glass, require an initial investment that is 12–18% higher than that of conventional materials. Nevertheless, their total Life Cycle Cost (LCC) over a 30-year analysis period is 9.5–9.8% lower, with the break-even point reached between the 9th and 11th years of operation, primarily due to reduced energy consumption and lower maintenance requirements. In addition to their economic advantages, these materials contributed 6 points in the GBCI Greenship v1.2 Material Resources and Cycle category, representing a meaningful contribution toward achieving Silver-level Greenship certification. These findings confirm that environmentally friendly material selection provides both long-term economic benefits and improved green building performance.

The findings have important practical implications for multiple stakeholders. For developers and contractors, the LCC approach provides a rational basis for material selection, particularly for projects with a planned service life exceeding 15 years. For government agencies and GBCI, the demonstrated relationship between LCC benefits and Greenship certification performance offers quantitative evidence to support fiscal incentives, such as tax reductions or green material procurement subsidies, aimed at accelerating sustainable construction adoption in Indonesia. As this study is based on secondary data and technical assumptions, future research should validate the proposed LCC model using actual project cost data and measured building energy performance, while integrating Life Cycle Assessment (LCA) to evaluate environmental impacts alongside economic performance.

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AUTHOR CONTRIBUTION STATEMENT

Asep Suhana contributed to the conceptualization, research design, methodology, data collection, analysis, and preparation of the original manuscript. Hetty Fadriani contributed to data interpretation, validation, and critical review of the manuscript. Handoko Subawi contributed to supervision, technical evaluation, and manuscript refinement.

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