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Enhancement of energy efficiency and sustainability through green building index platinum certification in Malaysian building design

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Abstract:

This paper presents a comprehensive study on enhancing energy efficiency (EE) and sustainability in building design, focusing on implementing the Green Building Index (GBI) Platinum standards for a proposed office development in Malaysia. While international green building standards, such as LEED, BREEAM, and Green Star, offer robust frameworks, they often fail to address Malaysia's tropical climate challenges. The GBI framework bridges this gap by tailoring its criteria to local environmental, social, and economic conditions. This study emphasizes advanced commissioning processes, renewable energy integration, and sustainable maintenance practices, including calculations of U-values, Overall Thermal Transfer Value (OTTV), Total Building Energy Consumption (TBEC), and Building Energy Intensity (BEI) through simulations and optimizations. Results show significant improvements, including OTTV reduced to 39.48 W/m^2, TBEC reduced by over 65%, and BEI decreased by 66% compared to baseline designs. GBI Platinum certification yields higher annual savings and a longer payback period compared to MS1525:2007, with benefits validated through a 4.08-year payback period. This study provides a valuable framework for sustainable building development by addressing Malaysia's climatic challenges and leveraging innovative EE strategies.

Keywords: Energy efficiency; Building performance modelling; Green building index; Sustainable design; Cost-benefit analysis

1. Introduction

The building sector contributes to global energy consumption, accounting for approximately 40% of total energy use and 36% of CO_2 emissions worldwide [1]. Regional variations reveal even higher contributions in developed nations, such as over 30% in the United States and more than 40% in the European Union [2]. In tropical climates such as Malaysia, the energy demand for cooling dominates due to high temperatures and humidity, highlighting the urgent need for tailored solutions to mitigate these challenges [3].
Global green building standards, including Leadership in Energy and Environmental Design (LEED) from the United States [4], the Building Research Establishment Environmental Assessment Method (BREEAM) from the United Kingdom [5], and Australia's Green Star rating system [6] provide frameworks to guide sustainable design. However, these standards often do not fully address unique climatic and socio-economic conditions. Recognising this gap, Malaysia developed the Green Building Index (GBI), which incorporates metrics such as Overall Thermal Transfer Value (OTTV) and Building Energy Intensity (BEI) to assess energy efficiency (EE) in tropical climates [7].
The GBI framework offers localised solutions while aligning with global sustainability goals.
Recent advancements in construction materials provide innovative opportunities to improve EE. Insulation materials, such as novel plasters, reduce heat transfer coefficients by up to 47.9%, while bamboo fibre-reinforced briquettes enhance thermal resistance by 49.9%, offering sustainable and cost-effective retrofitting solutions [8, 9]. Superinsulation technologies like aerogels and vacuum insulation panels further reduce heat loss coefficients by over 60%, though their widespread use faces cost and implementation barriers [10, 11].
Similarly, the building envelope plays a critical role in EE. Advanced glazing systems and vertical greenery integrated into façades enhance thermal performance, reduce cooling loads, and lower carbon emissions [12, 13]. Roof systems incorporating phase-change materials (PCM) and photovoltaic (PV) panels provide additional energy savings, sup-

porting net-zero energy goals [14, 15].
Building Information Modeling (BIM) is a pivotal technology in modern building design. BIM facilitates multidimensional simulations that integrate energy analysis, material selection, and carbon footprint assessment from the beginning of the design phase. Its advantages are significant, including identifying design flaws before construction, thereby optimising energy performance and ensuring cost efficiency [16]. Tools like Dynamo further enhance BIM's capabilities, allowing for advanced workflows such as embodied carbon calculations and error minimisation, which can lead to more sustainable design outcomes [17]. However, the adoption of BIM is not without its challenges. The high implementation costs, the necessity for specialised skills among personnel, and issues related to data interoperability can pose barriers to its widespread use [17]. Furthermore, while BIM provides a robust framework for planning and simulation, the actual performance of buildings can vary due to unforeseen construction quality issues, changes in occupancy patterns, or shifts in environmental conditions [18]. Despite these limitations, BIM has become a cornerstone technology in architecture, offering invaluable insights into the lifecycle performance of buildings, particularly in tropical climates where EE is crucial. By leveraging BIM, designers and planners in Malaysia can simulate how different building materials, orientations, and systems interact with the local climate, thus tailoring solutions that align with the GBI standards for sustainable development [19].
This study explores the integration of advanced materials, renewable energy systems, and BIM-based simulations to enhance the achievement of GBI Platinum certification in Malaysia's tropical climate, addressing a significant gap in the literature by offering a holistic approach to EE in buildings. While previous studies have concentrated on singular elements of sustainability, this research innovatively combines these aspects into a comprehensive framework tailored to local climatic conditions. This originality fills an existing research void and sets expectations for significant EE gains, cost savings, and environmental benefits. Potential limitations include the variability in simulation accuracy and real-world performance. The forthcoming sections detail the methodology, including energy performance modelling, material evaluation, and cost-benefit analysis, providing insights into how these techniques can practically advance GBI's application, improve building performance, and support Malaysia's sustainability objectives.

2. State-of-the-ART

The initial phase of EE modelling in building design involves meticulous planning and feasibility studies to establish specific sustainability and energy conservation objectives. Key stakeholders, including architects, engineers, project managers, and GBI consultants, are engaged early to ensure alignment and integration of expert insights into the planning process. Comprehensive feasibility studies are essential for gathering relevant data, reviewing GBI criteria, and evaluating the project's viability [20]. Advanced simulation tools like EnergyPlus are utilised to analyse the building's interaction with its environment, optimising orientation and shading coefficients to minimise direct solar radiation and reduce cooling loads [16].
Calculations of thermal properties are essential to refine the building's energy performance further. The thermal performance of a building envelope is typically measured using U-values, which indicate the heat transfer rate through building components, and the OTVV, which assesses the thermal performance of the entire building envelope. U-values and OTTV calculation refine the building envelope to enhance energy performance [16, 21]. This thorough planning and feasibility assessment ensure that projects are well-prepared to meet GBI certification standards. Early stakeholder involvement aids in understanding and mitigating risks and making informed decisions about the design and construction processes. This collaborative approach fosters innovation and ensures that all aspects of the building's performance are considered and optimised from the very beginning. This stage is crucial for laying a solid foundation that guides the subsequent design and construction phases, ensuring that EE goals are consistently prioritised [16].
In Southeast Asia, particularly in tropical climates, specific strategies have been developed to address EE. As reported in [22], a comprehensive review of organisational energy reduction policies across Southeast Asia underscores the importance of retrofitting, Low-Carbon Buildings (LCB), and Energy Management Systems (EMS) in reducing carbon footprints, with retrofitting showing varied effectiveness depending on existing building conditions. Similarly, research reported in [23] highlights the potential for energy savings through strategic building design, demonstrating that using low thermal conductance materials for building walls can reduce energy demand by up to 28% and advocating for passive techniques like natural ventilation and shading to enhance thermal comfort without heavy reliance on mechanical cooling systems.
The implementation and verification phase involves installing specified heating, ventilation, and air conditioning (HVAC) systems, renewable energy systems, and smart building controls followed by comprehensive commissioning. Detailed commissioning plans and functional testing are critical for verifying system performance under operating conditions [16]. This phase also includes a cost-benefit analysis, evaluating initial investment costs and projected annual savings to determine the financial viability of EE measures [24]. Iterative processes in simulation and optimisation, where models are continuously refined based on simulation results, are essential for meeting predefined energy targets [25]. Integrating lighting zoning, electrical sub-metering, and building-integrated photovoltaic systems has significantly reduced energy usage and enhanced building performance [26]. Furthermore, advanced controls and automation in lighting and HVAC systems can lead to substantial energy savings by ensuring that energy is used only when and where it is needed [27]. This phase underscores the importance of a holistic approach to implementation, where technology and human factors are seamlessly integrated to achieve the desired outcomes. The successful implementation of these systems improves EE and enhances occupant comfort and building functionality [28, 29].

Sustainable maintenance practices are crucial for the long-term performance of energy-efficient systems. Establishing dedicated maintenance teams and developing comprehensive long-term maintenance plans ensure systems perform as intended beyond the initial commissioning phase. Ongoing commissioning and maintenance are necessary to sustain high energy performance [30, 31]. By integrating advanced simulation tools, rigorous commissioning processes, and sustainable maintenance, stakeholders can achieve substantial energy savings and comply with high standards like GBI Platinum [32]. This holistic approach significantly improves building performance, contributing to developing more sustainable building designs that are better adapted to local environmental conditions [33]. Moreover, the commitment to sustainable maintenance practices helps extend the lifespan of building components and systems, reducing the overall environmental impact [34]. Continuous monitoring and optimisation of building systems through energy management systems and regular maintenance activities ensure that EE measures remain effective over time, providing long-term energy savings, operational costs, and environmental sustainability [35, 36]. This phase is essential for maintaining the integrity of energy-efficient designs and ensuring that the benefits of initial investments are realised and sustained throughout the building's lifecycle [37].

3. Methodology

This section covers the overall methodology proposed in this paper. Fig. 1 elucidates the flowchart of the proposed methodology. The process in the figure includes planning

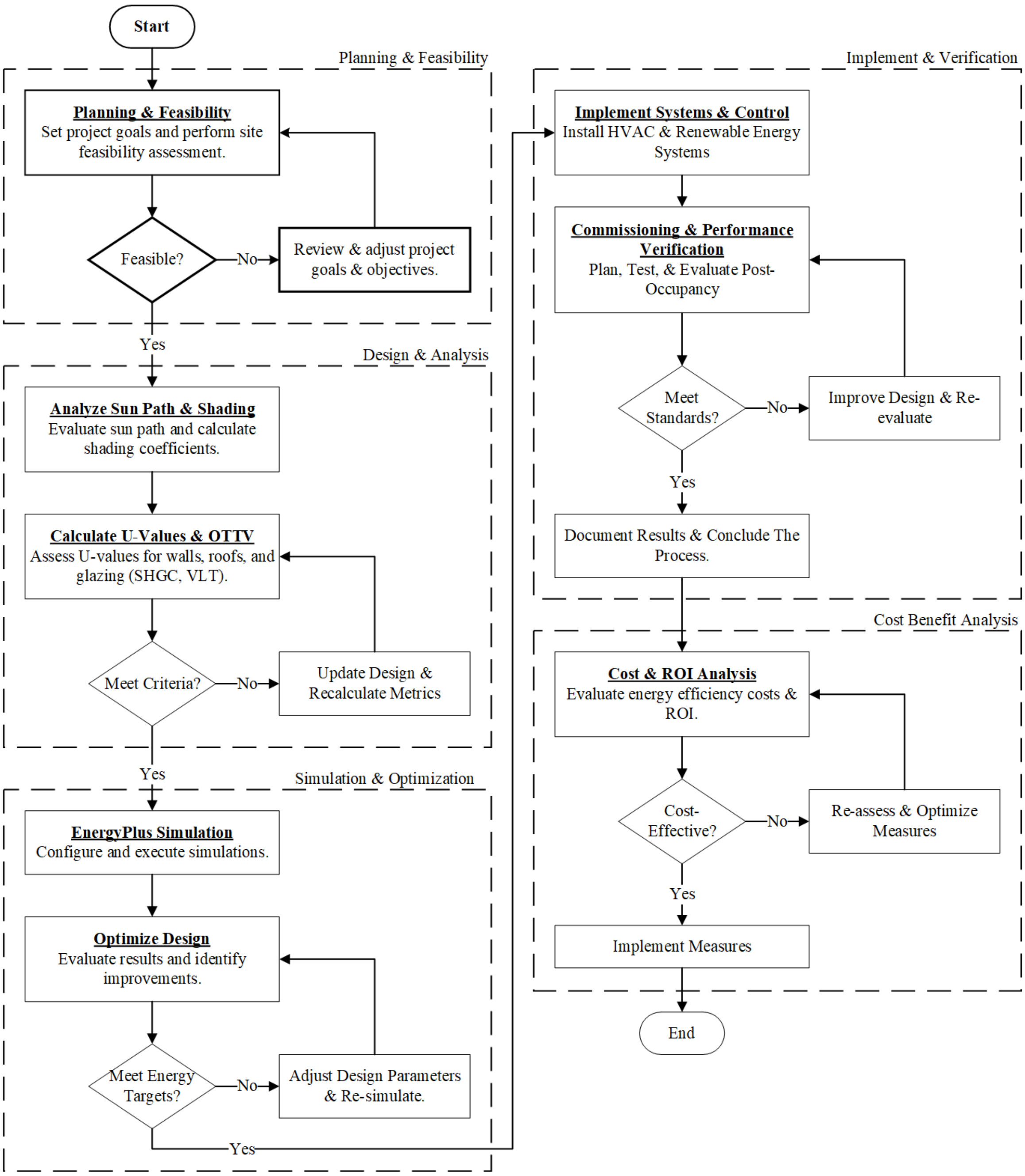

Figure 1. Methodology flowchart.

and feasibility, design and analysis, simulation and optimisation, implementation and verification, and cost-benefit analysis stages utilised in this study [3, 38]. Each stage is critical to ensuring the project's success and alignment with the GBI standards for EE and sustainability.

This study selects an office building as the case study. The choice is strategic due to consistent occupancy patterns and HVAC requirements conducive to detailed energy performance analysis. Office buildings are known for significant energy consumption, particularly from lighting, cooling, and heating systems. This focus demonstrates substantial potential for energy savings and cost reductions, providing a practical example of how GBI Platinum standards can be effectively applied in a typical commercial setting.

3.1 Planning and feasibility

The initial phase of the methodology involves defining the project scope and establishing specific objectives, setting the foundation for all subsequent phases. This phase begins with articulating the overall goals of achieving EE and sustainability, including benchmarks for reducing energy consumption, improving building performance, and enhancing occupant comfort. Key stakeholders, such as architects, engineers, project managers, and GBI consultants, are identified and involved early to ensure alignment and integration of expert insights into the planning process.

A comprehensive feasibility study and site assessment are then conducted to gather relevant data, review GBI criteria and evaluate the project's viability. This includes assessing environmental, technical, and economic feasibility to identify potential challenges and opportunities. At this stage, a critical decision is made regarding the project's feasibility. Suppose the feasibility study and site assessment indicate that the project can be realised within the defined scope and objectives. In that case, it moves to the design and analysis phase, finalising planning documents and preparing for detailed design work. However, if significant challenges are identified, the project scope and objectives may need re-evaluation, potentially modifying the design approach or reassessing the site.

3.2 Design and analysis

The design and analysis phases are pivotal in evaluating and optimising the energy performance of the building design. This phase includes a comprehensive examination of the building's interaction with its environment and the thermal performance of its materials and structure. Advanced simulation tools such as EnergyPlus are initially employed to analyse the sun's path and potential shading from surrounding structures. This analysis provides detailed insights into how the building interacts with sunlight throughout the year, enabling the optimisation of building orientation and the calculation of shading coefficients. These coefficients help minimise direct solar radiation, reduce cooling loads, and enhance EE.

Next, the thermal performance of the building envelope is evaluated by calculating U-values and the OTTV. U-values for walls, roofs, and glazing materials are determined to assess their insulation effectiveness [39]. The formula used to calculate the U-value for the roof U_{roof} is given in (1):

$$U_{\text{roof}} = \frac{1}{U_{\text{total}}^{\text{roof}}} \text{W/m}^2\,\text{K} \tag{1}$$

From the equation, $R_{\text{total}}^{\text{roof}}$ is the total thermal resistance of the roof, which represents the sum of the thermal resistances of all individual layers of the building component, including any associated air films. In addition, the OTTV is calculated to assess the thermal performance of the entire building envelope [40]. Its value accounts for the combined effect of walls, roofs, and glazing materials. Equation (2) is used to calculate the OTTV of the building:

$$\begin{aligned} \text{OTTV} =& (15 \times (1 - \text{WWR}) \times U_{\text{wall}}) + (6 \times \text{WWR} \times U_{\text{wall}}) \\ &+ (194 \times \text{WWR} \times SC_{\text{total}}) \end{aligned} \tag{2}$$

where,
WWR = Window-to-wall ratio,
U_{wall} = U-values for the wall,
U_{window} = U-values for the window,
SC_{total} = Total shading coefficient

At this phase, a critical decision is made to determine if the design meets the required EE criteria. The project proceeds to the Simulation and Optimization phase if the design meets the requirements. If it does not, the design elements are revised, and the calculations for U-values and OTTV are re-evaluated. This iterative process ensures the building design is optimised according to EE and sustainability goals before moving forward.

Fig. 2 illustrates an example of the building elements considered for OTTV calculation. In the figure, the blue line highlights the facade walls and windows, which are crucial for the OTTV calculation. These elements are part of the building envelope and directly exposed to the external environment. Their thermal properties significantly influence the building's EE by controlling heat transfer between the conditioned interior and the outside. In contrast, car park areas, mechanical rooms, and emergency staircases are represented by red lines. These elements are excluded

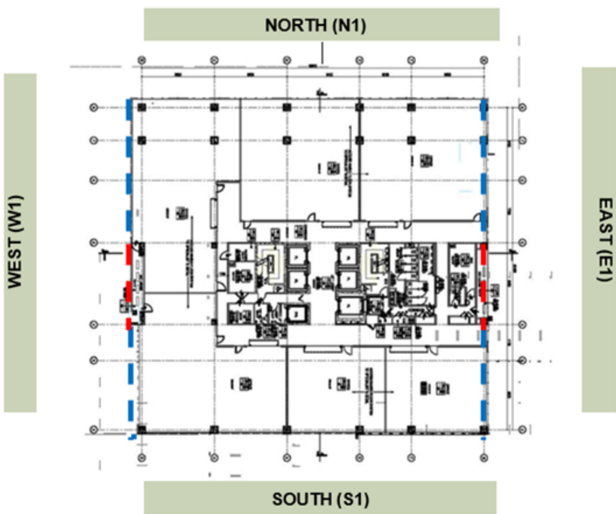

Figure 2. Example of OTTV calculation areas.

from the OTTV calculation because they are not part of the building envelope. Areas marked in red are typically unconditioned spaces with minimal impact on the overall thermal performance of the building envelope.

3.3 Simulation and optimization

This phase begins by creating detailed models incorporating essential input data such as building geometry, material properties, HVAC systems, and occupancy schedules. Using EnergyPlus software, detailed models simulate the building's operating conditions, representing both baseline and improved design scenarios to evaluate energy performance comprehensively.

The Total Building Energy Consumption (TBEC) is first calculated to provide a baseline of the building's energy demand across systems [41]. TBEC is derived using (3).

$$\text{TBEC} = \sum(\text{Rated Load} \times \text{Diversity Factor} \times \text{Operational Hours}) \tag{3}$$

In (3), the rated load is the peak power demand for each system, the diversity factor accounts for typical occupancy patterns, and Operational Hours represent annual usage specific to each system. This calculation allows for targeted adjustments to energy-intensive systems, supporting EE goals aligned with GBI standards. Following TBEC, the Building Energy Intensity (BEI) is calculated to measure the EE per unit area using (4).

$$\text{BEI} = \frac{\text{Annual Energy Consumption (kWh)}}{\text{Total Building Floor Area (m}^2\text{)}} \tag{4}$$

The simulation results identify areas for improvement in energy performance, enabling design modifications such as insulation levels, window glazing, and HVAC settings to optimise EE. While simulations are powerful tools for predictive analysis, they rely on certain assumptions and inputs which may not fully account for real-world complexities or unforeseen costs during construction and operation. Factors like construction quality, occupant behaviour, or climatic variations can introduce variability in actual performance compared to simulated outcomes.

To address these challenges, it is beneficial to validate simulation results against real-world data where possible. This validation can be done through field measurements, ongoing monitoring, and post-occupancy evaluations. Comparing simulated and measured performance helps identify discrepancies and refines simulation models to better mirror actual conditions. This practice not only strengthens the methodology but also enhances the reliability of the research findings, ensuring that the final design aligns with performance goals before proceeding to the Implementation and Verification phase.

3.4 Implement and verification

This phase begins by installing the specified HVAC systems, renewable energy systems such as rooftop solar PV, and smart building controls, including occupancy-based lighting and demand-controlled ventilation. Ensuring all components are installed correctly and integrated to function cohesively is crucial. Following the installation, the phase continues developing a detailed commissioning plan outlining the steps for pre-functional testing. The plan must verify that each system and component operates as intended in isolation.

Consequently, the functional test ensures that all systems work together as designed. The test includes a post-occupancy evaluation to verify the building's performance under operating conditions. The key decision point is to assess whether the building's performance meets the established standards. The processes and results are documented and concluded comprehensively if the performance criteria are met. In contrast, areas for improvement must be identified, and design adjustments must be implemented. The building's performance must be re-evaluated following these adjustments to align with the desired standards. This iterative verification process is crucial to achieving optimal EE and functionality in the building.

3.5 Cost-benefit analysis

This phase begins by assessing the cost implications of EE measures and systems. It is crucial to analyse initial investment costs and the projected annual savings thoroughly. This calculation involves detailed cost estimation for installing energy-efficient technologies, such as advanced HVAC systems, renewable energy installations, and smart building controls. Additionally, maintenance and operational costs must be considered to provide a comprehensive financial overview [42]. Then, the Return on Investment (ROI) is calculated using the equation given in (5):

$$\text{ROI} = \frac{\text{Annual Savings}}{\text{Initial Investment}} \times 100 \tag{5}$$

The ROI calculation is essential in determining the viability of the proposed EE investments. A higher ROI indicates a more financially beneficial investment because it reflects more significant savings relative to the initial expenditure. However, energy prices and construction costs can fluctuate, potentially affecting ROI. To account for this, a sensitivity analysis is implemented, where costs and savings are expressed as percentages of the base design's annual electricity bill, providing insight into how changes in energy prices might impact the investment's effectiveness. This analysis aids in justifying the investment to stakeholders, prioritising which EE measures to implement based on their cost-effectiveness and ensuring that the measures provide significant financial returns while enhancing the building's overall energy performance and sustainability.

4. Results and analysis

This section outlines improvements to the proposed office development at Persiaran Setia Cemerlang, Setia Alam, Malaysia, emphasising the implementation of MS1525:2007 and GBI Platinum certification criteria over baseline design specifications. The following sections provide an in-depth analysis of how these EE performance targets are achieved. Additionally, an examination of incremental costs associated with implementing these enhancements based on MS1525:2007 and GBI Platinum standards is included, along with a cost-benefit analysis of this case study presented at the end of this section.

4.1 EE performance

The EE performance criteria used in this project are based on the GBI Platinum certification standards [43], with several aspects also aligning with the MS1525:2007 guidelines [44]. While the GBI Platinum criteria comprehensively cover all nine performance areas, MS1525:2007 only provides specific guidance on select criteria. The requirements are as follows:

i) Minimum EE Performance
ii) Lighting Zoning
iii) Electrical Sub-metering
iv) Renewable Energy
v) Advanced EE Performance
vi) Enhanced Commissioning
vii) Post-Occupancy Commissioning
viii) EE Verification
ix) Sustainable Maintenance

4.1.1 Minimum EE performance

The building envelope specifications were analysed and enhanced to align with the MS1525:2007 and GBI Platinum criteria to achieve the minimum EE performance. Table 1 provides a detailed comparison of key specifications for the walls, windows, and roofs, contrasting the base design with the requirements set by MS1525:2007 and the more rigorous GBI Platinum standards. This comparative analysis highlights the improvements across critical building envelope elements that contribute to achieving enhanced EE.

For the walls, the base design employs a grey external finish with high solar absorption (0.95) and spandrel glass integrated with brickwork and aluminium, resulting in a U-value of 2.06 W/m^{2}K. To meet the EE goals outlined in MS1525:2007 and GBI Platinum, additional shading devices (aluminium fins with a reflectance (R2) value of less than 0.3) were introduced to minimise heat gain from solar exposure. The window glazing shows significant thermal performance and solar control advancements as the design transitions from the base to the proposed standards. The base design features laminated glass with a U-value of 5.7 W/m^{2}K and a Shading Coefficient (SC) of 0.40, which is then upgraded in the MS1525:2007 standard to 6 mm ASG Green Tempered Glass, reducing the U-value to 4.3 W/m^{2}K and SC to 0.25. Further enhancement under GBI Platinum introduces double glazing with ceramic printing and airspace, yielding a U-value of 1.92 W/m^{2}K and an SC of 0.21, significantly reducing thermal transmittance and solar heat gain. These glazing improvements reduce the need for artificial cooling by lowering solar load through the windows. The roof specifications improved RC flat slab and metal roof types by adding extruded polystyrene insulation.

Table 1. Comparison of building envelope specifications for base, MS1525:2007, and GBI platinum standards.

Building Envelope Specification	Criteria		
	Base	**MS1525:2007**	**GBI Platinum**
Wall	• The design specifies a grey colour for external plastered wall surfaces, with a solar absorption value of 0.95. • Spandrel glass incorporates brickwork and 4 mm aluminium without a backpan or insulation, resulting in a U-value of 2.06 W/m^{2}K • In line with the design intent, vertical aluminium fins with a depth of 750 mm serve as shading devices with a reflectance (R2) value of less than 0.3.		
Window	**Glazing Type**		
	Laminated glass with 8 mm Eurogrey Heat Strengthened Tempered Glass	6 mm ASG Green Tempered Heat-soaked Soft Coated Solar Control TCS	Double-glazed glass with 8 mm ASG Green Float, 30% ceramic printing, 12 mm airspace and 8 mm ASG Green Float
	U-Value (W/m^{2}K)		
	5.7	4.3	1.92
	Shading Coefficient (SC)		
	0.40	0.25	0.21
	Visible Light Transmittance (VLT) (%)		
	48	40	48
Roof	**RC Flat Slab Roof Type**		
	RC flat slab with waterproofing and screed to fall	RC flat slab with waterproofing, extruded polystyrene insulation board, and screed to fall	RC flat slab with waterproofing, extruded polystyrene insulation board, and screed to fall
	RC Flat Slab Roof U-Value (W/m^{2}K)		
	2.42	0.56	0.56
	Metal Roof Type		
	Basic	Metal roof with extruded polystyrene insulation board	Metal roof with extruded polystyrene insulation board
	Metal Roof U-Value (W/m^{2}K)		
	2.88	0.37	0.37

Initially, the base RC flat slab roof with a U-value of 2.42 W/m^{2}K was modified with insulation to achieve a U-value of 0.56 W/m^{2}K, consistent with GBI Platinum standards. Similarly, the base metal roof design's U-value decreased from 2.88 W/m^{2}K to 0.37 W/m^{2}K with insulation, reducing thermal gain and improving the roof's EE.

Fig. 3 shows the OTTV for Base, MS1525:2007, and GBI Platinum specifications, which further illustrates the impact of these design modifications on the building's thermal performance. The base design exhibits an OTTV of 66.59 W/m^{2}K, representing a higher thermal transfer rate that would increase cooling demand. Adopting MS1525:2007 specifications reduces the OTTV to 49.58 W/m^{2}K, reflecting the effectiveness of improved materials and structural adjustments in limiting heat transfer. Advancing to GBI Platinum standards further reduces the OTTV to 39.48 W/m^{2}K, underscoring the benefits of additional insulation, high-performance glazing, and shading devices in achieving superior EE. The progressive decrease in OTTV from the base design to MS1525:2007 and GBI Platinum standards demonstrates the cumulative effect of each EE enhancement, with each stage contributing to a reduction in thermal load. Together, the improvements shown in the results indicate a significant enhancement in EE, helping to lower cooling energy requirements and promoting a more comfortable indoor environment with reduced energy consumption.

To further assess the financial implications of achieving GBI Platinum standards, additional cost analyses were conducted on the proposed upgrades for windows and roofs, as outlined in Table 1. Table 2 tabulates the incremental costs of upgrading the window glazing from the baseline laminated glass to more advanced materials under MS1525:2007 and GBI Platinum standards. As indicated, the transition to ASG Green Tempered Heat-Soaked Solar Control glass for MS1525:2007 adds an incremental cost of MYR 246,000. In contrast, the double-glazed glass required for GBI Platinum certification incurs a significantly higher incremental cost of MYR 902,000.

Table 3 details the incremental costs associated with roof enhancements, specifically the addition of extruded polystyrene insulation for both the RC flat slab and metal roof types. The analysis reveals that the upgrade to insulation, necessary to achieve both MS1525:2007 and GBI Platinum requirements, incurs a total incremental cost of MYR 101,100. This cost-effective measure significantly reduces thermal transmittance through the roof, as illustrated by the U-value improvements discussed in Table 1 and contributes directly to the lowered OTTV observed in Fig. 3.

Table 4 summarises the total incremental cost needed for these upgrades, particularly in high-performance window glazing and roof insulation, amounting to MYR 1,249,100. These costs cover the window glazing and roof insulation improvements, with no additional expenditure for wall enhancements, as the base wall specifications meet MS1525:2007 and GBI Platinum criteria. In addition to these improvements, GBI Platinum certification mandates the installation of a Building Management System (BMS). The BMS supports effective energy management and monitoring, enhancing the building's overall operational efficiency. The installation cost for the BMS is MYR 1,000,000. Therefore, the total incremental cost to achieve GBI Platinum standards, including the BMS, amounts to MYR 2,249,100. This investment information is crucial for the upcoming cost-benefit analysis to evaluate the potential long-term savings and performance benefits associated with these EE measures.

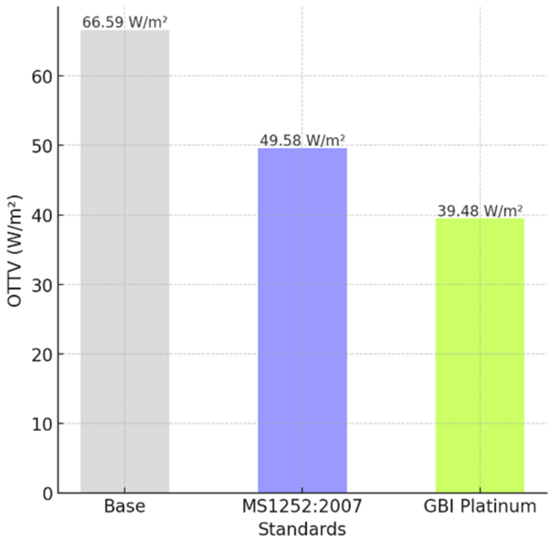

Figure 3. OTTV for base, MS1525:2007, and GBI platinum specifications.

4.1.2 Lighting zoning

Fig. 4 shows the lighting zones within the office floor plan, highlighting areas equipped with photocell sensors and those with motion detectors. Table 5 provides a breakdown of each zone's area and the type of sensor installed to optimise lighting based on occupancy and daylight availability. Perimeter office areas that benefit from natural daylight are equipped with photocell sensors. Specifically, Zone 1, Zone 2, Zone 4, Zone 5, Zone 7, Zone 9, Zone 12, Zone 14, and Zone 16 have photocell sensors, covering 460.20 m^2. These

Table 2. Incremental cost analysis for window glazing upgrades to meet MS1525:2007 and GBI platinum standards.

Criteria	Material	Area (m^2)	Unit Price (MYR)	Total Price (MYR)	Incremental Cost (MYR)
Baseline	Laminated Glass	4,100	100	410,000	-
MS 1252:2007	ASG Green Tempered Heat-Soaked Soft Coated Solar Control		160	656,000	246,000
GBI Platinum	Double-glazed Glass		380	1,558,000	902,000
Total Incremental Cost to Achieve GBI Platinum					**1,148,000**

Table 3. Incremental cost analysis for roof insulation upgrades to meet MS1525:2007 and GBI platinum standards.

Criteria	Material	Area (m^2)	Unit Price (MYR)	Total Price (MYR)	Incremental Cost (MYR)
Baseline	RC Flat Slab Roof	1,314.53	-	-	-
	Metal Roof	444.56	-	-	
MS 1252:2007	RC Flat Slab Roof with Insulation	1,314.53	60.00	78,872	101,100
	Metal Roof with Insulation	444.56	50.00	22,228	
GBI Platinum	RC Flat Slab Roof with Insulation	1,314.53	60.00	78,871	-
	Metal Roof with Insulation	444.56	50.00	22,228	
Total Incremental Cost to Achieve GBI Platinum					**101,100**

Table 4. Total incremental cost summary for achieving GBI platinum certification across building components.

Item	Total Cost (MYR)
Wall	-
Window	1,148,000
Roof	101,100
Building Management System	1,000,000
Total Incremental Cost	2,249,100

sensors adjust lighting levels based on natural light to reduce unnecessary artificial lighting. The remaining zones (Zone 3, Zone 6, Zone 8, Zone 10, Zone 11, Zone 13, and Zone 15) are equipped with motion detectors and cover a total area of 365.35 m^2. These sensors automatically switch off lights when no occupants are present, enhancing energy savings in rentable office spaces. Together, the zones with motion sensors account for 44.26% of the total net lettable area (NLA) of 825.55 m^2, exceeding the 25% requirement stipulated by GBI for occupancy-sensing lighting controls. The lighting zoning strategy implemented across Level 2 to Level 16 combines daylight-responsive photocell sensors in perimeter zones with motion detectors in interior zones. This design maximises EE by adjusting lighting based on real-time occupancy and daylight conditions to meet GBI Platinum requirements for sustainable lighting control. The total cost for implementing these lighting controls is MYR 100,000.

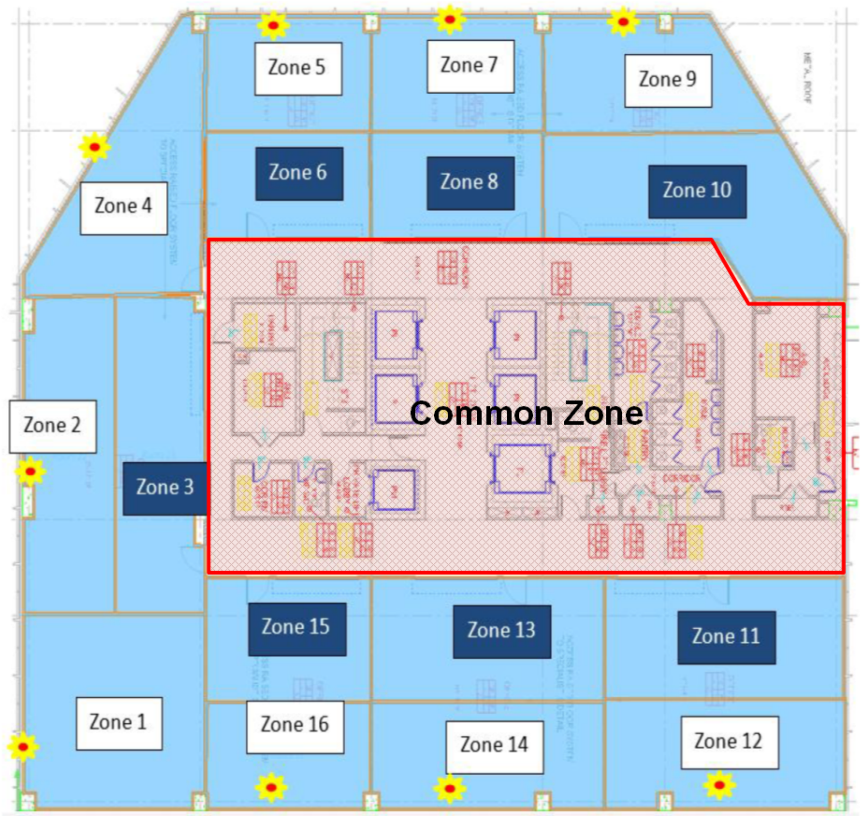

Figure 4. Lighting zoning plan with photocell and motion sensors for energy-efficient lighting control.

Table 5. Summary of area and sensor type for each lighting zone in the office floor plan.

Zone	Area (m^2)	Sensor Type
Zone 1	71.82	Photocell Sensor
Zone 2	57.47	Photocell Sensor
Zone 3	57.31	Motion Sensor
Zone 4	60.31	Photocell Sensor
Zone 5	38.71	Photocell Sensor
Zone 6	36.18	Motion Sensor
Zone 7	40.15	Photocell Sensor
Zone 8	37.82	Motion Sensor
Zone 9	47.19	Photocell Sensor
Zone 10	73.17	Motion Sensor
Zone 11	59.47	Motion Sensor
Zone 12	58.47	Photocell Sensor
Zone 13	58.98	Motion Sensor
Zone 14	50.67	Photocell Sensor
Zone 15	42.42	Motion Sensor
Zone 16	35.41	Photocell Sensor

4.1.3 Electrical sub-metering

This project will utilise the EasyLogic PM1120H power and energy meter by Schneider Electric for comprehensive electrical sub-metering, as shown in Fig. 5. This high-precision meter is designed to monitor power and energy consumption with Class 1.0 accuracy. Equipped with RS485 communication capabilities, the meter facilitates efficient data collection and seamless integration with the building management system to enable real-time energy use tracking across different zones. This sub-metering strategy supports the project's EE goals by providing detailed insights into consumption patterns and enabling targeted energy management. It also aligns with GBI Platinum standards for effective energy monitoring.

Table 6 outlines the cost implications for deploying the proposed sub-metering strategy across multiple building levels. To implement this strategy and support the project's goal of achieving GBI Platinum certification, RM 300,000 is required to install meters, covering supply and installation expenses. The installation plan includes placing meters strategically across various building levels, with 12 meters on Ground Level 1 to Ground Level 4, 4 meters on Level 1, 42 meters on Level 2 to Level 8, 49 meters on Level 9 to Level 15, 7 meters on Level 16, and 6 meters on Level 17. This distribution ensures that each level has the necessary meters to effectively monitor and manage energy consumption, reinforcing the project's commitment to sustainable and efficient energy use.

Figure 5. EasyLogic PM1120H power and energy meter for electrical sub-metering.

4.1.4 Renewable energy

Fig. 6 illustrates the proposed solar PV system configuration designed to meet GBI Platinum standards. This setup includes PV panels connected to a charger controller, which regulates energy flow into a battery bank for storage. The stored energy is then converted to AC power by an inverter before being distributed to the building's AC load through a distribution board. This configuration provides a dual advantage of direct power supply and stored energy when sunlight is unavailable, ensuring a stable renewable energy contribution.

Table 7 shows the building's energy load based on GBI load estimations using EnergyPlus simulations. Each category, including air conditioning and mechanical ventilation (ACMV), lighting, and equipment, is detailed with its estimated load in kW and annual energy consumption in kWh. This load estimation establishes the baseline total building energy consumption (TBEC) of 2,407,283.48 kWh, which serves as the reference for determining the renewable energy system's contribution.

Table 8 outlines the specifications and expected performance of the proposed PV system. With a total installed capacity of 54.45 kWp, the system is designed to offset approximately 2.04% of the building's annual energy requirements, generating an estimated 49,005 kWh per year. This offset slightly exceeds the 2% renewable energy contribution required for GBI Platinum certification. It is important to note that MS1525:2007 has no requirement for solar panel installation, making the PV system installation a strategic choice solely to meet GBI Platinum standards. The table provides further details, including the number of panels, total panel area, and estimated yield per kWp, ensuring the system is well-optimized to fulfil the GBI requirements for sustainable energy generation. The cost of the PV system installation is MYR 408,375.00.

4.1.5 Advanced EE performance

Fig. 7 illustrates the comparison in cooling load density across three standards. The base design demonstrates the highest cooling load density at 75 BTU/hr per sqft, while GBI Platinum substantially reduces the cooling load density to 66 BTU/hr per sqft. MS1252:2007 sits in between, indicating moderate improvements in cooling efficiency over the base design. These reductions in CLD are largely due to upgrades in building envelope materials, specifically the advanced window glazing and rooftop insulation detailed in Section 4.1.1 The base design's laminated glass was upgraded to high-performance, double-glazed units under GBI Platinum standards, significantly improving thermal control by reducing the U-value and SC. Likewise, adding polystyrene insulation to the roof reduced its thermal transmittance, limiting solar heat gain. Together, these material

Table 6. Sub-metering cost summary by level.

Levels	Number of Meters	Cost per Meter (RM)	Total Cost (RM)
Ground Level 1-4	12	2,500	30,000
Level 1	4		10,000
Level 2-8	42		105,000
Level 9-15	49		122,500
Level 16	7		17,500
Level 17	6		15,000
	Total	**300,000**	

improvements play a critical role in lowering the demand for cooling, thereby reducing energy requirements for maintaining comfortable indoor temperatures.
Table 9 outlines the energy requirements for cooling load across the base design, MS1252:2007, and GBI Platinum standards, showing a clear trend of efficiency improvement and reduced energy consumption as the standards advance. The base design's cooling load is 17,856,000 BTU/hr, with a total refrigerant requirement of 1,488 tons. The cooling efficiency of the air-cooled ducted system is 1.4 kW/ton, resulting in a total power consumption of 2,084 kW and an annual energy consumption of 5,635.14 MWh. This setup reflects a conventional system with relatively high energy demands.
The MS1252:2007 standard introduces enhancements, reducing the cooling load to 16,800,000 BTU/hr and the refrigerant requirement to 1,400 tons. The cooling system under this standard is more efficient, with a 1.2 kW/ton cooling efficiency, lowering the total power consumption to 1,680 kW and the annual energy consumption to 4,542.72 MWh. These improvements indicate moderate gains in EE over the base design, aligning with MS1252:2007's goals.
The GBI Platinum standard achieves the highest efficiency level, with a cooling load reduced further to 15,612,000 BTU/hr and a total refrigerant requirement of 1,301 tons. This standard employs a water-cooled ducted system with a remarkable cooling efficiency of 0.49 kW/ton, resulting in a total power consumption of only 635 kW and a significantly

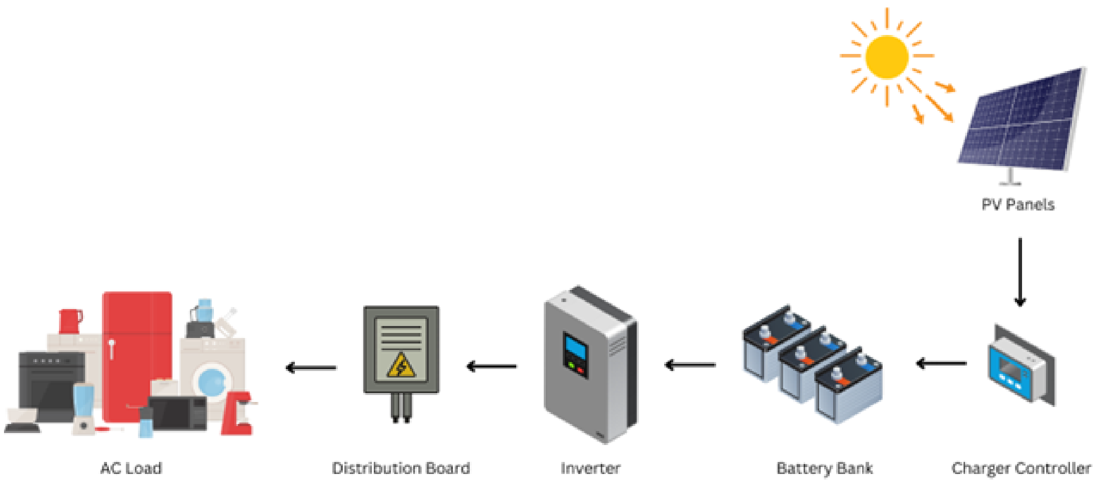

Figure 6. Proposed solar PV system configuration for GBI compliance.

Table 7. Renewable energy load estimation.

EE Index	Rating Load (kW)	Diversity Factor	Estimated Load (kW)	Weekly Energy Consumption (kWh)	Annual Energy Consumption (MWh)
Chiller Plant	635.00	0.85	539.75	28,067.00	1,459.48
AHU	64.26	0.85	54.62	2,840.11	147.69
Mechanical Ventilation	3.00	0.70	2.10	109.20	5.68
Lifts	80.00	0.50	40.00	2,080.00	108.16
Office Lighting	74.00	0.90	66.60	3,463.20	180.09
Common Area Lighting	8.00	0.90	7.20	374.40	19.47
Receptacle Equipment	352.00	0.50	176.00	9,152.00	475.90
Pumps (Domestic Water)	10.00	0.40	4.00	208.00	10.82
Total Building Energy Consumption (TBEC) (MWh)					**2,407.28**

Table 8. Solar PV system specifications and performance.

Description	Amount
TBEC (kWh)	2,407,283.48
2% of TBEC (kWh)	48,145.67
Power Output per Solar Panel (W)	330
Solar Panel Dimensions (mm)	1980 × 991
Number of Solar Panels Installed	165
Total Solar Panel Area (m^2)	313.9488
Total System Capacity (kWp)	54.45
Estimated PV Yield (kWh/kWp/year)	900
Total Annual Energy Generated by PV (kWh)	49,005
Percentage of Energy Supplied by PV (%)	2.04%

lower annual energy consumption of 1,717.04 MWh. These figures illustrate the substantial energy savings of the GBI Platinum standard, driven by the water-cooled system and high-performance building materials.

Table 10 provides a detailed breakdown of the Total Building Energy Consumption (TBEC) across different components and standards, illustrating how energy requirements decrease as standards progress from the base design to GBI Platinum. In the ACMV section, the chiller plant shows significant improvements. The base design chiller plant operates with a rated load of 2,084 kW and a diversity factor of 0.85, resulting in an annual energy consumption of 4,789.87 MWh. Under the MS1525:2007 standard, efficiency improvements lower the chiller's rated load to 1,680 kW, reducing the annual energy requirement to 3,861.31 MWh. The GBI Platinum standard achieves the highest efficiency, with the chiller plant's load dropping to 635 kW and annual energy consumption decreasing dramatically to 1,459.48 MWh. This improvement reflects adopting a more efficient water-cooled system and enhanced building insulation. For the air handling units (AHU), the base design and MS1525:2007 standards maintain a load of 170 kW, each consuming 390.73 MWh annually. GBI Platinum further reduces this load to 64.26 kW, bringing annual consumption down to 147.69 MWh. Similar efficiency gains are observed for the mechanical ventilation system, where the base design and MS1525:2007 standards use 10 kW with an annual energy consumption of 18.93 MWh. In contrast, GBI Platinum reduces these figures to 3 kW and 5.68 MWh. These savings are achieved through motion sensors and timer controllers in low-occupancy areas, such as storage rooms, toilets, and electrical rooms, as well as high-efficiency fans and CO or CO_2 sensors in indoor parking bays and other large rooms with variable occupancy.

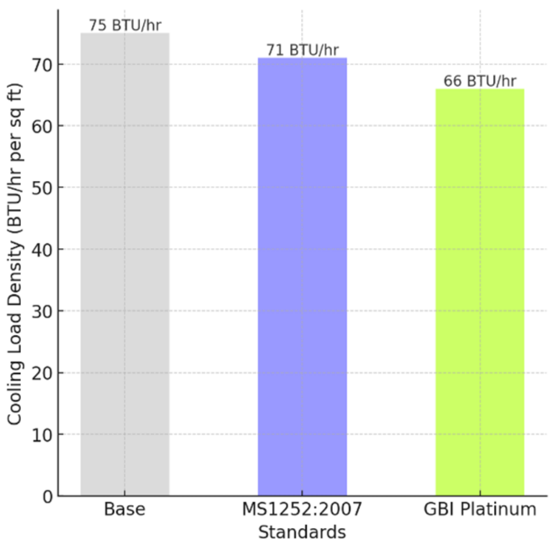

Figure 7. Cooling load density.

The lift system shows efficiency improvements under the GBI Platinum standard. It uses an AC variable voltage and variable frequency (VVVF) motor drive and energy-saving features like sleep mode, gearless drives, and regenerative drives that capture and recycle energy. These enhancements reduce the lift load from 100 kW in the base design and MS1525:2007 standards to 80 kW in GBI Platinum. This enhancement reduces the annual consumption of lift from an annual energy of 135.20 MWh to 108.16 MWh. Lighting also sees progressive improvements. Both office and common zone lighting transition to LED fittings, meeting MS1525:2019 lux level requirements while using less energy. Office lighting drops from 766.58 MWh annually in the base design to 511.06 MWh in MS1525:2007 and further to 180.09 MWh in GBI Platinum. Common zone lighting follows a similar pattern, with loads decreasing from 118 kW in the base design to 8 kW in GBI Platinum. In the other equipment category, receptacle equipment and pumps for domestic water remain consistent across all standards. Receptacle equipment operates at 352 kW with 475.90 MWh annually, while pumps use 10.82 MWh annually at 10 kW. Overall, Table 10 highlights the impact of EE measures. The base design has the highest TBEC at 6,875.19 MWh, which reduces to 5,523.19 MWh in MS1525:2007 and 2,407.28 MWh in GBI Platinum. With an additional 49.005 MWh of PV energy in GBI Platinum, the Net TBEC decreases to 2,362.73 MWh. The cost of implementing GBI Platinum measures is MYR 3,220,000, which includes advanced cooling, ventilation, and lift technologies. The costs associated with lighting and renewable energy integration are detailed separately in Sections 4.12 and Section 4.14, respectively. This combination of energy-efficient systems and on-site renewable energy demonstrates the cumulative benefits of integrated EE measures on building performance.

Fig. 8 illustrates the improvements in Building Energy Intensity (BEI). The base design exhibits the highest BEI, with an energy intensity of 312.65 kWh/m^2/yr, reflecting

Table 9. Energy requirement for cooling load.

Description	Base	MS1252:2007	GBI Platinum
Cooling Load	17,856,000 BTU/hr	16,800,000 BTU/hr	15,612,000 BTU/hr
Total Refrigerant Requirement	1,488 tons	1,400 tons	1,301 tons
Cooling Efficiency	1.4 kW/ton	1.2 kW/ton	0.49 kW/ton
Total Power Consumption	2,084 kW	1,680 kW	635 kW
Total Annual Energy Consumption	5,635.14 MWh	4,542.72 MWh	1,717.04 MWh

Table 10. Total energy requirement.

Description	Base			MS1525:2007			GBI Platinum		
	Rated Load (kW)	Div. Factor	Annual Energy (MWh)	Rated Load (kW)	Div. Factor	Annual Energy (MWh)	Rated Load (kW)	Div. Factor	Annual Energy (MWh)
Air-conditioning and Mechanical Ventilation (ACMV)									
Chiller plant	2,084	0.85	4,789.87	1,680	0.85	3,861.31	635	0.85	1,459.48
AHU	170	0.85	390.73	170	0.85	390.73	64.26	0.85	147.69
Mechanical Ventilation	10	0.70	18.93	10	0.70	18.93	3	0.70	5.68
Vertical Transport									
Lifts	100	0.50	135.20	100	0.50	135.20	80	0.50	108.16
Lighting									
Office	315	0.90	766.58	210	0.90	511.06	74	0.90	180.09
Common Zone	118	0.90	287.16	49	0.90	119.25	8	0.90	19.47
Others									
Receptacle Equipment	352.00	0.50	475.90	352	0.50	475.90	352.00	0.50	475.90
Pumps (Dom. Water)	10.00	0.40	10.82	10	0.40	10.82	10.00	0.40	10.82
TBEC (MWh)			**6,875.19**			**5,523.19**			**2,407.28**
PV Gained (MWh)			**-**			**-**			**49.005**
Net TBEC (MWh)			**6,875.19**			**5,523.19**			**2,362.73**

the conventional energy consumption profile. Adopting the MS1252:2007 standard achieves a moderate reduction, with a BEI of 251.17 kWh/m^2/yr, showcasing improvements in building efficiency due to intermediate energy-saving measures. The GBI Platinum standard demonstrates the most substantial reduction, with the BEI decreasing to 107.24 kWh/m^2/yr. This significant improvement aligns with GBI Platinum's rigorous EE criteria, including advanced building envelope materials, high-performance air-conditioning systems, efficient lighting, and on-site renewable energy sources.

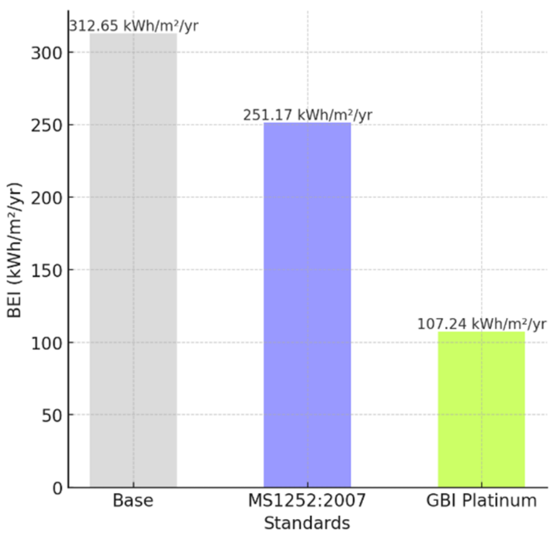

Figure 8. BEI improvement.

4.1.6 Enhanced commissioning

Enhanced commissioning ensures that all energy-related systems within the building are designed, installed, and operated to meet specified performance standards. An independent GBI-recognized Commissioning Specialist (CxS) is appointed at the onset of the design phase to oversee the commissioning process, adhering to ASHRAE Commissioning Guidelines or an equivalent GBI-approved standard. The CxS conducts a design review, incorporates commissioning requirements into tender documents, develops a commissioning plan, verifies system installation and performance, reviews contractor submittals, develops a systems manual, and verifies training for operating personnel. This structured approach supports optimal performance and prepares systems for future operation.

The role of the CxS is to verify that each step is rigorously followed, ensuring compliance and performance standards are met to support GBI certification requirements. Appointing the Commissioning Specialist under this criterion is RM 300,000. This investment reinforces quality assurance, ensuring the building's energy systems align with GBI standards for enhanced performance and operational efficiency.

4.1.7 Post-occupancy commissioning

Post Occupancy Commissioning is implemented to verify that the building's energy-related systems continue to perform as intended once the building is occupied. This process is overseen by the CxS, which conducts a thorough post-commissioning review within 12 months of practical completion or earlier if occupancy reaches at least 50%. This review aims to ensure that system performance remains consistent and aligns with the building's design intent, even as tenancy fit-outs are completed.

The CxS will re-commission all energy-related systems to verify sustained performance and adjust systems as needed based on occupancy patterns. This step involves assessing system operations, confirming tenant modifications do not compromise EE, and fine-tuning installations where necessary. The CxS fee for this post-commissioning process is covered under the enhanced commissioning discussed in Section 4.1.6 The same CxS is retained for a one-time post/re-commissioning effort, ensuring continuity and alignment with original commissioning standards.

4.1.8 EE verification

An energy management system (EMS) will monitor and analyse energy consumption within 12 months of practical completion to verify and optimise the building's energy performance. The EMS integrates sub-meters, digital power meters, and a maximum demand limiting system to provide comprehensive data on energy usage across the building's systems. Fig. 9 illustrates the network configuration of the EMS, showing the connectivity between the local area network, communication units, and various direct digital controller (DDC) controllers used to manage different building systems. This setup is essential for optimising performance and reducing energy consumption by enabling continuous monitoring, control, and adjustment of key building systems.

The EMS will oversee various components, including ACMV, AHU, lighting and plug loads, ventilation fans, and water pumps. It will also provide sub-metering for all primary energy consumers and generate reports for data analysis, helping to manage and limit maximum power demand effectively. This EMS setup will be integrated into the BMS, providing real-time data and allowing ongoing adjustments to meet EE goals. The cost of implementing the EMS is covered as part of the overall BMS system and electrical submetering, which includes energy management functionalities. This integration minimises additional expenses while maximising the building's capacity to maintain efficient energy performance.

4.1.9 Sustainable maintenance

A dedicated maintenance team is established on-site to ensure sustained EE and optimal performance post-occupancy. This team is stationed in a designated office located in the building, providing direct access to operational facilities and enabling timely responses to maintenance needs. The maintenance team operates under a structured facility maintenance and preventive maintenance plan. This plan covers all essential building systems, including HVAC, electrical, IT, and landscape management, aligning with GBI standards for sustainable and efficient operations. An annual budget supports these maintenance activities, ensuring a proactive approach to equipment longevity and system performance is required.

The building maintenance division forms a critical part of the building's operational framework, with specific roles tailored to cover various systems within the facility. Table 11

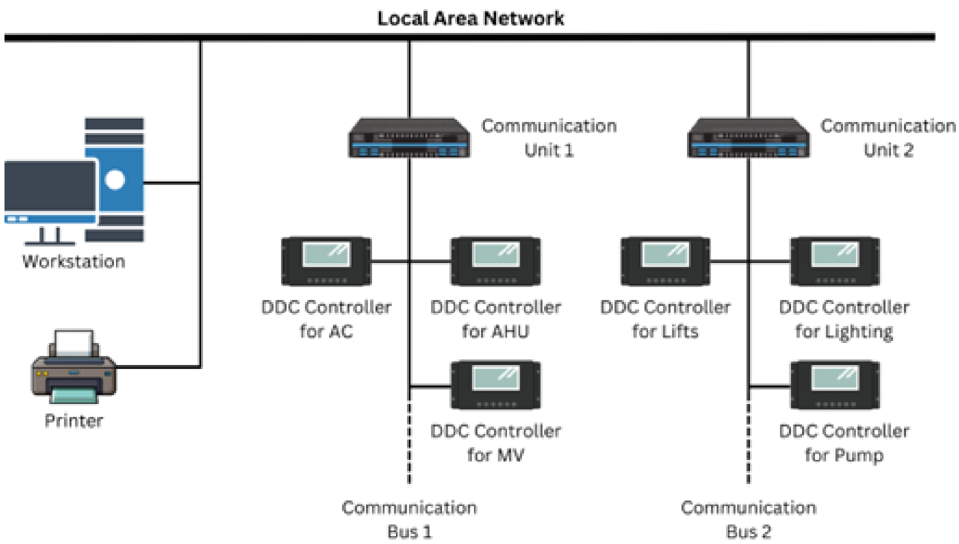

Figure 9. The network configuration of the EMS.

Table 11. Maintenance division staffing and annual salary breakdown.

Job Position	**Job Scope Coverage**	**Annual Salary (MYR)**
Head of Department	Maintenance Manager	96,000
Mechanical Executive	Air Conditioning, Fire Protection, Water Systems	60,000
Electrical Executive	HT/LV Electrical, PV System, Lighting	60,000
ITC Executive	Telecommunications, Public Address, SMATV	60,000
	Total Annual Salary	**276,000**

outlines the core maintenance staff's positions, job scope, and associated annual salaries.

The maintenance team is required to be on board six months before occupancy. Thus, an additional cost of MYR 138,000 is incurred, covering the initial half-year salaries. This proactive measure aligns with sustainable building management practices, reducing long-term repair costs and supporting the building's EE objectives through regular system maintenance and timely updates. This structured approach to maintenance and management ensures that the building consistently meets the high standards established during initial commissioning, enhancing sustainability over its lifecycle.

4.2 Cost-benefit analysis

This section overviews the incremental costs and benefits of achieving GBI Platinum certification, a benchmark for high EE and environmental sustainability standards. Achieving this certification requires an incremental expenditure totalling MYR 6,715,475, covering specific improvements designed to enhance the building's operational efficiency and environmental performance. Table 12 summarises the incremental cost breakdown for implementing the GBI platinum criteria.

From the table, the largest portion, MYR 3,220,000, is dedicated to advanced EE measures that significantly reduce energy consumption beyond baseline requirements. Additionally, MYR 2,249,100 is allocated to meet the minimum EE performance standard, including installing a BMS to monitor and manage energy use effectively. Lighting zoning is budgeted at MYR 100,000 to enable precise control over lighting based on usage patterns, while MYR 300,000 is allocated for electrical sub-metering to facilitate detailed tracking of energy consumption across building zones, supporting energy management and verification. Renewable energy integration required MYR 408,375 to promote sustainability by reducing reliance on non-renewable sources. Enhanced commissioning, costing MYR 300,000, ensures systems operate as intended and includes post-occupancy commissioning to verify that actual performance aligns with design goals. MYR 138,000 is allocated for sustainable maintenance, extending the lifespan and efficiency of building systems. Notably, costs related to post-occupancy commissioning and EE verification are embedded within enhanced commissioning, electrical sub-metering, and minimum EE performance measures, reflecting a streamlined and efficient approach to meeting GBI Platinum standards. Table 13 highlights the financial performance of EE improvements under MS1525:2007 and GBI Platinum standards. MS1525:2007 offers a shorter payback period of 3.82 years compared to 4.08 years for GBI Platinum.

Table 12. Incremental cost breakdown based on GBI platinum criteria.

GBI Platinum Criteria	**Incremental Cost for GBI Platinum (MYR)**	**Percentage of Total Incremental Cost**
Minimum EE Performance	2,249,100	33.49%
Lighting Zoning	100,000	1.49%
Electrical Sub-metering	300,000	4.47%
Renewable Energy	408,375	6.08%
Advanced EE Performance	3,220,000	47.95%
Enhanced Commissioning	300,000	4.47%
Post-Occupancy Commissioning	-	-
EE Verification	-	-
Sustainable Maintenance	138,000	2.06%
Total	**6,715,475**	**100%**

Table 13. Cost-benefit analysis for implementing GBI platinum.

Description	**MS1252:2007**	**GBI Platinum**
Annual Electricity Bill for Base Design	MYR 2,509,438.33	
Total Incremental Cost	MYR 1,885,100.00	MYR 6,715,475.00
Annual Electricity Bill with EE Enhancement	MYR 2,015,978.33	MYR 860,745.77
Annual Savings	MYR 493,460.00	MYR 1,647,047.90
Annual Savings as Compared to Base Design	19.66%	65.66%
Payback Period (Years)	3.82 years	4.08 years

However, GBI Platinum delivers far superior annual savings of MYR 1,647,047.90 (65.66%), over three times the MYR 493,460.00 (19.66%) achieved under MS1525:2007. This leads to significantly reduced energy costs, with annual electricity bills decreasing to MYR 860,745.77 under GBI Platinum, compared to MYR 2,015,978.33 under MS1525:2007. Although the incremental cost for GBI Platinum is higher at MYR 6,715,475 compared to MYR 1,885,100 for MS1525:2007, the larger savings achieved over time validate the investment.

This analysis demonstrates the resilience and long-term value of GBI Platinum certification, particularly in delivering cumulative savings and robust performance. By expressing costs and savings as percentages of baseline annual energy expenditures, the analysis highlights the ability of GBI Platinum-certified measures to adapt to fluctuations in energy prices and operational variables. While MS1525:2007 provides a cost-effective entry point, its outcomes are less impactful in achieving significant long-term energy savings and sustainability. GBI Platinum certification is a practical benchmark for sustainable building development, offering extensive operational savings, enhanced asset value, and alignment with global sustainability goals. The results establish a foundational framework for evaluating similar investments' financial and environmental viability in diverse economic and geographic contexts.

4.3 Key insights and implications

This study highlights the effectiveness of GBI Platinum certification in achieving significant EE improvements and promoting sustainability in building design and operation. Advanced measures, including optimised building envelope design, efficient HVAC systems, and renewable energy technologies, contributed to substantial reductions in energy consumption, operational costs, and carbon footprint.

GBI Platinum standards resulted in significant energy savings, with reductions in OTTV, BEI, and TBEC that improved overall building performance while enhancing indoor environmental quality and occupant comfort. Integrating renewable energy sources reduced the building's greenhouse gas emissions, aligning with broader sustainability objectives. Cost analyses demonstrated that while GBI Platinum certification involves higher incremental costs, substantial long-term energy savings effectively offset these, validating its financial feasibility.

The findings provide actionable guidance for architects, engineers, and developers to implement GBI Platinum standards effectively. By tailoring these energy-saving strategies to local climatic and economic contexts, stakeholders can achieve cost-effective EE while advancing environmental goals. This case study serves as a practical reference for the construction industry, promoting the integration of high-performance design principles into sustainable building practices.

5. Conclusion

This study establishes the GBI Platinum standard's pivotal role in enhancing energy efficiency and promoting sustainability within Malaysia's building and construction sectors. A comprehensive methodology involving planning, simulation, implementation, and verification emphasises energy efficiency measures that significantly reduce energy consumption while simultaneously improving indoor comfort, in strict alignment with GBI's rigorous criteria. The analysis reveals key findings, including a drastic reduction in energy use, demonstrated by an OTTV of 39.48 W/m^2, a 65% decrease in TBEC, and a 66% reduction in BEI compared to conventional designs. Economically, the GBI Platinum certification proves advantageous, offering annual savings of MYR 1,647,047.90, significantly higher than those from MS1252:2007 (MYR 493,460.00), despite a slightly longer payback period. This highlights the financial feasibility and the long-term benefits of adopting such high standards. Moreover, integrating advanced materials and systems enhances occupant comfort in Malaysia's challenging tropical climate, supporting national and global sustainability goals by minimising operational costs and environmental impact. The study opens avenues for future technological innovations and policy adjustments tailored to tropical climates, serves educational purposes, and calls for empirical validation of these findings through performance metrics from GBI Platinum-certified structures. This research guides future projects in balancing economic viability and environmental stewardship, setting a new benchmark for innovative, context-specific building practices in Malaysia and potentially beyond.

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Authors contributions

Authors have contributed equally in preparing and writing the manuscript.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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