

Research Article

A BIM-Enabled Workflow for Energy Use Intensity (EUI) Assessment to Support Sustainable Building Design: Case-Study Validation

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Article Info	Abstract
Article History	Building Information Modelling (BIM) is a powerful tool that enhances sustainability in campus buildings by enabling precise energy analysis, optimizing design for energy efficiency, and integrating sustainable practices throughout the building lifecycle. BIM facilitates detailed simulations and assessments, minimizing energy consumption and reducing environmental impact from design to decommissioning. This study is set against the urgent global need for decarbonization in the building sector, a key driver of energy-related carbon emissions. BIM can model and predict energy performance in institutions with substantial energy demands, leading to significant sustainability gains. This study investigates the energy performance of the Faculty of Science and Natural Resources at Universiti Malaysia Sabah by analyzing EUI (energy use intensity) using BIM technology. A 3D model of the faculty building was created with Autodesk Revit 2023, followed by energy optimization using Autodesk Insight 360. Seven design approaches were evaluated, resulting in a 63.7% improvement in energy efficiency, reducing EUI from 343 to 115 kWh/m ² /year, significantly below the Malaysian Standard MS1525:2007 benchmark of 135 kWh/m ² /year. The findings demonstrate that BIM can optimize EUI, reduce carbon emissions, and enhance the energy performance of institutional buildings, supporting Malaysia's goal of becoming a carbon-free nation by 2050 and ensuring sustainable and efficient energy.
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1. Introduction

Since the publication of the "Our Common Future" report in 1987 by the World Commission on Environment and Development, sustainability in campus environments has become a growing global concern [1]. Given escalating concerns over the depletion of nonrenewable energy reserves and the critical demand for sustainable alternatives, energy conservation has become a paramount global priority [2]. A sustainable campus integrates environmentally responsible practices into daily operations, academic curricula, and planning strategies. The United Nations' adoption of the Sustainable Development Goals (SDGs) in 2015, particularly SDG 7.3, which targets the doubling of global energy efficiency, has reinforced the necessity for accessible, dependable, and sustainable energy [3]. Within this context, energy sustainability on university campuses is critical due to the significant energy demands of operations

involving building infrastructure, equipment usage, and HVAC systems [4].

In response to these demands, integrating Building Information Modelling (BIM) has emerged as a promising approach to optimize energy efficiency in campus buildings. BIM enables precise energy analysis, early-stage design optimization, and the integration of sustainable practices throughout a building's lifecycle. Previous studies have demonstrated BIM's potential to reduce energy consumption, enhance building performance, and support green retrofitting strategies [1, 5]. Achieving low energy consumption throughout a building's lifecycle requires the integration of BIM with building energy performance analysis [6]. Factors such as building size, location, orientation, envelope, and HVAC systems have significantly influenced energy consumption [7, 8], while energy use and CO₂ emissions remain critical concerns for assessing environmental impact [9].

Despite these advancements, there remains a notable research gap regarding the practical application of BIM for energy optimization in higher education institutions, particularly within the Malaysian context. Existing research predominantly focuses on developed countries, leaving a limited understanding of BIM's effectiveness under Malaysia's tropical climatic conditions and energy consumption patterns.

To address this gap, this study investigates the energy performance of the Faculty of Science and Natural Resources at Universiti Malaysia Sabah (UMS) using a BIM-enabled energy use intensity (EUI) evaluation approach. Autodesk Revit and Insight 360 are employed to create a detailed building energy model and simulate various design scenarios to identify optimal energy-saving strategies, benchmarking against the Malaysian Standard MS1525:2007.

The significance of this study lies in its contribution to enhancing energy efficiency within Malaysia's tropical climate, where cooling loads are particularly high. By demonstrating the application of BIM tools for energy optimization in campus buildings, this research provides practical insights for designers, engineers, and facility managers aiming to reduce operational costs and environmental impacts [10]. Additionally, the outcomes support Malaysia's national sustainability goals, including the ambition to achieve carbon neutrality by 2050 as outlined in the Twelfth Malaysia Plan and the Long-Term Low Emissions Development Strategy (LT-LEDS) [11].

2. Literature Review

The drive towards energy-efficient campus environments has led to a growing interest in applying BIM. In addition, existing research on energy retrofits needs to consider the latest technologies and methods, such as BIM, as another alternative to improve energy efficiency [12, 13]. It is currently a developing research area that applies BIM to retrofit existing buildings [14], and the research is at a fundamental level, especially in Malaysian institutions [15]. Retrofit studies are shifting toward using BIM due to the numerous advantages and cost savings associated with adequately implementing it [16].

Autodesk Revit Insight 360 evaluates building performance by analyzing a variety of variables. These include energy use intensity, lifecycle energy use, annual carbon emissions, monthly heating and cooling loads, monthly peak demand, and monthly electricity consumption [17]. A study by Yusuf, et al. [18] shows that the energy model can be optimized based on the manipulation of variables in different design approaches, such as building orientation, window-to-wall ratio, shaded and glazed windows, wall and roof types, infiltration rate, lighting efficiency, plug load efficiency, daylighting and occupancy controls, HVAC systems, operating schedules, photovoltaic panel efficiency, payback limits, and coverage.

Autodesk Insight 360 has effectively demonstrated its capability for optimizing energy efficiency, such as utilizing alternate roof construction, building orientation, wall construction, daylighting, and occupancy controls, as well as lighting efficiency [18]. By utilizing daylight as a primary light source, buildings can minimize their energy demand by utilizing more efficient technologies. It will enable them to achieve higher comfort levels at lower costs.

Integrating BIM for enhancing energy efficiency in buildings has been extensively studied globally. Numerous studies have consistently demonstrated the efficacy of BIM strategies in improving energy sustainability outcomes, particularly on university campuses. Previous studies by Zhang, et al. [19] on BIM's contribution to energy sustainability emphasize that evaluating pre-retrofitting lighting performance is essential to ensure effective energy savings, particularly when integrated with BIM-based measurement frameworks. Moreover, integrating BIM into sustainable building design processes has significantly reduced energy consumption compared to conventional methods.

According to Liu and Wang [20], studies evaluating university buildings designed using BIM integration have reported energy savings ranging from 25% to 70% after optimization of the building design. These findings highlight how BIM is key in improving energy performance through early-stage energy analysis, passive design strategies, daylighting analysis, and renewable energy integration.

Furthermore, an empirical study by Thepsaskul, et al. [11] demonstrated the tangible benefits of employing BIM throughout the project lifecycle, using the University of British Columbia's CIRS (Centre for Interactive Research on Sustainability) as a case study. By utilizing BIM, this building achieved LEED (Leadership in Energy and Environmental Design) platinum certification and significantly reduced energy consumption through enhanced collaborative design processes, performance analysis, and informed decision-making.

In an international context, the recent study by Piras and Muzi [21] further demonstrates the potential of BIM for energy-efficient building redevelopment. Their research on a major office building in Rome developed a digital workflow that integrates Building Information Modelling (BIM) with Building Energy Modelling (BEM) to optimize sustainable retrofitting strategies. The study emphasizes the importance of a BIM-based approach for accurately assessing energy performance improvements during redevelopment

through detailed energy simulations and scenario analyses. Piras and Muzi [21] showed that specific retrofit interventions, such as improvements in envelope insulation and HVAC system upgrades, could significantly reduce the building's energy consumption. Unlike earlier studies that rely only on pre-retrofitting modeling, their work integrates energy performance feedback directly into the BIM environment, enabling continuous performance assessment throughout the project lifecycle. Although the study focused on office buildings rather than campus environments, it provides valuable insights into how BIM-BEM integration can drive sustainable redevelopment, improve energy efficiency, and support informed decision-making during retrofits.

Overall, the case studies and empirical research prove how BIM effectively promotes energy sustainability goals on university campuses and beyond. Despite BIM's significant potential in enhancing energy sustainability, several research gaps need to be addressed. One major gap is the lack of empirical studies focusing on BIM applications for energy sustainability in higher education institutions, particularly in Malaysia. Further research is required to comprehensively explore how BIM can be effectively leveraged to enhance campus building energy performance in the Malaysian context.

Moreover, stakeholder engagement and interdisciplinary collaboration are essential to implementing BIM for energy sustainability successfully. Future research should investigate the dynamics of collaboration among architects, engineers, facility managers, and sustainability experts to foster a holistic approach to sustainable campus development. Addressing these gaps will pave the way for more effective and widespread BIM adoption, contributing to sustainable and energy-efficient campuses and aligning with broader environmental conservation and sustainability goals.

3. Research Methodology

Autodesk Revit was used to create 3D models from a 2D plan for the Faculty of Science and Natural Resources at UMS (Universiti Malaysia Sabah) (Figure 1).

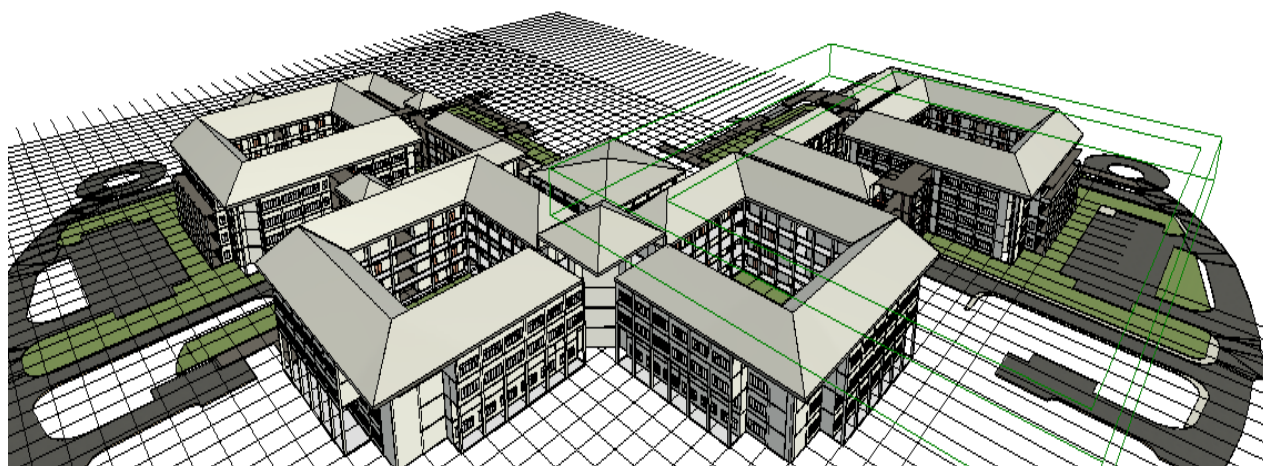


Figure 1. 3D drawing in Revit software of the Faculty of Science and Natural Resources, UMS

3.1. Development Building Energy Model

The development of the BEM (building energy model) by Autodesk Insight 360, a built-in feature of Revit software, was employed after modeling the building. The interface for project settings in Autodesk Revit, as shown in Figure 2, facilitated geographical mapping and weather station data integration. The project location was defined using the "location" and "site" tabs, with an address entry of "Jalan UMS, 88450 Kota Kinabalu, Sabah." This setup allowed the selection of the nearest weather stations for precise data input, which is crucial for accurate energy analysis. The pins on the map marked various weather stations around Kota Kinabalu Sabah, ensuring the selection of the most relevant data source.

According to Figure 2, internet mapping services refer to online tools that offer geographical data and mapping features for various applications. These services are commonly used for various purposes, from simple route planning to complex spatial analysis and energy modeling. They are crucial for energy modeling because they provide accurate geographical information for analyzing energy usage. It also provides a precise geographical location for the site in question, which is crucial for any site-specific analysis.

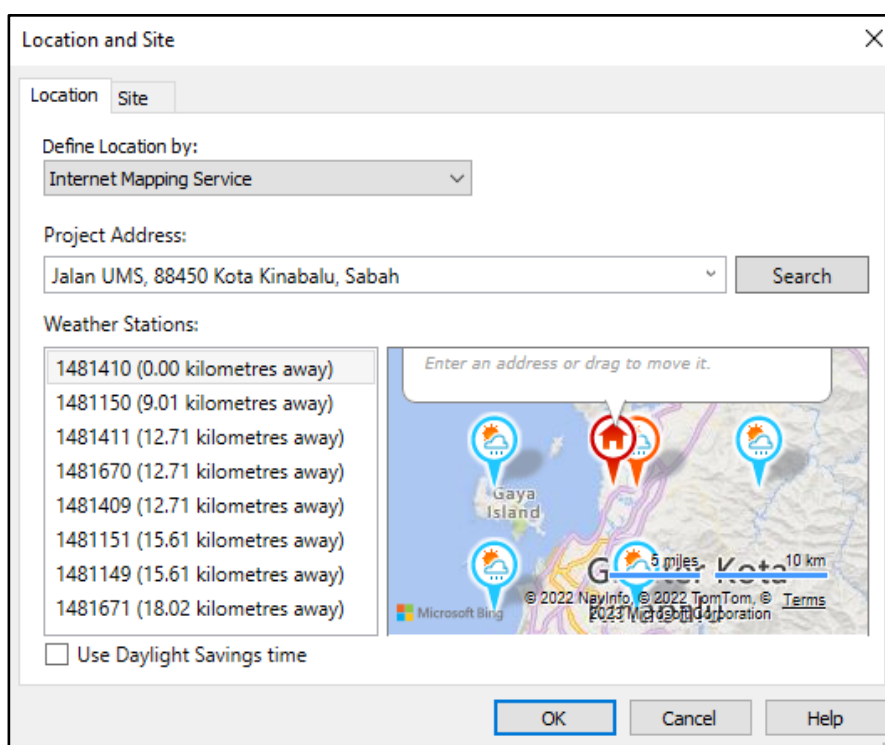


Figure 2. Location setting of the project

Using an internet mapping service, authors can identify the exact coordinates of the case study building. This level of precision is necessary for accurate energy modelling, as even small differences in location can lead to significant variations in environmental conditions that affect energy use, such as local weather patterns, solar irradiance, and wind speeds.

Selecting "1481410 (0.00 kilometres away)" in the weather section of the software interface means

choosing the weather station that is labelled with the ID "1481410," which is located at the same point or very close to the location entered for the project. This station is the closest available, offering that site's most specific weather data. Using the closest weather station is crucial for precise energy modelling as it provides data on temperature, humidity, wind, and solar radiation that accurately reflect the building's conditions. This specific data improves the accuracy of modelling the building's energy requirements and performance.

Then, in the energy settings tab in the analysis pane of Autodesk Revit, all relevant information, such as the building type, building operating schedule, and HVAC system type, was entered. Finally, the building energy model was created by clicking on the "generate model" tab (Figure 3) and then selecting the "optimization" tab to obtain the EUI value before optimization in the Autodesk Insight 360 cloud. The Autodesk Insight 360 cloud presented the possible design approaches, including (1) operating schedule, (2) HVAC system type, (3) lighting type, (4) plug load type, (5) installation of daylighting and occupant controls, and (6) wall construction type.

In a nutshell, the building energy model (BEM) development was further enhanced by refining the input parameters and simulating different energy strategies to optimize energy use. Autodesk Insight 360, a cloud-based tool integrated with Revit, enabled advanced energy simulations that provided insights into the building's energy performance under various conditions. The tool assessed different design scenarios, allowing for a detailed comparison of energy use intensity (EUI) before and after optimization. This comprehensive modelling approach ensured that every aspect of the building's design and operation was considered for maximum energy efficiency, aligning with sustainability objectives. Using Autodesk Insight 360's performance-driven recommendations provided a framework for refining the building's systems and ultimately achieving a reduced EUI value.

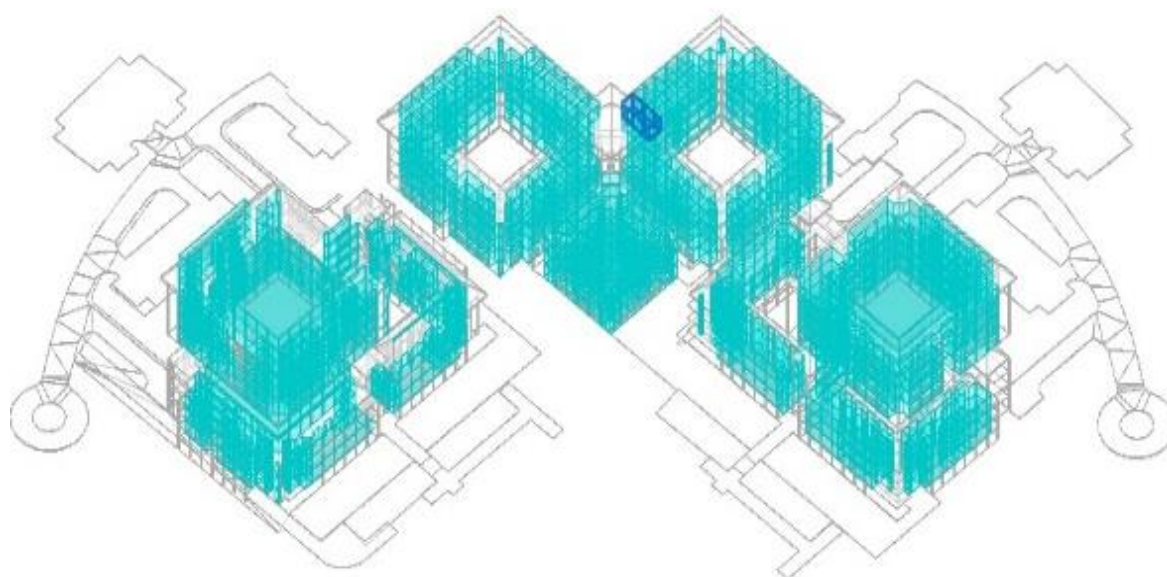


Figure 3. Building energy model

3.2. Utilization of Autodesk Insight 360

Autodesk Insight 360 is a powerful tool that allows users to analyze building energy efficiency and identify improvement opportunities during the design phase and energy retrofitting. It helps identify improvement opportunities by simulating energy-related parameters and supports efficient decision-making to reduce EUI. The tool allows users to manipulate and visualize various parameters to optimize the building's energy performance and identify the best design options to achieve energy savings in the early design phase and retrofit existing structures [22]. It allows for comparing different approaches and standards and evaluates energy use based on the unit of EUI. These approaches include building orientation, WWR for each façade, wall, and roof construction, infiltration, lighting efficiency, daylighting, occupancy controls, plug load efficiency, HVAC, and operating schedule.

In addition, it leverages BIM integration. Autodesk Insight 360 is designed to work seamlessly with Autodesk's BIM software, such as Revit. This integration can enable a more efficient workflow by allowing users to analyze their BIM models directly without complex data transfers or manual model updates [23].

Multidisciplinary Optimization helps achieve a level of performance that requires optimal combinations of several strategies rather than applying individual strategies to improve energy efficiency [24]. The tool enables users to analyze and optimize building energy performance, identify opportunities for improvement, and select the solution that delivers the best result in the planning and design phase. The modifications proposed by Autodesk Insight should help achieve the required energy savings in the building, highlight the reasons for choosing different design approaches, and quantify the expected energy savings. The tool allows users to propose energy savings, critical criteria, and methods to achieve optimal energy savings [25]. Autodesk Insight is an effective tool for improving building sustainability and energy efficiency.

3.3. Energy Optimization by Manipulating Variables in Approaches Designed

For this study, the EUI was extracted from the BEM to improve the energy efficiency of the building. Energy optimization of the building was obtained by manipulating the variables in the design approaches to determine the lowest EUI. Figure 4 shows the EUI value for the Faculty of Science and Natural Resources building before optimization, which is 343 kWh/m²/year, higher than the energy use intensity of Malaysian Standard MS1525: 2007.

Seven approaches were designed for this study, namely (1) operating schedule, (2) type of air conditioning, (3) type of lighting efficiency, (4) type of plug load, (5) installation of daylighting and occupant controls, (6) type of wall construction and (7) integration of all approaches with selected variables. The selection of variables with the lowest EUI was determined by adjusting from existing to target variables. Figure 5, corresponding to Approach No. 7, demonstrates the optimized EUI value of 115

kWh/m²/year after integrating all selected variables, highlighting the significant improvement in energy efficiency.

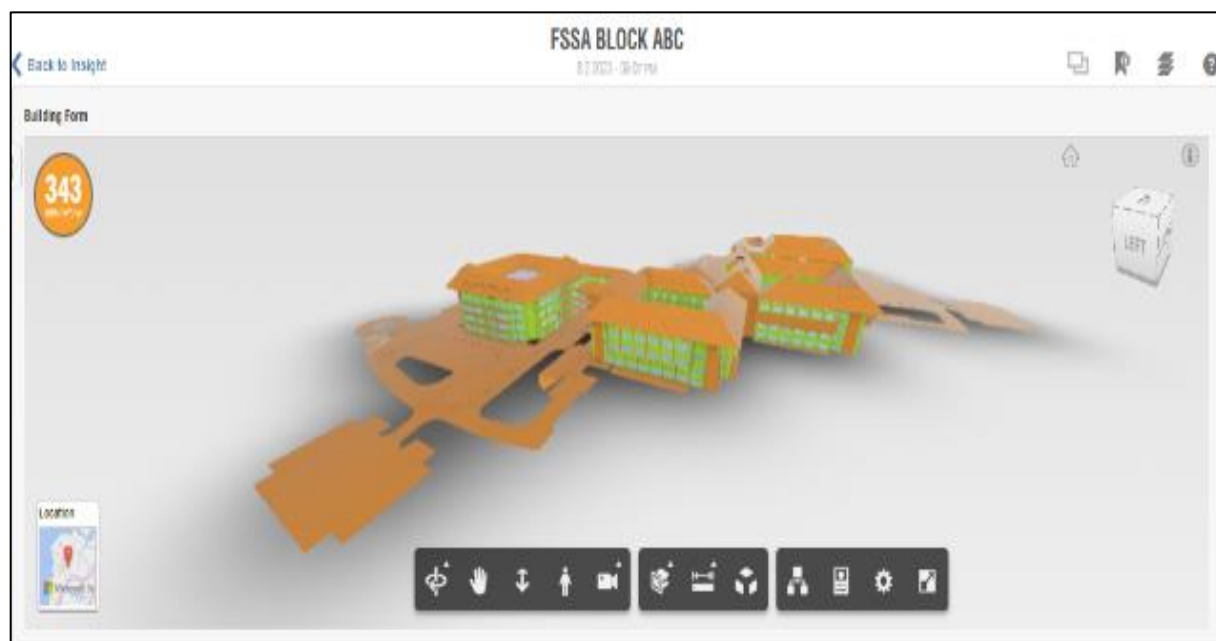


Figure 4. EUI value before Optimization in Autodesk Insight 360

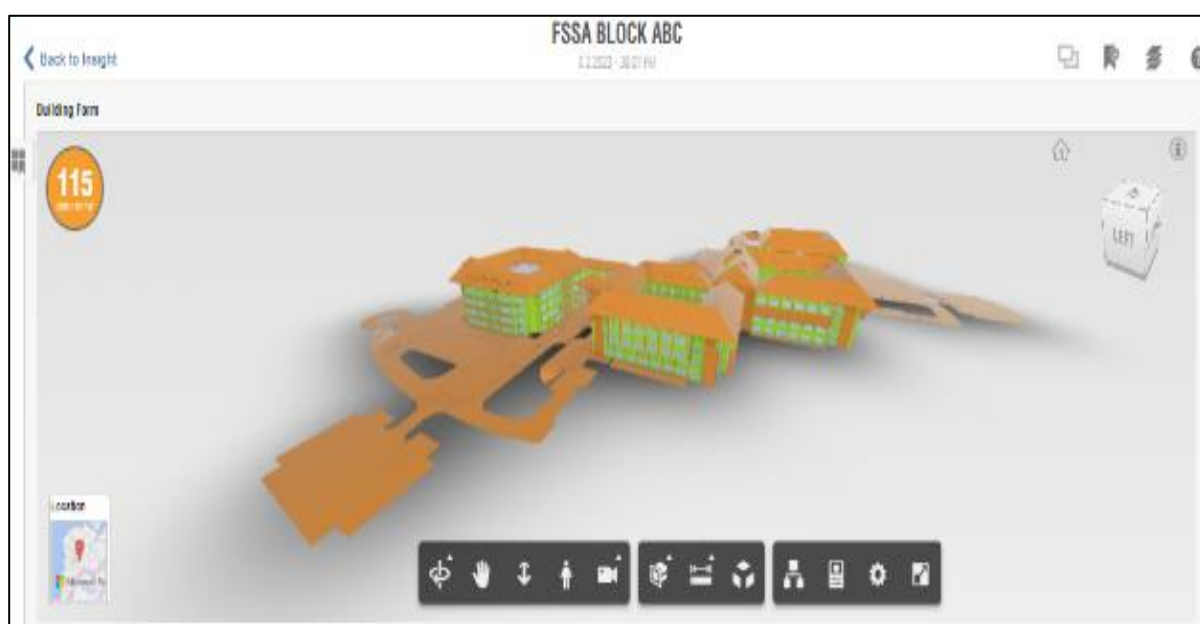


Figure 5. EUI value after Optimization in Autodesk Insight 360

4. Results and Discussion

4.1. Energy Consumption Results After Optimization

The energy consumption results obtained after applying various optimization approaches are summarized in Table 1. The baseline EUI, before any optimization was applied, was measured at 343 kWh/m²/year, indicating substantial energy consumption for a non-residential academic building. Several

strategies were implemented to reduce this consumption, each targeting variables such as operational hours, HVAC systems, lighting, and plug loads. These interventions were designed to evaluate their individual and combined impacts on energy performance, reflecting practical retrofitting scenarios.

Table 1 shows that each approach contributed to a measurable reduction in EUI, although with varying levels of effectiveness. Notably, the comprehensive Optimization (Approach 7), which integrated all selected variables, produced the most significant improvement in energy performance, achieving a reduced EUI of 115 kWh/m²/year. This reduction reflects a considerable enhancement in building efficiency and demonstrates the potential of a multi-faceted approach to energy retrofitting.

Table 1. Energy Consumption Results After Optimization

No	Approaches	Variable/ Alternatives	Energy Consumption
-	Baseline (Before optimization)		343
1	Operating Schedule	12/5	202
2	HVAC	PTHPs	243
3	Lighting Efficiency	3.23 W/m ²	315
4	Plug Load	6.46 W/m ²	307
5	Daylight And Occupant Control	Install Daylight and Occupant Controls	335
6	Wall Construction	14-inch ICF	339
7	All variables (Best Approach After Optimization)	12/5 + PTHPs + 3.23 W/m ² +6.46 W/m ² + Install Daylight and Occupant Controls + 14-inch ICF	115

4.2. Energy Savings and Efficiency Contributions

Table 2 presents the energy savings in EUI and the corresponding percentage contribution to overall energy efficiency for each optimization approach.

Table 2. Energy savings and energy efficiency contributions (%) after optimization

No.	Approaches	Energy Saving (EUI)	% Energy Efficiency Contribution
	Baseline (Before optimization)	-	0.00%
1	Operating Schedule	142	41.3%
2	HVAC	101	29.4%
3	Lighting Efficiency	29	8.4%
4	Plug Load	37	10.76%
5	Daylight And Occupant Control	9	2.6%
6	Wall Construction	9	2.6%
7	All variables (Best Approach After Optimization)	229	63.7%

4.3. Energy Savings and Efficiency Contributions (%) after Optimization

The baseline EUI before optimization was 343 kWh/m²/year, which provided the reference point for energy savings analysis. Various optimization strategies were applied, each contributing differently to the

overall energy efficiency:

- Operating Schedule (Approach 1): Adjusting the operating schedule to 12 hours per day, 5 days per week, resulted in energy savings of 142 kWh/m²/year, contributing 41.3% to the overall energy efficiency improvement.
- HVAC System (Approach 2): Upgrading the HVAC system to a more efficient model (packaged terminal heat pumps, PTHPs) resulted in energy savings of 101 kWh/m²/year, contributing 29.4% to the overall efficiency.
- Lighting Efficiency (Approach 3): Implementing energy-efficient LED lighting with a power density of 3.23 W/m² saved 29 kWh/m²/year, contributing 8.4% to the overall energy efficiency.
- Plug Load Efficiency (Approach 4): Optimizing plug load efficiency achieved energy savings of 37 kWh/m²/year, contributing 10.76% to the overall energy efficiency.
- Daylight and Occupant Controls (Approach 5): Installing daylight and occupant controls saved 9 kWh/m²/year, contributing 2.6% to the overall efficiency.
- Wall Construction (Approach 6): Upgrading the wall construction to a 14-inch Insulated Concrete Form (ICF) saved 9 kWh/m²/year, contributing 2.6% to the overall efficiency.
- Comprehensive Optimization (Approach 7): Combining all variables, including the 12/5 operating schedule, PTHPs HVAC system, efficient lighting, plug load optimization, daylight, and occupant controls, and 14-inch ICF walls, resulted in the most significant reduction in EUI to 115 kWh/m²/year. This approach achieved energy savings of 229 kWh/m²/year, representing a 63.7% contribution to overall energy efficiency.

4.4. Implications of Each Energy Efficiency Approach for Building Optimization

Understanding the energy contribution of each strategy is crucial for making informed decisions about which strategies to prioritize, particularly in retrofitting existing buildings or designing new ones. A detailed comparison of the energy contributions from each approach allows stakeholders to focus on the most effective measures, ensuring that efforts are directed toward achieving the highest energy savings while managing budgetary constraints effectively. This analysis is fundamental because different strategies may offer varying energy savings, and a clear understanding of their contributions helps make data-driven decisions tailored to the project's specific needs and goals.

The Operating Schedule (Approach 1), with a 41.3% energy savings contribution, stands out as the most effective single strategy. This significant impact underscores the importance of optimizing operational hours to reduce energy consumption, particularly in institutional buildings with fluctuating occupancy rates. By adjusting the operating schedule to 12 hours per day, 5 days a week, a considerable amount of energy can be conserved, which is especially relevant in non-residential buildings where full-time operation is

often unnecessary.

The HVAC system optimization (Approach 2) contributes 29.4% to the overall energy efficiency, making it the second most impactful approach. Given the significant energy demand [26] associated with climate control in tropical regions like Malaysia, this high contribution is expected. Upgrading to more efficient HVAC systems, such as PTHPs, can yield substantial energy savings, making this approach a key focus for building energy optimization.

Plug Load Efficiency (Approach 4), with a 10.76% contribution, and Lighting Efficiency (Approach 3), contributing 8.4%, are notable strategies. These approaches address everyday energy consumption from devices and lighting, which, while individually smaller than HVAC or operational changes, collectively account for a significant portion of a building's energy use. Enhancing plug load and lighting efficiency should be an integral part of any energy optimization plan, particularly in settings where electronic devices and lighting are used extensively.

On the lower end of the spectrum, Wall Construction (Approach 6) and Daylight and Occupant Controls (Approach 5) contribute 2.6% to overall energy efficiency. While these approaches offer fewer substantial savings individually, their role in reducing energy consumption should not be overlooked, especially in designing new buildings where they can be more easily integrated. However, their lower impact and the higher costs associated with wall and roof reconstruction make them less attractive for retrofitting existing buildings. The cost-benefit analysis of these approaches is particularly crucial in determining their viability.

By examining the percentage contribution of each approach individually, this discussion aims to provide a clear understanding of where the most significant energy savings can be achieved. This granular analysis is essential because it allows stakeholders to prioritize interventions based on their specific context, whether retrofitting an existing building with limited options for structural changes or designing a new building where comprehensive energy optimization is feasible. Understanding each strategy's energy contribution helps make data-driven decisions that align with energy efficiency goals and budgetary constraints.

4.5. Benchmark Comparison Against Malaysian Standard MS1525:2007

A comparative assessment evaluated the building's EUI concerning the Malaysian Standard MS1525:2007, a nationally recognized benchmark for energy efficiency in non-residential building design [26]. This standard outlines technical guidelines to ensure minimum energy performance and encourage the integration of renewable energy technologies within the built environment.

Before implementing any optimization strategies, the case study building recorded an EUI of 343 kWh/m²/year, exceeding the benchmark value of 135 kWh/m²/year specified in MS1525:2007. This significant deviation highlighted the necessity for performance enhancement. After applying the targeted

energy optimization measures, the EUI was successfully reduced to 114 kWh/m²/year, as presented in Table 1. This result not only meets but surpasses the benchmark threshold, thereby validating the effectiveness of the implemented interventions.

The comparison with the national standard serves two key purposes. First, it demonstrates the efficacy of the optimization strategies in achieving compliance with Malaysian energy efficiency requirements. Second, it underscores the capability of BIM as a comprehensive tool for driving substantial energy reductions and ensuring adherence to regulatory benchmarks.

In addition, integrating BIM with tools such as Autodesk Insight 360 enabled continuous monitoring and iterative refinement throughout the analysis process. This ensured that the building's energy performance remained consistently aligned with the requirements of MS1525:2007. Moreover, the optimization process highlighted the potential for sustained energy efficiency improvements, aligning with Malaysia's commitment to a more sustainable built environment. BIM tools also pave the way for future innovations in energy-efficient building design.

4.6. Limitations

This study faced several challenges, including the technical learning curve associated with BIM tools, the weather station data precision limitation, and constraints in replicating actual building usage schedules during simulations.

5. Conclusions

This study evaluates campus buildings' Energy Use Intensity (EUI) using BIM to optimize energy performance during both the design and retrofitting phases. By utilizing Revit and Autodesk Insight 360, the research enabled comprehensive energy assessments and early-stage optimization, identifying Approach 7 as the most effective strategy. This integrated approach, which combines a 12/5 operating schedule, PTHPs HVAC system, efficient lighting, plug load optimization, daylighting, and occupant controls, along with 14-inch ICF wall construction, reduced the EUI to 114 kWh/m²/year, well below the Malaysian Standard MS1525 2007 benchmark of 135 kWh/m²/year. The results demonstrated that the optimized design met and exceeded energy performance requirements, highlighting BIM's efficacy as a reliable energy assessment and optimization tool. This research provides valuable insights into BIM's potential for energy optimization in Malaysia, positioning it as a key tool for advancing sustainable campus initiatives in tropical climates. The study further supports Malaysia's carbon neutrality goals by 2050, emphasizing BIM's role in high-energy-demand environments like higher education institutions. Future work may explore the integration of AI for dynamic optimization, IoT-based energy monitoring, and the application of BIM retrofitting assessments across various Malaysian universities to improve accuracy and scalability.

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