

Optimizing Retrofitting in Educational Institutions with IoT Integration by Analyzing a BIM-Based Energy Model: Jordan University of Science and Technology's Case Study

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Abstract Buildings require improvements in their structures to be more energy efficient and sustainable. This study focuses on holistic energy analysis that aids in enhancing energy efficiency and reducing consumption by retrofitting buildings. A quantitative approach is utilized in the study by using a unique methodology that integrated Building Information Modeling (BIM) with the Internet of Things (IoT) to develop a model that supports specialists in making well-informed decisions regarding future refits, and the research is based on a complex building at Jordan University of Science and Technology, located in Irbid, Jordan, as a case study. A comprehensive BIM model was developed specifically for this facility, and several retrofit methods were used in combination with IoT. Some of the IoT applications implemented included plug load efficiency, operation schedules, shading techniques, daylight management, lighting efficiency, HVAC system upgrades, and physical modifications like window glass types. Thereafter, a Building Energy Model (BEM) was established to evaluate energy consumption behavior. The results assessed several retrofitting options for their impact on total energy use (EUI) and identified ways to improve energy efficiency. According to the results, integrating BIM with IoT led to total annual energy savings of \$9.19

per square meter.

Keywords BIM, BEM, Energy Analysis, IoT, Retrofitting

1. Introduction

Energy consumption in the construction industry constitutes a huge proportion of global energy usage [1]. The construction and building sector is considered a major global energy consumer (40%) and waste producer (32%), as well as one of the leading sources of greenhouse gas emissions (30%). Thus, building energy load has been recognized as a significant driver for increased power usage and climate change [2]. As a result, building energy demand has been identified as a key driver of rising power consumption and climate change [3]. This sector consumes a greater share of total energy than any other, impacting both the environment and natural resources, which is why experts warn that if left unaddressed, building energy consumption could double by 2050, leading to a corresponding increase in greenhouse gas emissions [4].

Additionally, global electricity consumption is projected to rise by approximately 50% by 2050 due to population growth and economic development [5].

In Jordan, only a small portion of energy is produced domestically, as nearly 80% of Jordan's electricity supply is sourced from Egyptian gas [6]; with over 96% imported, it poses a significant threat to the country's energy security [7]. The country's heavy reliance on external energy sources makes its power system highly vulnerable. Due to this dependency, Jordan faces pressing challenges in securing a stable energy supply, which necessitates the adoption of innovative solutions, alternative energy sources, and a stronger focus on renewable energy to enhance resilience and sustainability [8].

Educational buildings have unique energy consumption patterns compared to other types of structures [9]. They require particular attention due to their specialized functions, diverse occupant behaviors, and cultural considerations. Research suggests that students spend approximately 25% of their time in educational buildings, which presents an excellent opportunity for improving energy efficiency and indoor environmental quality [10].

Energy-efficient retrofitting plays a crucial role in achieving the Sustainable Development Goals (SDGs), particularly Goals 7, 11, and 13. Upgrading existing buildings to net-zero energy standards can significantly reduce energy consumption and lower CO₂ emissions, thus supporting efforts toward affordable and clean energy as well as climate action [11]. Additionally, retrofitting infrastructure, such as district heating systems, has been shown to cut CO₂ emissions by as much as 40% [12]. Community-led energy initiatives, including energy cooperatives, are instrumental in advancing SDGs by fostering sustainable energy systems, technological innovation, and social resilience [13]. However, implementing energy efficiency measures in buildings is often hindered by social, economic, and technical barriers. Key factors for overcoming these challenges include standardizing processes, reducing transaction costs, setting appropriate energy prices, and maintaining a stable regulatory framework [14].

Building Information Modeling (BIM) is one of the

technologies that has been widely adopted by many countries around the world [11]; it enables the use of simulation tools like Autodesk Revit Insight to create virtual models that replicate real-life construction scenarios [12]. Table 1 presents a comparison of three widely used retrofitting approaches.

Recent advancements in BIM, particularly its integration with the Internet of Things (IoT), have introduced promising solutions for building energy retrofits and facilities management. The combination of BIM and IoT allows for real-time monitoring of energy consumption and indoor conditions, enabling data-driven decision-making for retrofit interventions [22]. Examination indicates that BIM can be utilized for energy analysis and optimization, leading to significant cost and energy savings. For instance, a case study found that integrating BIM in energy management could reduce building energy costs by up to 30% [23]. For example, in Saudi Arabia, BIM-based energy retrofitting of educational buildings led to a 22.7% reduction in annual energy consumption, with a payback period of just 2.7 years [24].

Beyond energy efficiency, the adoption of BIM and IoT enhances process productivity and occupant well-being. However, successful implementation requires more than just acquiring the technology. It also demands strategic planning and expertise [25]. Studies have shown that integrating BIM with IoT can optimize energy use through improved natural lighting strategies. For example, research based on NBC and ASHRAE standards found that using low-emissivity glass in windows significantly reduces energy depletion and lowers annual energy costs. Moreover, the integration of BIM with IoT enables real-time energy monitoring by visualizing sensor data within BIM models. This approach, combined with machine learning techniques, allows for the optimization of electrical consumption [26].

Further studies have explored comprehensive frameworks that integrate optimization, BIM, and life cycle assessment, achieving energy consumption reductions ranging from 24% to 58.2%, along with a 45% decrease in global warming potential [27].

Table 1. Comparison of Popular Retrofitting Approaches

Approach	Advantages	Disadvantages
BIM-IoT Integration [15,16]	<ul style="list-style-type: none"> - Real-time energy and building systems monitoring - Data-driven decision making - Optimized energy efficiency 	<ul style="list-style-type: none"> - Interoperability, - Security, and privacy concerns
Traditional Retrofitting [17,18]	<ul style="list-style-type: none"> - Lower initial cost - Simplicity in implementation 	<ul style="list-style-type: none"> - Less precision in upgrades - No real-time monitoring - Higher long-term maintenance costs
Smart Building Systems [19,20,21]	<ul style="list-style-type: none"> - Real-time control of building systems - Improved occupant comfort and operational efficiency 	<ul style="list-style-type: none"> - Lack of comprehensive standards

In terms of user behavior, IoT-enabled systems can capture occupant preferences and adjust in real time to enhance energy efficiency and comfort, smart home technologies leverage machine learning to recognize user habits and automatically adjust settings for optimal energy use [28]. Unsupervised learning techniques analyze sensor data to detect behavioral patterns and generate operational policies, reducing the need for manual configurations [29]. Smart HVAC systems, for example, can minimize energy consumption while maintaining comfort, adapting to variable energy prices, and allowing users to modify temperature settings remotely [29]; similarly, digital twins powered by machine learning can predict energy usage patterns for smart appliances, enabling users to optimize their schedules for greater efficiency [29]. These advancements highlight how IoT can create adaptive environments that enhance both energy savings and personalized comfort in smart buildings.

Despite its potential, BIM-IoT integration for retrofitting presents several challenges, high costs and the need for specialized skills remain significant barriers, as these technologies require advanced expertise and investment [29]. Infrastructure-related issues, such as difficulties in monitoring existing electrical and plumbing systems, further complicate implementation [30]; in addition, interoperability concerns and the reliance on cloud computing pose technical hurdles [31].

Institutional barriers also hinder large-scale energy efficiency retrofitting, regulatory constraints, entrenched norms, and cultural resistance to change obstacles that slow down adoption [32].

Educational buildings, in particular, have distinct energy consumption patterns compared to other types of structures. Their energy use is influenced by various factors, including operating hours, student and faculty presence, seasonal academic schedules, and visitor activity [33]. The energy

profile of educational facilities differs significantly from that of typical non-residential buildings. Data from the 2012 Commercial Building Energy Usage Survey (CBECS) shows that space heating accounts for 36% of total energy consumption in educational buildings, compared to 25% in standard non-residential structures. Cooling contributes 11%, while computers account for 9% of total energy use. The primary differences between educational buildings and other non-residential structures lie in energy demands for space heating, computing, and cooking. Educational buildings require significantly more energy for computing but considerably less for space heating and cooking. Between 1999 and 2012, the number of computers per floor space in educational institutions grew by an average of 71%, with these buildings housing nearly twice as many computers per square meter as commercial buildings [8].

2. Methodology

This study employs a quantitative approach using a unique methodology that integrates Building Information Modelling (BIM) with the Internet of Things (IoT) to develop a model that helps specialists make well-informed decisions regarding future retrofits. The study used a complex building at Jordan University of Science and Technology in Irbid, Jordan, as a case study.

The study strategy consists of two key components, inspired by previous research on BIM technology and other energy-saving measures for buildings: a theoretical study and a practical study [34]. The methodology flowchart, shown in Figure 1, outlines these components. In the theoretical study, a comprehensive literature review was conducted, covering relevant research on BIM and energy efficiency in educational buildings, including theses, books, journals, and online sources.

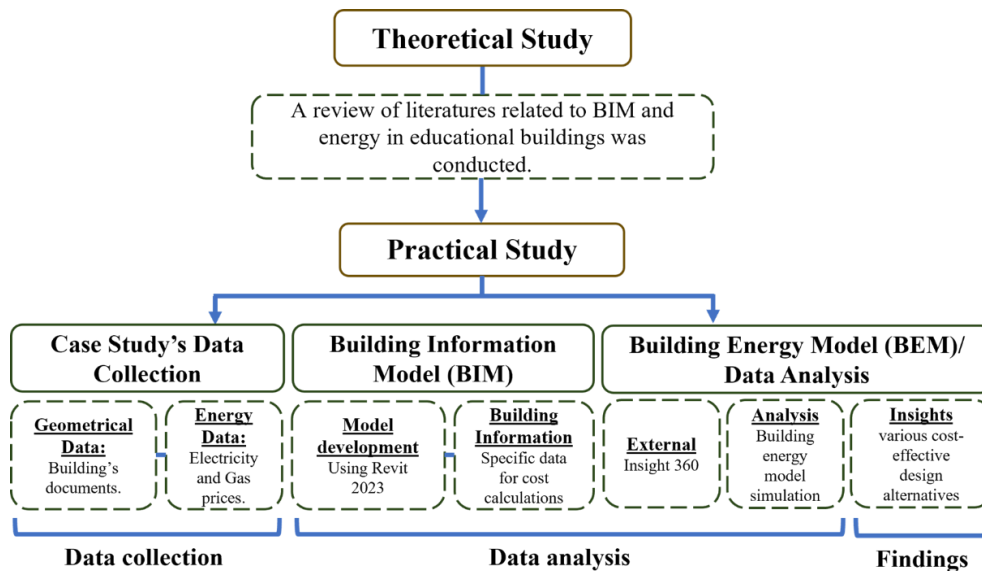


Figure 1. Methodology Flowchart

In the practical study, energy-saving alternatives were assessed by analyzing the building in Autodesk Insight 360 Cloud, a tool featured in Revit 2023. This analysis was further supplemented by other energy-saving technologies. The study also explores the integration of renewable energy systems such as solar panels and wind turbines, along with advanced insulation materials like aerogels and vacuum insulation panels. Additionally, smart IoT-enabled building systems are incorporated to further enhance energy performance. Then, the existing performance of the case study building was compared with the proposed 3D model to evaluate the impact of BIM and IoT on energy consumption and formulate an effective retrofit plan.

2.1. Case Study (Existing Situation)

During the initial phase of the practical study, the focus was on identifying a key energy-intensive building within the Jordan University of Science and Technology. The selected structure, known as the Complex of Halls (or "The Mall"), serves as a central hub frequently used by students. This selection aims to conduct a comprehensive case study on an educational facility in Irbid city, Jordan. The chosen building represents a model for the university, characterized by high energy consumption and significant user traffic. The study examines a three-story, two-winged structure with a total floor area of 14,807.845 m², with detailed floor area breakdowns provided in Table 2.

Table 2. Complex of halls' total areas

Floor name	Area (m ²)	Cost of energy every year for the actual plan
Basement floor	4399.57 m ²	A
Ground floor	5629.135 m ²	B
First floor	4779.14 m ²	C
Total	14807.845 m ²	D

Figure 2 features the case study building, which primarily has a curved architectural design with extensive

glass facades. Its exterior combines beige stone cladding with blue-tinted windows, harmonizing with the surrounding environment. The structure is spacious, with multiple entry points, landscaped areas, and adjacent pathways that facilitate accessibility. Table 3 highlights the construction material for the building.



Figure 2. The Complex of Halls Building, Jordan University of Science and Technology (By author)

2.2. Creation of BIM Model

The model was created to accurately reflect the current state of the complex's construction, with its accuracy verified by an expert. The building's energy consumption was assessed as Energy Use Intensity (EUI) in kWh/m² annually based on the project's energy settings. The EUI is calculated by dividing the total energy used by the building over a year by its gross floor area. The simulation provides a wide range of design options, including daylight and occupancy control, HVAC systems, lighting efficiency, operating schedules, plug load efficiency, window glass types, and window shades to help manage and adjust the building's energy usage. The research report presents information on the project's energy consumption as well as its annual cost per square meter.

Table 4 summarizes energy performance tested variables with reference to previous studies. The energy usage data from the model also aligned with real-world consumption. The building's annual energy consumption is 214 kWh/m²yr, with a cost of 18 USD/m²yr. Moreover, Table 5 summarizes Internet of Things (IoT) tested variables that enhance energy efficiency with reference to previous studies.

Table 3. Types of material used in complex

Component	Construction materials
Exterior walls	Most of the elevation glass local stone course as elevation (mechanical fixing), 100mm void, 150mm solid block wall, 100mm hollow block wall, and 25mm cement plaster + paint and glass.
Interior wall to wall	50mm extruded polystyrene for expansion joint, 200mm hollow block wall, and 25mm cement plaster + paint
Roof	Water proofing membrane rolls, 4 mm thick as specified, 5cm foam concrete as specified, 5-15cm plain concrete as specified, and r.c. slab
Floor	100mm height skirting as per schedule, 20mm mortar bed, sand filling as required, and 700mm r.c slab
Windows	Aluminum door, wooden door, and door with steel frame
Doors	Dbglz window type with air isolation

Table 4. Energy Performance Tested Variables

Variables Affecting Energy Performance with References	Description
Daylighting and Occupancy Controls	Electrical fixtures and systems regulate artificial light output based on occupancy and daylight levels. These measures could cut lighting energy consumption by 63-88% and thus reduce total consumption by 7-14.5% [35].
Heating, Ventilation, and Air Conditioning (HVAC) System	Green HVAC systems and innovative control measures can save 10-28% of the energy used by heating, cooling, and ventilation processes [35].
Lighting Efficiency	Modification of lighting techniques to the energy-efficient ones can lead to obtaining energy savings from 43-71% to a significant extent which in turn cuts electricity consumption [35].
Operating Schedule (Human behavior user control)	The safe timing of operations is necessary for the protection of the energy system, and hence, energy savings, but the percentage varies with the usage patterns [36].
Efficiency of Plug Loads	Plug load management is a good way of saving energy. The percentage of energy reduction that is coming through this method is a factor of equipment and usage [36].
Windows with Smart Window Sensors	The size, the type (Single-Glazed Windows, Double-Glazed Windows, Triple-Glazed Windows) and the placement of windows can help the property owner to control heat gain and loss contributing up to 25% of total energy consumption [37]. The results of simulation studies for Smart Window Sensors indicate the potential of such systems to cut down energy use from lighting and cooling by quite substantial amounts [37].

Table 5. Internet of Things Tested Variables

Lighting with IOT	The suggested best technology is Daylight sensors that continuously adapt and actively decrease as natural light rises [38].
HVAC system with IOT	Energy Effectiveness for tethered warmth pumps can be substantially accelerated with progressed control techniques [39].
LED system with IOT	When it involves a strong economic system and monetary financial savings, LED lights provide some benefits over conventional fluorescent systems. Studies have shown that conducted tubes employ 50–60% of often inferior electrical energy than light tube level arsenic generating 17–34% redundant fall [40]. The integration of IoT Tech with smart LED systems further improves energy-saving potential in residential uses [41].
Operating schedule with IOT application	The integration of IoT Tech with smart LED systems further improves energy-saving potential in residential uses. [42]. By optimizing on-web place base and adjusting these systems, we can keep electrical energy employment and effective charges level arsenic holding sponsor plume during off-season hours [43].
Triple glazing in windows with Smart Window Sensors	Triple glazing systems with non-structural centre layers can achieve U-factors as low as 0.57 W/m ² K potentially overcoming production challenges associated with traditional triple glazing [44].

3. Results

After importing the model into Autodesk Insight (Figure 3) and analyzing the data, a comparative analysis was conducted using the Insight building performance analysis software. The following sections highlight the results.

3.1. Daylight and Occupancy Controls

Table 6 and figure 4 illustrate the comparative analysis of the daylight and occupancy controls. The existing building did not include daylight or occupancy controls. It is highly recommended to install daylight and occupancy sensors using the most effective sensor type resulting in annual energy savings of \$0.62/m² ?

As shown in the results above, combining daylight and occupancy sensors with IoT technology offers significant advantages in energy efficiency and savings. These sensors

play a crucial role in minimizing energy waste by automatically adjusting energy use based on actual occupancy and ambient light levels. The financial savings from this system not only reduce operational costs but also contribute to sustainability by lowering the overall energy footprint of the building.

3.2. HVAC System

Table 7 and figure 5 illustrate the comparative analysis of the HVAC system. The existing building's HVAC system is a 12 SEER/8.3 HSPF Package Terminal Heat Pump (PTAC) system. According to ASHRAE, package terminal heat pumps (PTHPs) are among the most efficient systems for achieving better energy performance. The recommended HVAC system type is expected to result in total savings of 1.42 USD/m² ?year.

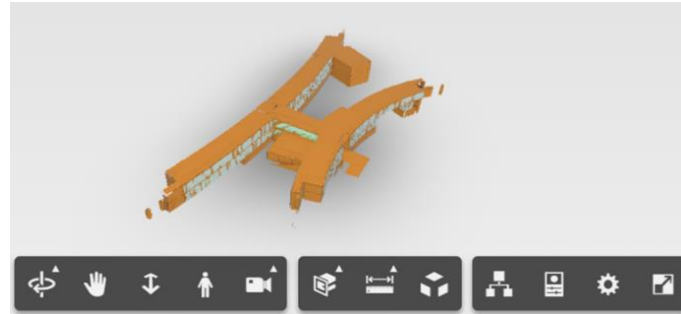


Figure 3. Insight model (Building energy model) by the author

Table 6. Proposed daylight and occupancy system analysis

CASE	System
Case study	No systems installed
Proposed case	<ul style="list-style-type: none"> IoT (internet of things) Daylight sensors continuously adapt and actively decrease as natural light rises. Occupancy sensors that react to the presence of people or animals within a space and control lights and appliances due to occupancy status
Annual cost of saved energy per square meter (USD/ m ² / year)	0.62 Total cost of saved energy (USD/ year) $0.62 * 14807.845 \text{ m}^2 = 9180.86$

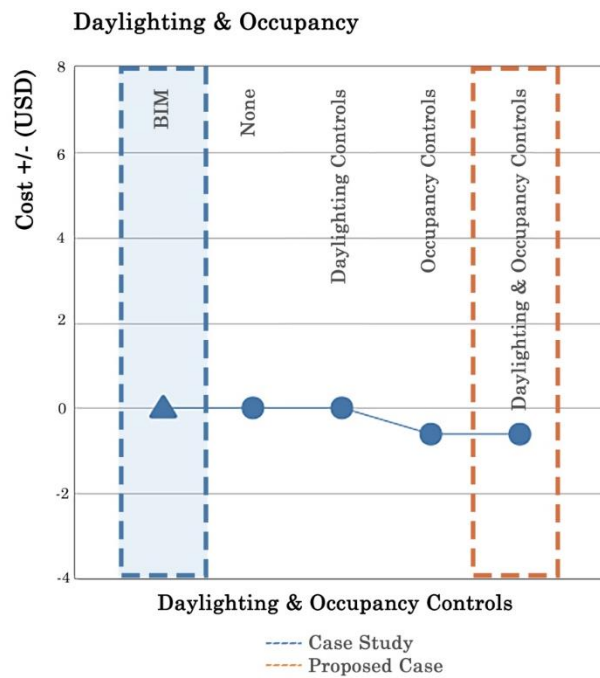


Figure 4. Daylight and occupancy control analysis on Autodesk insight by the author

Table 7. Suggested HVAC system analysis

CASE	HVAC system
Case study	12 SEER/8.3 HSPF Package Terminal Heat Pump (PTAC)
Proposed case	ASHRAE package terminal heat pumps (PTHPs) with IOT application
Annual cost of saved energy per square meter (USD/ m ² / year)	1.42 Total cost of saved energy (USD/ year) $1.42 * 14807.845 \text{ m}^2 = 21027.1399$

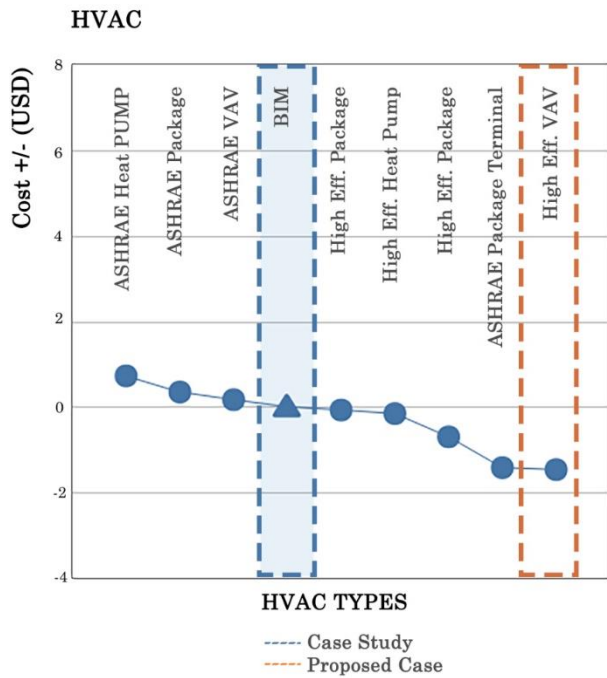


Figure 5. Suggested HVAC system analysis on Autodesk insight by the author

The results above demonstrate that significant savings and substantial improvements in energy efficiency can be achieved by transitioning to ASHRAE-compliant package terminal heat pumps with IoT applications. This system allows for additional savings by enabling smart technologies to automatically adjust HVAC settings in real-time based on the building's specific needs.

3.3. Lighting Efficiency

Table 8 and figure 6 illustrate the comparative analysis of the lighting efficiency. This case study aims to examine artificial lighting systems with a focus on optimizing energy efficiency as well as the quality of light through the use of advanced technologies. The ideal situation would involve using LED lamps such as ENDO GXLX7009W together with fluorescent light fixtures like TL 5000 5506/236/6/EB in order to achieve this goal. Such

luminaires can be combined with Internet of Things (IoT) applications for smart control, monitoring and energy management. In addition to lowering costs related to the electric power consumed during illumination, these types of setups consistently provide flexible specifications that can be adjusted within various contexts thereby ensuring improved overall lighting conditions.

The installation of LED and fluorescent lighting fixtures with IoT-enabled energy management systems results in notable reductions in energy consumption and cost savings. Integrating intelligent technology enables instant adjustments, therefore not only improving energy efficiency but also enhancing adaptability to the structure's specific needs, resulting in continued savings and improved environmental impact.

3.4. Operating Schedule

Table 9 and figure 7 illustrate the operating schedule. This case study explores Building Operating Systems in relation to Internet of Things (IoT) applications, with an emphasis on improving building management. Ideally, intelligent systems can be implemented for functions such as heating, ventilation, air conditioning, lighting, and energy monitoring. These systems make real-time adjustments based on data from IoT-enabled sensors and devices that monitor occupancy and external conditions. For instance, an intelligent HVAC system can optimize temperature settings while tracking energy consumption, thereby enhancing overall efficiency. These setups not only reduce operating costs but also improve comfort and sustainability within the building environment.

The results and comparison of the case study with the proposed model highlight the operational efficiencies introduced by the IoT application. Although the proposed model operates more days per week, the optimization of energy consumption through smart systems results in significant cost savings and improved sustainability. This clearly demonstrates that integrating advanced technologies like IoT into building management systems is essential for achieving long-term economic and environmental benefits.

Table 8. Lighting Efficiency and Energy Savings Analysis

CASE	luminaires type	Lightning efficiency w/m ²
Case study	Artificial luminaire	9.6
Proposed case	LED luminaires (ENDO GXLX7009W) and fluorescent luminaires (TL 5000 5506/236/6/EB)) with IOT application	3.23
(USD/ m ² / year)	2.76	Total cost of saved energy (USD/ year) = 2.76 *14807.845 m ² = 40869.65

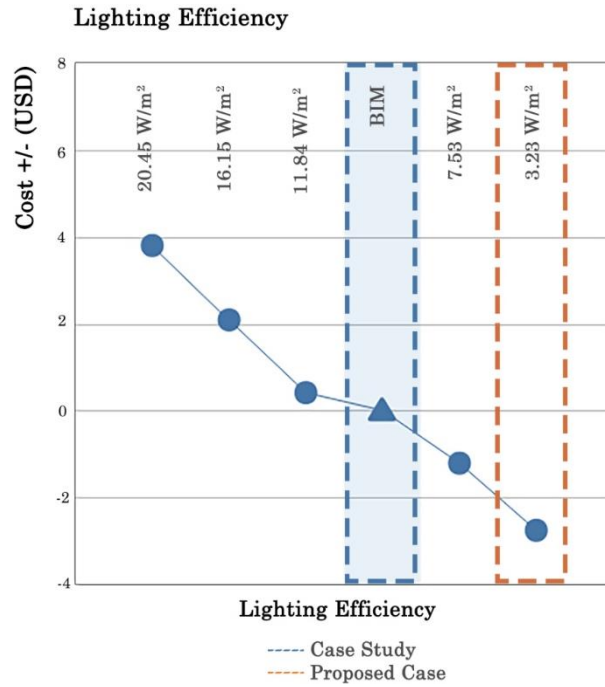


Figure 6. Lighting efficiency analysis on Autodesk insight by author

Table 9. Operating Schedule and Energy Savings Analysis

CASE	Office days/hours	break times/ weekends	
Case study	Year-round school	2 days/48 hours	
Proposed case	5 days/12 hours (Used) with IOT application to manage the operation)	2 days/48 hours	
(USD/ m²/ year)	1.18	Total cost of saved energy (USD/ year)	$1.18 * 14807.845 \text{ m}^2 = 17473.2571$

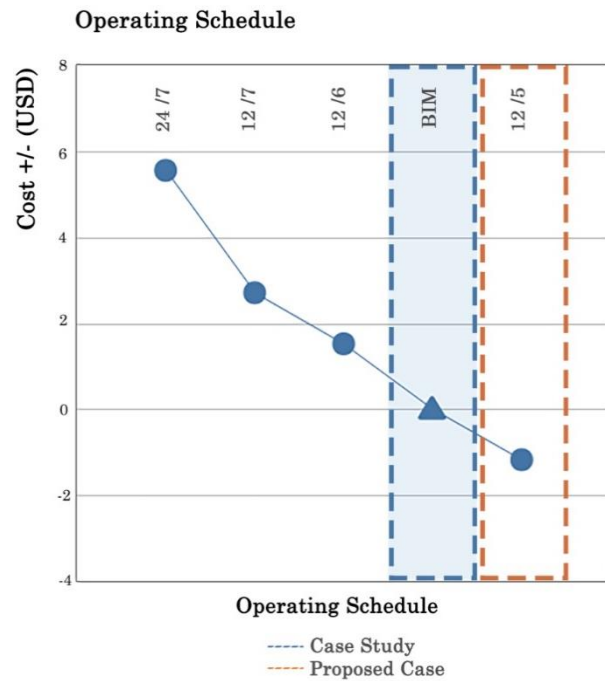


Figure 7. Operating schedule analysis on Autodesk insight by author

3.5. Window Shades

Table 10 and figure 8 illustrate the comparative analysis of the window shades. This case study explores the application of shading systems in a building that currently lacks any shading installations. The best approach is to install shading systems on the southern façades, which have more glazing and experience higher solar heat gain. These shading mechanisms will cover approximately two-thirds of the window height, optimizing solar regulation while still maintaining natural light levels. Integrated with IoT technology, the system can adapt to real-time solar conditions and internal temperature changes, enhancing both energy efficiency and occupant comfort. These systems are crucial in reducing cooling costs and improving the overall environmental efficiency of the building.

3.6. Window Glass

Table 11 and figure 9 illustrate the comparative analysis of the window glass. The window glass type of the case study is Dblglz. The best-proposed window system is triple Low-E.

The results show that transitioning to triple-glazed, Low-E window significantly reduces heat loss through the windows and greatly enhances the building's thermal performance. The lower U-value leads to a reduction in heating and cooling energy costs, contributing to both savings and a more sustainable building. Upgrading the windows not only improves comfort but also saves energy, making it one of the most effective ways to minimize the building's environmental impact.

Table 10. Proposed window shades analysis

CASE	Length of shades	Shades thickness	Direction of shades
Case study	none	none	none
Proposed case (south fa çades)		100 cm	Horizontal
(USD/ m ² / year)	South: 0.29	Total cost of saved energy (USD/ year)	0.29 * 14807.845 m ² = 4,294.27

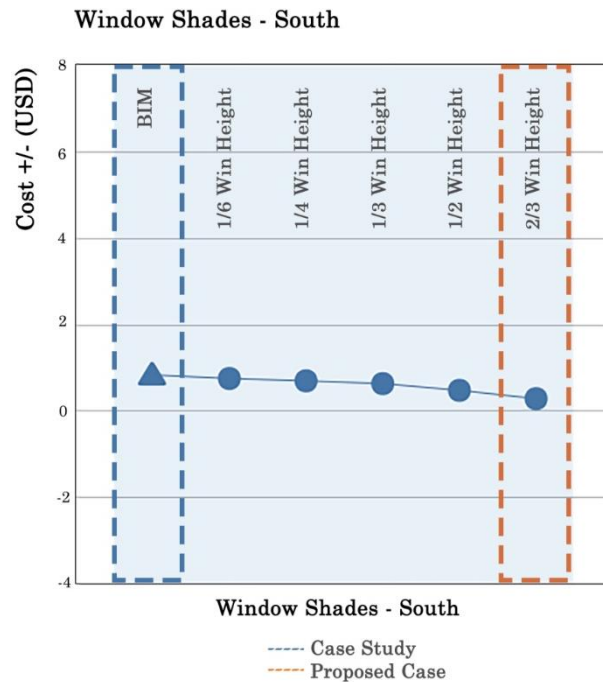


Figure 8. Window shade type analysis on Autodesk insight by the author

Table 11. Proposed window glass type analysis

CASE	Glass characteristics	Glass thickness	Cavity gas	Glass U-value (w/m ² k)
Case study	Double glaze	6 mm	18 mm air	2.8
Proposed case	Triple glazed low-E	6/ 4/ 6 mm	6 mm air	0.15
(USD/ m ² / year)		0.15	Total cost of saved energy (USD/ year)	0.15 * 14807.845 m ² = 2221.17

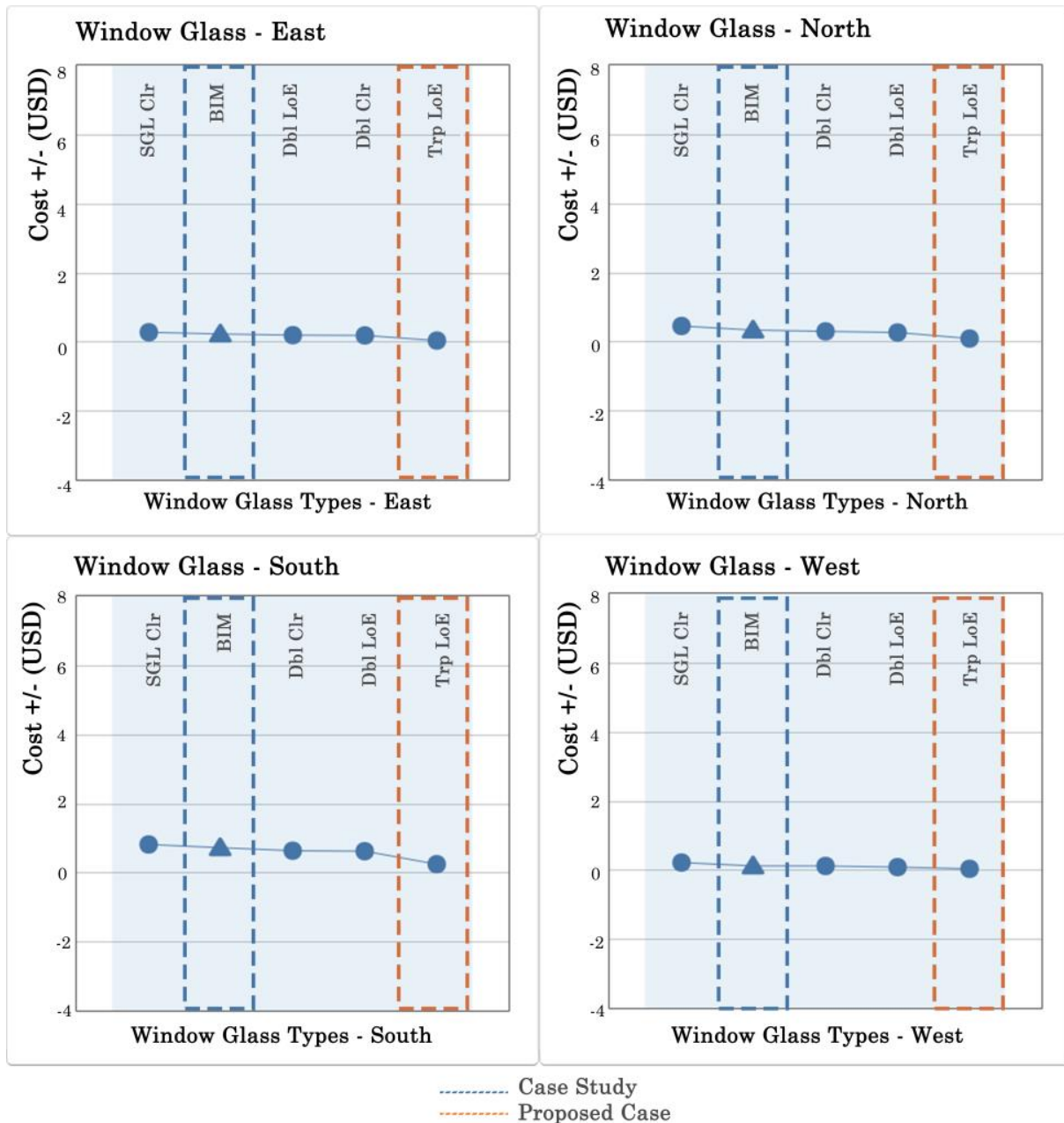


Figure 9. Window glass type with Smart Window Sensors analysis on Autodesk insight by author

4. Findings

The results of the comparative energy analysis were used to estimate both the energy savings and the financial feasibility of the proposed energy-efficient building retrofits. As shown in Table 12, plug load efficiency and lighting efficiency with IoT have the greatest impact on the overall budget, saving -2.77 and -2.76, respectively, while changing the window type proved to be the least effective. These results help decision-makers identify the most suitable energy-saving upgrades or retrofits. The improvements focus on various factors, including daylight and occupancy control, HVAC systems, lighting efficiency, operating schedules, plug load efficiency, window glass

type, and shading. Together, these variables contribute to total energy savings of 9.19 USD/m²/year, offering a comprehensive understanding of the significant benefits made possible by the proposed retrofitting techniques and strategies.

The integration of IoT with BIM has proven to be an effective method for making informed decisions about energy efficiency. This approach should guide retrofitting efforts, focusing on areas with the highest potential for savings. The retrofitting process should first prioritize lighting efficiency, which accounts for 30% of the total savings, by replacing outdated lighting systems with energy-efficient ones. Next, plug load efficiency—also contributing 30% of the savings—should be improved by

installing smart control systems that minimize unnecessary energy use. The HVAC system, contributing 15% of the savings, should be upgraded to more energy-efficient models to enhance performance. Operating schedules, which account for 13% of savings, should be optimized through IoT to reduce unnecessary runtime and better manage energy demand. Daylight and occupancy control systems, contributing 7% of the savings, will regulate lighting and HVAC loads in real-time based on occupancy and the availability of natural light. Finally, window glass type and south façade shading, accounting for 2% and 3%, respectively, will be upgraded by installing triple-glazed Low-E windows and adding shading devices to reduce heat gain, as shown in Table 13.

The findings of the study demonstrate that IoT-enabled systems provide energy savings across all parameters when compared to the existing systems, with results closely aligning with those reported in similar research. For

instance, daylight and occupancy controls resulted in an energy saving of 0.45%, which is consistent with values reported between 0.3% and 0.4%. Similarly, energy savings from HVAC improvements were 1.03%, falling within the range of 1.1% to 3.4% observed in various studies.

Lighting efficiencies showed a 2.00% savings, slightly lower than the 3.4%–6.4% reported in other research. Operating schedule optimization achieved 0.86%, in line with prior studies that reported savings of 0.29% to 0.615%. Plug load efficiency led to a 2.01% saving, compared to the 5.17% seen in similar studies. Smart window glass sensors and south façade shading contributed savings of 0.36% and 0.21%, respectively, matching estimates in the literature of 0.17%–0.37% and 0.18%–0.20%, respectively. These results validate the study, reinforcing the conclusion that IoT-enabled systems are a reliable and effective solution for improving energy efficiency.

Table 12. Amount of savings in budget based on the suggested retrofits

Variable	Existing case	Best proposed case	USD/ m ² / year
Daylight and occupancy control with Iot	none	Daylighting & Occupancy Controls	-0.62
HVAC system with IOT	12 SEER/8.3 HSPF Package Terminal Heat Pump (PTAC)	ASHRAE package terminal heat pumps (PHTPs)	-1.42
Lightning efficiency with IOT	9.6 w/m ²	3.23 w/m ²	-2.76
Operating schedule with IOT management	Year-round school	12 h/5 d	-1.18
Plug load efficiency with IOT	--	6.64 w/m ²	-2.77
Window glass type with Smart Window Sensors	Dbl/glz	Trpl/glz low-E	-0.5
South facade shaders with IOT	none	2/3 window height	-0.29
9.19*14807.845 USD/ m²/ year	(137416.8) USD/ year		

Table 13. Validation of Energy Efficiency Improvements with IoT: Comparative Analysis of Savings

Variable	Comparison (Existing vs. Best Proposed)	Percentage Savings (%)	Comparison with Other Research
Daylight and Occupancy Control with IoT	None → Daylighting & Occupancy Controls	0.45%	Similar studies report that savings range from 0.3% - 0.4% through IoT-enabled daylight controls [45,46]
HVAC System with IoT	12 SEER/8.3 HSPF PTAC → ASHRAE PHTPs	1.03%	Similar studies report that savings range from 1.1% -3.4% through the HVAC system with IoT annually [47]
Lighting Efficiency with IoT	9.6 w/m ² → 3.23 w/m ²	2.00%	Similar studies report that savings range from 3.4% - 6.4% through Lighting Efficiency with IoT annually [48,49]
Operating Schedule with IoT Management	Year-round school → 12 h/5 d	0.86%	Similar studies report 0.29% - 0.615% savings through an operating schedule with IoT Management annually [50]
Plug Load Efficiency with IoT	-- → 6.64 w/m ²	2.01%	Similar studies report 5.17% savings through an operating schedule with IoT Management annually [51]
Window Glass Type with Smart Sensors	Dbl/glz → Trpl/glz low-E	0.36%	Similar studies report 0.17% - 0.37% savings through an operating schedule with IoT [52]
South Facade Shaders with IoT	None → 2/3 Window Height	0.21%	Similar studies report 0.18% - 0.20% savings through an operating schedule with IoT [53]

4.1. Limitations

This study results were shared with students, faculty, and facilities managers, and the feedback has been summarized as follows:

- Feedback from Students: "While the IoT systems on our campus offer useful features, such as automatic lighting and temperature adjustments, they occasionally lag during peak hours, impacting their responsiveness. It would be helpful if the system could prioritize critical functions, like classroom comfort during lectures, over less essential tasks."
- Feedback from Faculty: "The integration of IoT systems in classrooms has been beneficial for managing resources, but occasionally, the system becomes overly automated, adjusting settings in the middle of lectures without considering the context. Adding a manual override feature or more tailored settings would improve usability."
- Feedback from Facilities Managers: "The IoT-enabled systems have made resource management more efficient, but there are challenges in troubleshooting when technical issues arise. Clearer diagnostics and a more user-friendly interface for system control and maintenance would greatly enhance our ability to manage these technologies effectively."

The success of implementing BIM and IoT retrofitting within an existing educational building is limited by cost and infrastructure constraints. While in new buildings, owners allocate substantial investments in software, hardware, and integration costs, retrofitting older buildings adds more to the financial burden. Older buildings require extensive upgrades to all building systems, and ongoing maintenance costs further contribute to the financial strain of retrofitting [54].

Another barrier to integration is the lack of qualified professionals with a strong understanding of BIM and IoT technologies. Additionally, mismanagement of data and concerns about its security pose significant challenges. Above all, ensuring security in IoT systems remains a major challenge. Moreover, the need for compatibility with existing systems and compliance with building codes further add to the complexity and cost of implementing BIM and IoT in retrofitting [55].

5. Conclusions

According to this study and based on the results, any future retrofit in an existing building can be done with energy analysis and combined with IoT applications. The results evaluated several retrofitting options in terms of total energy use (EUI) and identified ways to improve energy efficiency. According to the results obtained, integrating BIM with IoT resulted in total annual energy savings of \$9.19 per square meter.

By coupling this with BIM, there arises an integrated high-powered way for the analysis of building performance enhancement. A platform such as the integration of building information modeling into IoT-connected devices enables management and decision-makers to view crystal clear and specific details on any patterns of energy usage, systems operating, and general occupancy of any building. BIM makes it easier to create detailed digital models of a building that includes all the architectural, structural, and operational elements, an important tool for pinpointing inefficiencies and areas that could be retrofitted or improved.

Integration of the IoT further enhances this by providing continuous monitoring and data collected from glitch systems, including lighting, HVAC, energy usage, and even occupancy.

Real data from sensors feeds into the BIM model in real time, bringing with its instant insight for automatic system adjustment and optimization. This ability means the performance of a building can be contentiously honed for efficiency without requiring manual intervention. If, for instance, it detects poor performance of HVAC, then the BIM model will find cost-effective solutions, such as upgrades or IoT-driven automation deployment to optimize energy usage. Moreover, the integration of IoT with BIM allows for predictive analytics. The system can predict future energy demands, predict system failures, and even discover opportunities for further efficiencies through historical data and trend analysis. This predictive capability does not only reduce operational expenses but also bolsters the long-term sustainability of the building by encouraging resource efficiency.

For instance, IoT sensors for lighting and temperature automatically trigger such controls to switch lights off or modulate HVAC settings depending on occupancy or external weather conditions, achieving great energy savings and extending the life of the system. This will also open up ways to monitor precisely the effectiveness of different retrofitting measures, from newly installed insulation and window frames to complex HVAC systems themselves. Internet of Thing sensors provide a means for observing real-time system interactions—for instance, in estimating immediate energy or environmental gains—following such updates, enabling refined building management policies with high fidelity over longer horizons.

This data-driven and real-time methodology will, in turn, feed into a continuous improvement cycle. Building managers are empowered to take swift actions in the optimization of building performance, respond to changes in occupancy or external conditions, and make informed decisions on energy use, equipment upgrades, and maintenance. With the implementation of IoT with BIM, buildings achieve reduced energy consumption and operational costs while advancing sustainability goals and minimizing their carbon footprint. This approach will have implications for buildings to be more cost-effective,

adaptive, resilient, and better prepared for future environmental and operational challenges.

Universities, IoT manufacturers, and research organizations can work together to refine and improve this approach. Looking ahead, collaboration will be key. These partnerships will help ensure the methodology is dependable, authentic, and scalable across different building types, from homes to large commercial structures. Academic institutions can develop advanced algorithms and conduct experiments, while IoT companies can provide the technology required for real-world testing.

Engaging with the energy sector through collaborating with utility companies and working with renewable energy are equally viable as it can open doors to pilot programs that test demand-response energy management and real-time optimization. Providers can explore how IoT integrates with solar, wind, and other sustainable energy sources, pushing the boundaries of clean air innovation.

By embracing these advancements, we can move toward a future where buildings are not only more efficient but also smarter, more responsive, and more sustainable.

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