Optimising Energy Consumption in Educational Facilities: A Case Study on Energy Conservation Practices in Malaysia

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Abstract

As environmental sustainability and energy consumption become growing concerns, educational institutions are increasingly implementing energy-saving practices to reduce their environmental impact. In Malaysia, the government's commitment to improving energy efficiency and reducing carbon emissions provides an ideal context for investigating energy conservation in educational facilities. However, many buildings still experience high energy consumption, leading to increased operational costs and environmental impact, underscoring the need for targeted energy-saving initiatives. This study investigates campus energy optimisation in a Malaysian educational facility, evaluating the impact of energy conservation practices on consumption, costs, and carbon emissions. The methodology consists of four stages: energy audits, implementation of energy-saving measures (ESMs), measurement and verification (M&V) of energy savings, and data analysis. Several important interventions include retrofitting lighting systems, optimising HVAC operations, and installing voltage optimisation units. Results of this study showed a 13.26% reduction in energy consumption, a 13.50% decrease in energy costs, and a reduction of 38,660.35 kg of CO_2 emissions per month. These findings highlight the effectiveness of ESMs in reducing energy consumption and environmental impact. By analysing the impact of these ESMs on energy consumption and costs, the study provides valuable insights that can serve as a model for other educational institutions seeking to improve energy efficiency and reduce their environmental impact. The findings suggest continuous monitoring and integration of renewable energy solutions could optimise campus energy use. This research underscores the potential for long-term sustainability by adopting energy-saving technologies and practices that reduce operational costs and carbon footprints. Ultimately, the study offers a replicable framework for educational institutions aiming to enhance energy performance and contribute to broader environmental sustainability goals.

Keywords: Carbon Emission Reduction, Electricity Optimisation, Energy Conservation Practices, Energy Efficiency, Sustainability

1.0 Introduction

Environmental sustainability and renewable energy consumption are becoming increasingly pressing concerns worldwide [1]. With rising energy demands and a growing focus on mitigating climate change, building types including residential, commercial, medical, industrial and educational play crucial roles in human lives [2]. Buildings are responsible for consuming over 40% of the global energy consumption [3]. Researchers worldwide are exploring ways to optimise energy use and minimize their carbon footprints in educational institutions by adopting energy-saving measures to reduce their environmental impact [4], [5]. In Malaysia, the government's commitment to improving energy efficiency and reducing carbon emissions aligns with global sustainability goals and provides a compelling framework for energy conservation in educational facilities. The education sector, known for its high energy consumption due to extensive infrastructure and operational hours, presents a significant opportunity for energy optimisation initiatives [6].

The International Energy Agency (IEA) highlighted the significant role of coal and natural gas in global CO_2 emissions, noting that coal-related emissions reached record highs in recent years [7]. At COP28 in 2023, Malaysia reiterated its commitment to addressing emissions, focusing on reducing greenhouse gas (GHG) emissions by 45% by 2030 compared to 2005 levels, in alignment with its Nationally Determined Contributions (NDCs). The country also aims for carbon neutrality by 2050 under the Twelfth Malaysia Plan and has integrated measures such as the National Energy Policy 2022-2040, which emphasizes energy efficiency, low-carbon development, and carbon capture technologies [8]. These objectives underscore Malaysia's active engagement in combating the global climate crisis. A critical strategy to meet these targets is retrofitting existing buildings to enhance energy efficiency. Retrofitting involves upgrading lighting, HVAC, and electrical distribution systems to decrease energy demand while improving building performance. The Malaysian government has championed energy retrofit projects in public buildings through the Sustainable Energy Management Committee, setting an example for the private sector [9]. This initiative aligns with national carbon reduction goals and highlights the role of public institutions as sustainability models.

Buildings are a significant source of energy consumption, accounting for nearly 40% of global energy demand [10]. In Malaysia, the National Energy Efficiency Action Plan (EEAP) promotes energy-efficient technologies across industrial, commercial, and residential sectors to reduce energy usage [11]. Retrofitting public institutions is crucial in these national efforts by improving energy performance and supporting long-term sustainability. Energy audits are a critical component of retrofitting initiatives. These audits identify areas where energy usage can be reduced without compromising occupant comfort or building functionality [12]. Recent studies show that targeted retrofitting of lighting systems and HVAC operations can result in energy savings of up to 30% [13]. Furthermore, energy audits and management practices have been proven effective in residential and commercial buildings, providing actionable insights for improving energy efficiency [14]. Despite their significance, few studies have focused on public institutions in Malaysia. This research assesses energy efficiency performance by conducting audits and retrofitting selected buildings. The study will identify energy consumption patterns, explore opportunities for improvement, and analyse the potential impacts of these improvements on energy costs. By contributing to Malaysia's sustainability agenda, this research provides valuable insights that can serve as a model for other institutions seeking to enhance energy efficiency.

2.0 Methodology

This study employs a systematic methodology to optimise energy consumption in educational facilities by strategically analysing energy conservation practices. The research is divided into four stages. The first stage is an energy audit and baseline data collection. This stage involves a detailed assessment of existing energy consumption patterns, serving as a benchmark for evaluating subsequent improvements [15]. The second stage focuses on implementing energy-efficient measures, which involves the installation of energy-saving technologies and operational adjustments [16]. Energy-saving measures (ESMs) such as replacing traditional lighting with T5 lighting systems, optimising HVAC operations, and installing Voltage Optimisation Units (VOU) are prioritised based on a cost-benefit analysis.

Following implementation, the third stage involves energy savings Measurement and Verification (M&V). Using protocols from the International Performance Measurement and Verification Protocol (IPMVP), the study compares post-implementation energy consumption with baseline data to validate the effectiveness of the installed measures. Adjustments are made for external factors such as Cooling Degree Days, CDD, and number of class days to ensure accuracy. The final stage is quantitative data analysis, which assesses the overall impact of the energy-saving initiatives. Key metrics analysed include reductions in energy consumption, cost savings in RM, and carbon footprint reductions measured in tonnes of CO2. Regression analysis explores correlations between energy savings and influencing factors. This comprehensive analysis highlights energy optimisation's environmental and economic impact and informs future energy management strategies, contributing to broader discussions on sustainable campus operations [16].

2.1 Energy Audit and Baseline Data Collection

The study begins with an energy audit to evaluate energy usage patterns and identify inefficiencies in key systems such as lighting, HVAC (Heating, Ventilation, and Air Conditioning), and Water-cooled Package Unit (WCPU). Monthly energy consumption data from January to December were collected from electricity bills to establish a reliable baseline for analysis. Collecting monthly data to evaluate baseline energy usage is common in energy audits to identify consumption patterns and establish reference points for assessing energy savings post-retrofit [17]. This baseline data provided a foundation for trend analysis and identifying high-energy consumption areas, enabling targeted optimisation efforts.

2.2 Installation of Energy-Efficient Technology Devices

Pre and post-retrofitting energy consumption data were analysed to quantify improvements in efficiency, cost savings, and sustainability. Energy-saving measures (ESMs) were also implemented, incorporating smart energy monitoring technologies to enable real-time usage tracking. These technologies can significantly enhance energy efficiency by providing real-time data on energy use, identifying inefficiencies, and automating energy-saving measures [18]. These solutions were further evaluated based on their impact on reducing electricity consumption, operational costs, and greenhouse gas emissions. Energy-saving measures (ESMs) were implemented to reduce energy consumption. These measures consist of several elements, which include lighting retrofit, voltage optimisation units, water-cooled package unit smart controller system, and installation of 1.5 HP energy-saving air conditioners for laboratories.

2.2.1 Lighting Retrofit

The average illuminance levels in the audited areas were below the recommended comfort threshold, indicating suboptimal working conditions that necessitated improvement [19]. To address this, a retrofit was carried out by replacing the existing T8 fluorescent lights with more energy-efficient T5 fluorescent tubes. The assessment of the illuminance profile was a critical component of this process, ensuring compliance with established lighting standards such as MS 1525 [20]. This step was essential for optimising energy efficiency and maintaining adequate visual comfort and productivity in the workspace [21].

2.2.2 Voltage Optimisation Units

Voltage Optimisation Units (VOUs) were strategically installed at key substations within the campus to address power quality issues such as voltage instability, over-voltage conditions, and energy inefficiencies. These problems often result in increased energy consumption, reduced equipment lifespan, and higher operational costs due to excessive energy losses and overheating in electrical systems [22], [23]. Implementing VOUs helped regulate and optimise voltage levels, ensuring that the supplied voltage remained within the ideal range for the efficient operation of electrical equipment.

2.2.3 Water-cooled Package Unit (WCPU) Smart Controller System

The WCPU Smart Controller regulates the compressor speed of the WCPU based on temperature parameters. The compressor operates proportionally to the detected temperature, ensuring efficient and responsive performance during operation. Smart controllers were installed in 44 WCPU units, optimising the operation of air conditioning systems by adjusting compressor speeds based on real-time temperature data.

2.2.4 Installation of 1.5 HP Energy-Saving Air Conditioners for Laboratories

In the past, laboratory facilities included designated preparation rooms for laboratory coordinators, where lecturers would work during operational hours. However, when students were not present in the laboratories, the central WCPU system remained active to meet the cooling requirements of these preparation rooms. This practice resulted in unnecessary energy consumption, as the WCPU operated even when the primary laboratory spaces were unoccupied [22]. 1.5 HP energy-efficient split air conditioning units were installed in the lecturers' preparation rooms to address this inefficiency. These units provided localized cooling to the preparation areas, significantly reducing reliance on the WCPU system [23]. Furthermore, an advanced control switch system was introduced to regulate the WCPU's operation, enabling it to switch on or off automatically based on student occupancy in the laboratories [24]. Studies have consistently demonstrated that adopting energy-efficient air conditioning systems and occupancy-based control mechanisms can achieve substantial energy savings in buildings characterized by fluctuating occupancy patterns [25].

2.3 Measurement and Verification of Energy Savings

The verification of energy savings followed the guidelines of the International Performance Measurement and Verification Protocol (IPMVP) [26]. The measurement and verification (M&V) process aimed to assess the effectiveness of energy-saving initiatives by comparing post-retrofit energy consumption with the baseline consumption before the measures were implemented. The Malaysian Green Technology Corporation conducted the M&V process, with final verification completed in September 2015. The formula used for calculating energy savings is as follows [26], [27]:

$$\textit{Energy Savings} = \textit{Base Year Energy Use} - \textit{Post-Retrofit Energy Use} \pm \textit{Adjustments} \quad (1)$$

The formula in Equation (1) allows for a detailed assessment of the impact of energy-saving interventions, accounting for any external variables or adjustments needed for accuracy [28].

2.4 Quantitative Data Analysis

Quantitative data analysis was conducted to measure the effectiveness of these interventions, focusing on metrics such as reductions in energy consumption, cost savings in RM, and decreases in carbon emissions (tonnes of CO2). The study also included a sustainability impact analysis to assess the alignment of energy-saving efforts with Malaysia's environmental goals under the Nationally Determined Contributions (NDCs).

3.0 Results and Discussion

This section analyses the energy savings achieved, focusing on energy consumption, cost reductions, and CO_2 emissions reductions. The analysis aims to meet the research objectives of identifying energy consumption patterns, investigating energy efficiency improvements, and evaluating cost and energy savings. The energy-saving initiatives implemented significant reductions in both energy consumption and energy costs. Table 1 shows the monthly energy consumption from January to December gathered from electricity bills in the year 2013 to establish as a baseline. The data included total energy consumption (kWh) and maximum demand (kW). Collecting monthly data to evaluate baseline energy usage is common in energy audits to identify consumption patterns and establish reference points for assessing energy savings post-retrofit [17].

Table 1: The monthly energy consumption from January to December 2013 gathered from electricity bills to establish a baseline

Month	Baseline Energy Consumption (Year 2013)				
	Monthly Energy Consumption		Monthly Maximum Demand		Monthly Energy Cost
	kWh	RM (kWh)	kW	RM (kW)	RM (Total)
January	448630	163750	1839	55722	219472
February	376346	137366	1765	53480	190846
March	514211	187687	1912	57934	245621
April	467108	170494	1922	58237	228731
May	407838	148861	1595	48329	197189
June	357702	130561	1525	46208	176769
July	435988	159136	1786	54116	213251
August	384918	140495	1956	59267	199762
September	400250	146091	1865	56510	202601
October	449324	164003	1837	55661	219664
November	326027	119000	1505	45602	164601
December	429303	156695.6	1849	56025	212720
Total	4997645	1667445	21356	591062	2471227
Average (kWh)	416470		1780		
Average (RM) (kWh)		152012		53924	205936

The baseline data indicate an average monthly electricity consumption of 416,470 kWh and a maximum demand of 1,780 kW, resulting in an average monthly energy cost of RM 205,936. This baseline provided the foundation for subsequent energy savings calculations post-retrofit, following the approach described in [14] for establishing baseline energy metrics. These measures have contributed to a measurable reduction in energy consumption (kWh) and maximum demand (kW). The decrement in maximum demand directly correlates with the improved efficiency of electrical systems, reducing peak load requirements. At the same time, the overall reduction in energy consumption reflects enhanced operational performance and decreased energy wastage. These outcomes underscore the effectiveness of the strategies implemented to achieve sustainable energy management goals.

The multiple regression analysis for baseline estimation was employed to investigate the relationship between electricity consumption (Y) and two critical, independent variables, the number of class days (X_1) and Cooling Degree Days (CDDs, X_2). The regression model generated the following equation:

$$Y = -96{,}280.68 + 6{,}298.32X_1 + 1{,}325.48X_2$$

Where Y = Electricity consumption (kWh),
X_1 = No. of class days
X_2 = CDDs

The coefficients indicate that each additional class day contributes approximately 6,298.32 kWh to electricity consumption, while a one-unit increase in CDD raises consumption by about 1,325.48 kWh. These findings demonstrate the substantial impact of building occupancy (captured by the number of class days) and cooling requirements (quantified through CDDs) on energy consumption patterns. The y-intercept, -96,280.68, represents the baseline energy consumption when both independent variables are zero, although this value has limited practical relevance.

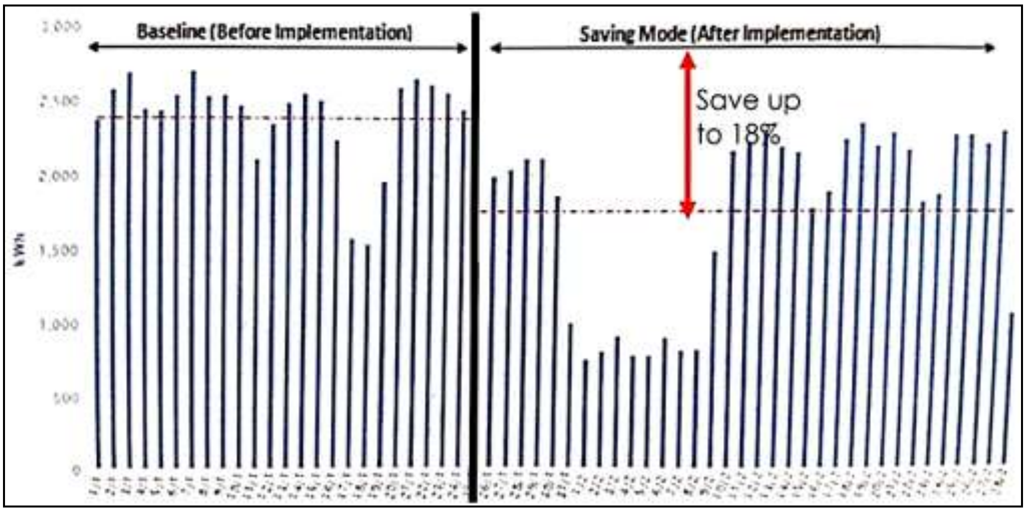
The regression model demonstrates a firm fit, with an R^2 value of 0.79, indicating that the independent variables explain 79% of the variation in energy consumption. The number of class days and cooling degree days (CDD) at 18 degrees significantly impact energy usage. Among these, the number of class days emerges as the key driver, exerting a more significant influence on energy consumption, as evidenced by its higher coefficient. These findings highlight practical opportunities for improving energy efficiency in educational facilities. Specifically, optimising classroom schedules and implementing effective cooling management strategies during periods of high CDD can lead to substantial energy consumption reductions, contributing to cost savings and environmental sustainability. Similar studies have highlighted the importance of cooling requirements, measured by CDDs, in driving HVAC energy consumption patterns [29]. Additionally, the utility of regression analysis for establishing baseline energy consumption has been emphasized in retrofitting scenarios to facilitate post-retrofit savings verification [30].

The energy saving measures (ESMs) were implemented in lighting retrofit by replacing the existing T8 fluorescent lights with energy-efficient T5 fluorescent tubes [31]. This retrofit involved the installation of 8,300 units of 18-watt T5 bulbs and 700 units of 20-watt T5 bulbs, resulting in a suitable illuminance level while achieving approximately a 50% reduction in lighting energy consumption [31]. Post-retrofit data confirmed significant energy savings, with average lux levels meeting the Malaysian Standard MS 1525 requirements for energy efficiency in buildings [19]. Table 2 presents the energy consumption, energy cost, and savings before and after the implementation of energy saving measures by replacing the lighting system. The lighting retrofit implemented energy-saving measures, resulting in substantial reductions in energy consumption (57,816 kWh per month) and costs (RM21,103.00 per month). This aligns with energy optimisation goals and underscores the importance of retrofitting traditional lighting systems to achieve energy efficiency and sustainability.

Table 2: Total energy consumption, energy cost, and savings before and after the implementation of energy saving measures by replacing the lighting system from T8 to T5

Metric	Before ESMs	After ESMs	Savings
Lamp Type	T8 Lamp (36W)	T5 Lamp (18W, 20W)	
Quantity (Unit)	9,000	9,000	
Total Energy Consumption (kWh/month)	116,640	58,824	57,816
Total Energy Cost (RM/month)	42,574	21,471	21,103

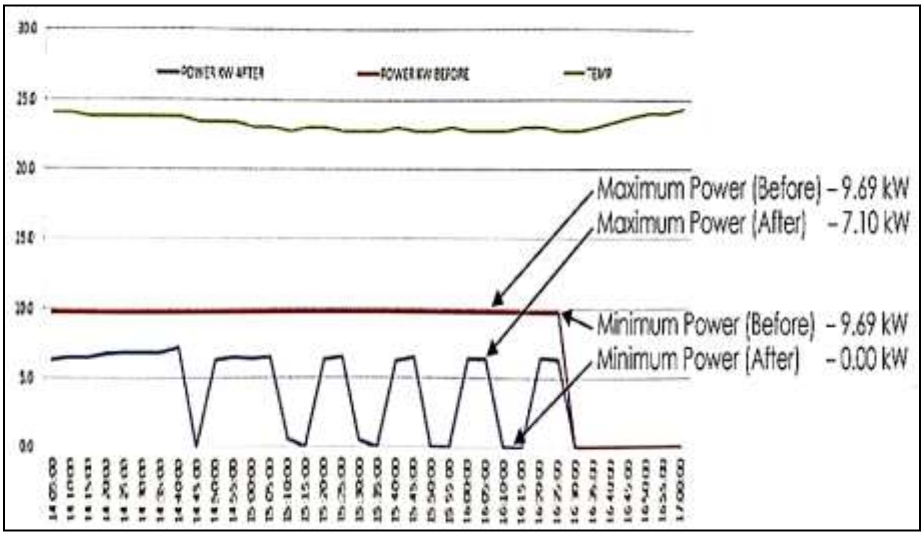
Figure 1 shows the difference in energy consumption before and after the implementation of VOU system. Implementing VOUs helped regulate and optimise voltage levels, ensuring that the supplied voltage remained within the ideal range for the efficient operation of electrical equipment. This optimisation enhanced system reliability and resulted in an average energy savings of 12.56% across all substations, with some locations achieving reductions of up to 18%. The significant improvement in energy efficiency highlights the critical role of voltage optimisation in mitigating power quality issues.



Source from Energy Meter M&V Report

Figure 1: The change of energy consumption at the substations before and after installing the VOU system

Figure 2 shows that the WCPU power consumption adopts an on-off pattern, enabling more accurate regulation of the compressor speed. This adjustment reduced maximum power from 9.69 kW to 7.10 kW and reduced minimum power from 9.69 kW to 0.00 kW, improving energy efficiency and optimising compressor performance. This system achieved up to a 50% reduction in energy consumption for cooling loads [30]. Smart controllers in HVAC systems have been demonstrated to optimise energy use, improve operational efficiency, and reduce overall energy consumption in commercial and institutional buildings [33].



Source from Energy Meter M&V Report

Figure 2: Comparison of the maximum/minimum power before and after the installation of the WCPU controller

3.1 Energy Savings Analysis

The data in Table 3 show the energy consumption and savings across different months based on class days and cooling degree days (CDD). Data for the six months from June to December reveals fluctuations in energy savings, with the highest savings observed in June (24%) and the lowest in December (12%). The highest avoided energy savings occurred in June (112,063.52 kWh), while December had the lowest (52,451.90 kWh). This variation underscores the importance of continuous monitoring to assess the effectiveness of energy-saving measures, identify operational inefficiencies, and optimise strategies to ensure consistent energy performance and long-term savings.

Table 4 illustrates significant energy consumption, demand, and cost reductions across the baseline and post-retrofit years. The average monthly energy consumption in the baseline year was 416,470 kWh, decreasing by 12.5% in Year 1 (364,457 kWh) and 14.0% in Year 2 (358,022 kWh). This reduction directly translates into lower electricity demand. The average demand, measured in kilowatts (kW), decreased from 1,780 kW in the baseline year to 1,512 kW in Year 1 (a 15.1% reduction) and further to 1,543 kW in Year 2 (a 13.3% reduction). Such energy demand reductions are consistent with findings from other retrofitting studies, which emphasize the effectiveness of energy-saving measures in decreasing both consumption and demand in public institutions [34].

Table 3: Energy consumption and savings across different months based on class days and cooling degree days (CDD) from June to December

Month	No of Class Day (day)	Cooling Degree Days (CDD)	Consumptions (kWh)	Adjusted Baseline (kWh) (Factor Total)	Final Energy Avoided	Percentage of Savings (%)
Jun	22	317	350,396.00	462,459.52	112,063.52	24%
Jul	18	328	347,351.00	451,846.52	104,495.52	23%
Aug	20	340	383,319.00	480,348.92	97,029.92	20%
Sep	20	322	385,408.00	456,490.28	71,082.28	16%
Oct	21	331.5	394,370.00	475,380.66	81,010.66	17%
Nov	6	312.5	301,424.00	355,721.74	54,297.74	15%
Dec	18	321.5	390,779.00	443,230.90	52,451.90	12%

Table 4: Energy consumption, demand, and cost reductions across baseline and post-retrofit years

Metric	Baseline Year	Post- Retrofit		% Reduction (Year 1)	% Reduction (Year 2)
		Year 1	Year 2		
Average Energy (kWh)	416,470	364,457	358,022	12.5%	14.0%
Average Demand (kW)	1,780	1,512	1,543	15.1%	13.3%
Average Cost (RM)	205,946	178,840	177,431	13.1%	13.8%

By the end of Year 1, energy costs were reduced by 13.1%, totalling RM 178,840, and in Year 2, a further reduction of 13.8% was achieved, bringing monthly costs down to RM 177,431. These reductions in energy use and demand resulted in significant cost savings, highlighting the effectiveness of the implemented energy-saving measures in lowering operational expenses and minimizing environmental impact. The consistent savings trend over the two years suggests that the energy-saving initiatives had a sustained and positive impact. Ongoing improvements in energy efficiency and cost reduction in Year 1 and Year 2 significantly contributed to achieving long-term sustainability goals.

The energy savings analysis for the entire period indicates notable reductions in energy consumption, cost, and CO2 emissions, as detailed in Table 5. The baseline monthly energy consumption was 416,470 kWh, while the average monthly consumption in Year 1 and Year 2 decreased to 361,239.5 kWh, resulting in an energy savings of 55,230.5 kWh per month.

This represents a 13.26% reduction in energy consumption and a 13.50% decrease in energy costs, confirming the effectiveness of the energy-saving measures. These findings align with previous studies, demonstrating that retrofitting can significantly reduce energy consumption annually [35].

Table 5: Energy consumption, cost reduction, and CO2 emission summary

Metric	Baseline	Post-Retrofit Average	Reduction	Percentage Reduction (%)
Energy Consumption (kWh)	416,470	361,239.5	55,230.5	13.26%
Energy Cost (RM)	205,946	178,135.5	27,810.5	13.50%
CO_2 Emissions (kg CO_2)	291529	252868.7	38660.3	

Beyond financial benefits, these energy savings have significant environmental implications, particularly in reducing CO_2 emissions, a critical factor in achieving sustainability targets. To estimate the CO_2 emissions reduction, we assume an average emission factor of 0.7 kg CO_2 per kWh, representing a typical energy mix of fossil fuels [35]. Based on this factor, the baseline monthly energy consumption of 416,470 kWh corresponds to approximately 291,529 kg of CO_2 emissions. The post-retrofit monthly average consumption of 361,239.5 kWh results in about 252,868.65 kg of CO_2 emissions. This reduction in energy use leads to a monthly CO_2 savings of 38,660.35 kg. On an annual basis, this equates to 463,924.2 kg of CO_2 emissions avoided. These findings are consistent with previous research demonstrating the environmental benefits of energy-saving measures, as retrofitting buildings can significantly reduce CO_2 emissions and contribute to climate change mitigation efforts [36].
The environmental impact of these savings is substantial. Annually, the CO_2 reduction is equivalent to removing around 100 passenger cars from the road, assuming each car emits 4.6 metric tons of CO_2 per year. Additionally, it corresponds to saving approximately 18,556 gallons of gasoline, considering that burning one litre of gasoline emits about 2.4 kg of CO_2. To sustain and amplify these benefits, enhanced real-time energy monitoring is recommended to ensure ongoing efficiency and identify further opportunities for reduction. Moreover, transitioning to renewable energy sources such as solar or wind power can significantly amplify CO_2 emission reductions. Future studies could focus on evaluating the long-term effectiveness of these energy-saving measures and their broader contributions to sustainability goals.

4.0 Conclusion

This study effectively achieved its objectives of identifying energy consumption patterns, evaluating energy efficiency improvements, and assessing cost and energy savings, contributing to optimised energy use and enhanced sustainability. The implementation of energy-saving measures (ESMs), such as lighting retrofits, voltage optimisation, and improved HVAC controls, resulted in a 13.26% reduction in energy consumption, a 13.50% decrease in energy costs, and a monthly reduction of 38,660.35 kg of CO_2 emissions—equivalent to removing approximately 100 cars from the road annually. These findings demonstrate the effectiveness of targeted interventions in reducing operational costs and environmental impact while supporting financial sustainability. The study also highlights the value of energy consumption regression models in understanding the relationship between occupancy patterns and cooling requirements, emphasising operational strategies for further optimisation. Additionally, the insights provide a practical framework for institutions to adopt scalable energy management systems adaptable for educational and commercial facilities. The outcomes offer significant potential for commercialisation, including the development of tailored ESM packages and advanced monitoring tools utilising IoT and AI-based analytics. Future work should focus on predictive models for real-time energy optimisation, integration of renewable energy sources like solar PV systems, and exploring industry partnerships to enhance the scalability and accessibility of energy-saving technologies, ensuring long-term environmental and financial sustainability.

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Author Contributions

Syahrunizam Buyamin: Methodology, Data Analysis, Writing-Original Draft Preparation, Validation, Result, and Discussion; **Nor Azura Osman**: Introduction, Literature Review, Conclusion, Result, Discussion, and Editing: **Azhar Ramli:** Data Collection, Writing Draft Preparation.

Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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