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Eco-Friendly Energy Efficient Classrooms and Sustainable Campus Strategies: A Case Study on Energy Management and Carbon Footprint Reduction

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ABSTRACT

This research paper presents a comprehensive study on energy management and carbon footprint reduction in an educational institutional campus. It focuses on implementing energy-efficient technologies and practices to minimize energy consumption and environmental impact. The study encompasses four cases, each addressing different aspects of energy use in a university setting, including the installation of LED lighting, programmable remote switches, and high-efficiency air conditioning systems. The methodology involves a detailed analysis of energy consumption patterns, using smart energy meters and theoretical calculations. Case I establishes a baseline energy consumption, while subsequent cases implement energy-saving measures. Case II involves replacing traditional tube lights with energy-efficient LED lights, resulting in considerable energy savings. Case III extends these savings further by integrating programmable remote switches mapped with student timetables. Finally, Case IV proposes the replacement of older air conditioning units with 25 SEER models, leading to significant reductions in energy use. The results highlight the effectiveness of these interventions. Case II achieves a 66.67% energy saving, while Case III yields up to 77.78% energy saving in lighting and 33.34% in air conditioning. In Case IV, the adoption of high-efficiency air conditioners can result in a 52% energy saving during teaching weeks. The economic benefits of these measures are substantial, with cost savings per classroom ranging from 7.65% in Case II to 53.46% in Case IV. Moreover, the environmental impact of these energy conservation techniques is substantial. The study reports reductions in carbon emissions from 14.71 metric tons of carbon dioxide equivalent (MT CO2e) in base Case I to 6.85 MT CO2e in Case IV. The overall carbon emission reductions for Cases II, III, and IV are 7.61%, 36.37%, and 53.43%, respectively. This study demonstrates the profound impact of integrated energy management strategies in reducing the carbon footprint and energy consumption in educational institutions, offering a model for sustainable and economically viable operations.

Keywords: Energy Management, Carbon Footprint Reduction, Sustainable Campus Initiatives, Smart Energy Monitoring, High-Efficiency Air Conditioning Systems
JEL Classifications: Q40, Q43, P18, P48, P28, L94

1. INTRODUCTION

Universities are crucial in addressing climate change through significant energy consumption and molding future energy policy leaders, necessitating an emphasis on efficient energy management and carbon footprint reduction. Various implemented strategies and technologies from campuses around the world for carbon footprint reduction have been studied and critically reviewed (Patil et al., 2023). In a residential setting, Amega et al. (2022) investigated how energy efficiency policies affect electricity consumption and carbon dioxide emissions in Lomé, Togo. Ramapragada et al. (2022) explored air conditioning's impact on electricity use in Indian homes, providing insights relevant to university energy management, though limited by its specific geographic focus.

The effectiveness of the Daylight-Saving Time (DST) policy in Brazil was studied by Giacomelli-Sobrinho et al. (2022). López (2020) explored the impact of daylight on electricity demand in Spain, specifically focusing on the influence of various Daylight Saving Time (DST) policies on energy consumption. Karasu (2010) investigated Daylight Saving Time's effect on electricity for lighting in Turkey, offering strategies potentially applicable to energy conservation on campuses. Nasriddinovna (2022) examined solar power's role in enhancing industrial energy savings, with implications for university power reliability, despite a need for more detailed research and consideration of implementation challenges. In a study by Qiu et al. (2022), the researchers investigated the difference between farmers' intended and actual use of electricity saving tricycles in Dazu District, China. Madlener et al. (2022) analyzed energy efficiency program discrepancies in actual versus predicted savings, offering a methodology beneficial for managing energy in educational settings, albeit with some geographic limitations.

Fu et al. (2021) investigated the influence of perceptions on electricity conservation intentions among 658 urban residents in the Yangtze River Delta, using the theory of planned behavior and the norm activation model. They discovered that monetary and environmental benefits increase, while inconvenience decreases willingness to conserve electricity, with policy understanding enhancing this relationship, although social expectations bias may affect these conclusions. Da Silva et al. (2018) developed a sustainable campus model for the University of Campinas, Brazil, focusing on renewable energy, electric mobility, and energy management, using the Living Lab concept in collaboration with CPFL. They proposed integrating various energy aspects into the campus environment, acknowledging challenges in data management and advocating for further research on Living Lab implementation and control centre efficiency. Attia et al. (2016) proposed a system to minimize energy consumption in university classrooms. Shafie et al. (2021) analyzed factors leading to high energy consumption at Universiti Utara Malaysia, suggesting energy efficiency strategies for reduction. The study, using a qualitative model, emphasized top management support for successful energy conservation, noting limitations in sample size and data sources, and recommended future research on weather impact, strategy effectiveness, technology's role, and renewable energy potential. Salim et al. (2022) aimed to identify wasteful electrical energy usage in the Faculty of Engineering at Universitas Negeri Gorontalo.

Negash Getu et al. (2016) emphasized the significance of energy audits in university campuses, identifying air conditioning and lighting as primary energy consumers and suggesting efficiency improvements and behavioral changes. Moran et al. (2013) studied electricity consumption patterns in public buildings, focusing on university campuses. Fuentes et al. (2022) examined the impact of energy storage on renewable energy integration in GCC countries, highlighting potential regulatory challenges and the need for detailed country-specific analysis. Zaidan et al. (2022) developed a framework for analyzing residential electricity usage in Qatar, considering factors like occupant motivation and building attributes, with implications for university housing energy management. Mi et al. (2020) conducted a 20-week controlled field experiment in Xuzhou, Jiangsu Province, China, to examine the effectiveness of personalized information interventions on promoting energy conservation among urban households. Bhattarai et al. (2023) reviewed the correlation between electricity consumption and night-time light imagery, suggesting AI and machine learning for better electricity consumption estimation in universities. Wang et al. (2021) conducted a study in four major Chinese cities to understand residents' energy-saving behavior. Yu and Chow (2007) identified energy-saving opportunities in commercial buildings in Hong Kong, focusing on mechanical ventilation and air-conditioning systems, with potential applications in university settings. Sadeghian et al. (2021) reviewed energy-saving strategies and their environmental impact across various sectors, including public lighting systems, providing insights for energy management in universities. Norton and Conlon (2016) aimed to optimize energy management for a university campus by integrating a Battery Energy Storage System (BESS) with a Photovoltaic Charging Station (PV-CS). Kang et al. (2022) analyzed the effect of daylight hours on Spain's electricity demand, suggesting daylight-saving time adjustments for energy savings, with potential insights for university campuses. Xin-gang and Pei-ling (2020) studied the impact of energy efficiency on residential electricity consumption in China, finding significant rebound effects, with implications for broader energy management research. Wang et al. (2020) evaluated China's step tariff policy's effectiveness in promoting electricity-saving behavior, offering insights for energy-saving policies in university campuses. He et al. (2021) proposed a methanol-electricity polygeneration system with improved energy efficiency, suggesting potential applications in universities. Guven et al. (2021) investigated the interaction between daylight saving time and weather on electricity consumption in Australia, providing guidance for energy management during peak cooling periods. Sadooghi (2022) analyzed the performance of an innovative switchable window to reduce the HVAC energy usage in a typical dwelling in Toronto, Canada. Kota (2021) proposed a microgrid system for a Dutch university, using Photovoltaics and Fuel Cell Electric Vehicles, enhancing self-sufficiency and reducing carbon emissions, with seasonal variability considerations.

Angelim and Affonso (2018) investigated energy cost reduction in a Brazilian university using a combination of photovoltaic generation and a battery storage system, employing the Simulated Annealing algorithm. While effective in reducing energy costs, the study's focus on one case and lack of environmental impact assessment limit its broader applicability, indicating a need for further research on environmental implications and comparison with other strategies. Sima et al. (2021) aimed to optimize energy consumption and reduce costs in educational buildings with photovoltaic installations and hybrid systems. Ullah et al. (2021) developed an optimal energy management system for university campuses, utilizing a hybrid Firefly Lion Algorithm to schedule appliances and integrate renewable energy sources, effectively decreasing energy costs and consumer waiting times. Despite its success, the model was tested only on a university load, suggesting further research to explore its effectiveness under different conditions and the influence of weather and user behaviour on energy consumption. Shyr et al. (2017) designed an Internet-of-Things-based energy management system for lighting control in a Taiwanese university, resulting in significant energy savings and offering practical applications for campus energy management. The system's success prompts future research directions in electricity usage analysis for equipment diagnostics and demand forecasting, enhancing energy conservation efforts.

Saidur et al. (2020) analyzed energy consumption in a Malaysian public hospital, suggesting that using efficient electric motors and variable speed drives can significantly save energy with a short payback period. While the study offers insights for energy management in universities, it is limited to one hospital and does not consider weather impacts. Kudela et al. (2020) evaluated the impact of Daylight Saving Time on electricity consumption in Slovakia, finding a 1% annual reduction and a smoother demand curve, though the study had limitations, including unknown emission impacts and lack of marginal technology data. Aponte and McConky (2022) introduced a demand response approach using machine learning models to reduce demand charges and inconvenience for electricity users, showing promising results but limited by small consumer sample size and lack of weather and behavior consideration. Zhou et al. (2022) used data mining to identify buildings with high energy-saving potential, aiding efficient energy conservation and fund allocation, though limited by the lack of detailed energy use information per building. Bjerregaard and Møller (2022) investigated the response of Danish industrial sectors to electricity price increases, revealing that some industries conserved electricity per output unit, but the study's findings are specific to Denmark and short-term effects. Guibentif et al. (2021) proposed a method to compare predicted and actual energy savings in small to medium-sized businesses and communal spaces, uncovering significant energy savings shortfalls due to calculation errors and rebound effects, but limited to lighting renovations and one region. Obiora et al. (2017) explored the transition to a paperless environment in a university in Cyprus, finding potential benefits in cost reduction and environmental sustainability, though the findings might not be universally applicable. Laghari et al. (2023) studied the complex relationship between electricity consumption, environmental degradation, and economic growth in China. Shafiullah et al. (2020) developed a stochastic mixed-integer linear programming model for optimizing energy management in buildings with local distributed energy resources, demonstrating cost and CO_2 emissions reductions in a case study in Amsterdam. Valsan and Kanakasabapathy (2017) designed an affordable Smart Energy Management System for a micro-hydro system in a remote tribal village, enhancing villagers' quality of life and offering potential applications in university campuses.

Linjia et al. (2015) examined the greenhouse gas emissions of room air conditioner refrigerants through a life cycle carbon footprint approach, finding that refrigerants with high global warming potential have larger emissions. The study suggests increasing refrigerant recycling and using lower GWP alternatives, though it had limitations such as assumptions about service life and usage rate, and lacked consideration for indoor air quality and energy requirements in production and disposal. Li et al. (2023) conducted a bibliometric analysis of carbon-electricity market interactions, identifying significant influences on low-carbon investment decisions and carbon emission reduction. The study recommends future research on medium and microscopic perspectives of market development and optimization of their coupling relationship. Zhang et al. (2021) developed an optimal clean heating model for an integrated electricity and heat energy system, finding that high back-pressure turbine heating is effective under certain conditions. The study proposed a combined heating mode to enhance system flexibility and coal-saving, but faced limitations due to assumptions about carbon tax rates and stable fuel prices. Clabeaux et al. (2020) compared carbon footprints among U.S. higher education institutions using the Greenhouse Gas Protocol and EIO-LCA tool, identifying varying factors like population size and emission sources. The study emphasized the need for accurate emission calculations and suggested future research to establish CF improvement baselines and consider electricity usage and waste disposal effects. Vrachni et al. (2022) analyzed the University of Patras' carbon footprint, identifying student commuting and purchased electricity as major emission sources. They proposed 2030 goals in line with Greece's National Plan for Energy and Climate, focusing on managing carbon and energy and enhancing environmental culture, despite financial constraints and uncertainties around future gas supplies.

These studies collectively suggest the necessity for comprehensive, adaptable strategies that consider local conditions, technological advancements, and behavioral dynamics. They also highlight the potential role of universities as models for sustainable energy practices, aligning with global climate goals. This body of work informs the development of our methodology, directing towards an integrated, practical framework for energy and carbon management in academic institutions.

2. METHODOLOGY

2.1. Energy Monitoring and Optimization

In this research, a multifaceted scientific methodology is adopted to advance energy efficiency and sustainability in an academic setting, delineated into four unique cases aimed at evaluating and enhancing energy consumption. The initial phase, Case I, involves a baseline assessment of existing energy use. Case II progresses to installing energy-efficient LED lighting and assesses their impact on energy consumption, including an economic evaluation. Case III furthers energy conservation by integrating programmable remote switches tailored to student schedules, assessing ongoing energy use and economic aspects. Case IV is centered on replacing older air conditioning units with more efficient models, analyzing potential energy savings and environmental advantages. Additionally, the study calculates the decrease in carbon footprint due to these energy-saving efforts, considering both power generation efficiency and the carbon intensity of energy sources. This approach yields not only insights into optimizing energy use in educational environments but also provides a comprehensive view of the related environmental and economic effects, contributing to the broader conversation on sustainable energy practices.

2.1.1. Case I: Energy monitoring in existing stage

The energy consumption monitoring study conducted in the Engineering campus can be described as follows: The campus comprises a total of 48 classrooms designated for academic instruction. For the purpose of this study, three classrooms were systematically selected as representative samples to monitor energy consumption patterns. Each of these classrooms was equipped with 72 fluorescent tube lights, each rated at 18 watts, and four air conditioning units, each having a capacity of 2 tons. The operational schedule of these electrical fixtures was aligned with the university's teaching timetable, which spans from 8 AM to 4 PM. Consequently, both the lighting and air conditioning systems were active from 7:30 AM to 4:30 PM daily to accommodate the setup and wind-down times around the scheduled classes. To accurately measure the energy consumption within these classrooms during a typical teaching week, smart energy meters were installed. These meters provided real-time data on electricity usage. Additionally, to validate the accuracy of the smart meter readings, theoretical calculations based on the known power ratings of the installed fixtures and their operational hours were conducted. This dual approach of empirical measurement and theoretical verification provided a comprehensive understanding of the energy usage patterns in the selected classrooms.

2.1.2. Case II: Energy monitoring after installation of energy efficient LED tube lights

The luminous requirement assessment and energy consumption analysis for the classrooms in the Engineering campus can be articulated scientifically as follows:

The study involved an in-depth evaluation of the lighting needs for classrooms with specific dimensions: A height of 345 cm, a width of 774 cm, and a length of 980 cm, resulting in a total room area of 75.85 square meters. The determination of the requisite lumens for optimal illumination was based on the standard classroom lux requirement of 500 lux, which is considered conducive for learning and visual tasks. The total lumens required were calculated using the formula: Total Lumens = Room Area × Lux Requirement. This calculation yielded a requirement of approximately 37,926 lumens for adequate illumination in each classroom.

Further, to estimate the number of LED tube lights needed to meet this luminescence requirement, the lumen output per tube light was considered. Assuming an LED tube light efficiency of 90 lumens per watt for a 9W LED tube light, each light produces approximately 810 lumens. Dividing the total lumens required (37,926 lumens) by the lumens output per tube light provided an estimate of the number of lights necessary for the desired illumination level. Consequently, for the specified classroom dimensions, approximately 47 LED tube lights of 9W each were required. Based on this assessment, 48 LED tube lights were installed in each classroom to achieve the optimal brightness.

During the teaching week, a Smart energy meter was installed in each classroom to monitor real-time energy consumption. To ensure the accuracy of the data collected by these meters, theoretical calculations based on the known power ratings of the LED lights and their operational hours were performed. This dual methodology of empirical data collection and theoretical validation facilitated a comprehensive analysis of energy usage.

Moreover, the study included an economic assessment, where the cost savings and return on investment (ROI) due to the installation of energy-efficient LED lighting were estimated. These financial implications were systematically tabulated, providing an insightful perspective on the economic benefits of energy conservation measures implemented in the academic setting.

2.1.3. Case III: Energy monitoring after installation of energy efficient LED tube lights and programmable remote switches

The implementation of energy-saving measures based on the analysis of student timetables and the subsequent monitoring of energy consumption can be detailed in scientific language as follows:

The study commenced with an analysis of student timetables to identify potential free time slots during which energy consumption could be minimized. This analysis revealed several periods throughout the day when classrooms were unoccupied, presenting opportunities for energy conservation. To capitalize on these opportunities, programmable remote switches equipped with timers were procured and installed for both LED tube lights and air conditioners in the three selected classrooms. These remote switches were meticulously programmed to automatically turn off the lights and air conditioners during the identified free slots, in alignment with the student timetable.

To quantify the impact of this intervention on energy consumption, Smart energy meters were installed in each of the classrooms. These meters were utilized to monitor the energy usage throughout a typical teaching week, providing real-time data on electricity consumption. To validate the accuracy of the smart meter readings, theoretical calculations based on the known operational schedules of the lighting and air conditioning systems, as well as their power ratings, were conducted. This approach ensured a rigorous verification of the empirical data collected.

Furthermore, the study encompassed a financial analysis to evaluate the cost savings and return on investment (ROI) resulting from the implementation of these energy-saving measures. The economic impact was systematically quantified and is presented in the accompanying table. This analysis provides a comprehensive understanding of the economic benefits, alongside the environmental impact, of implementing programmable remote switches in an academic setting. The overall methodology thus integrates a practical energy-saving solution with a robust monitoring and verification framework, enabling a thorough assessment of both the energy and economic efficiencies achieved.

2.1.4. Case IV: Energy monitoring after installation of energy efficient LED tube light, programmable switches, mapping of class timetables and proposed installation of 25 SEER ACs

The rationale and approach for replacing old air conditioners with high-efficiency models can be articulated in a scientific manner as follows:

The preliminary energy consumption analysis of the classrooms under study revealed that a significant portion of the energy usage was attributable to air conditioners that were 15 years old. Recognizing the potential for energy savings, it was proposed to replace these units with air conditioners boasting a 25 SEER (Seasonal Energy Efficiency Ratio) rating. SEER ratings are a measure of the energy efficiency of air conditioning systems, indicating the amount of cooling output during a typical cooling season divided by the total electric energy input. A 25 SEER rating represents a high level of efficiency in current cooling technology, allowing for substantial energy savings by utilizing less electricity to achieve the same cooling level as lower-rated models.

The adoption of these high-efficiency air conditioners, while entailing a higher initial investment, is projected to lead to significant cost reductions over time. This is primarily due to the lower operational energy costs associated with these units. Moreover, their enhanced efficiency contributes to a reduced environmental footprint by diminishing the demand on power generation facilities and consequently reducing greenhouse gas emissions. These air conditioners integrate advanced technologies, such as variable speed compressors, making them particularly advantageous in regions experiencing prolonged and intense cooling seasons.

The decision to upgrade to 25 SEER air conditioners was underpinned by a thorough evaluation of the potential energy savings and the associated return on investment (ROI). Theoretical calculations were employed to estimate these savings and ROI, taking into account the reduced energy consumption and the consequent decrease in electricity bills. These calculations and the estimated financial benefits are systematically presented in the accompanying table. This approach underscores the study's commitment to not only improving energy efficiency but also evaluating the economic viability and environmental benefits of adopting advanced cooling technologies in an academic setting.

2.2. Estimation of Carbon Footprint Reduction

The evaluation of energy generation requirements and the subsequent calculation of carbon footprint reduction for energy savings can be elucidated in a scientific context as follows:

The study begins with an analysis of the typical efficiency of an Oil/Gas power plant, which is approximately 33%. This efficiency rate is critical in determining the actual amount of energy that needs to be generated to supply electricity to the consumer. Additionally, the average transmission and distribution loss, which is around 5%, is considered to further refine the energy generation requirements. Consequently, to supply 1 kWh of electricity to a consumer, an Oil/Gas power plant is estimated to need to produce approximately 3.03 kWh of energy, factoring in its efficiency. However, when incorporating the transmission and distribution losses, the total energy requirement for supplying 1 kWh escalates to about 3.19 kWh. Thus, a saving of 1 kWh in energy consumption at the consumer end translates to a decrease in demand for approximately 3.19 kWh of energy generation at the power plant. This calculation considers the combined effects of generation efficiency and the losses incurred during the transmission and distribution of electricity.

Furthermore, the methodology extends to calculate the carbon footprint reduction for 100 kWh of energy saved at the point of utilization. This calculation takes into account an energy generation mix of 65% crude oil and 35% natural gas. The CO_2 emission factors for crude oil (2.13 kg CO_2 per kWh) and natural gas (0.55 kg CO_2 per kWh) are obtained from the U.S. Environmental Protection Agency. A weighted average emission factor is then computed, reflective of the 65% crude oil and 35% natural gas composition. This factor is applied to the total CO_2 emissions calculation for the production of 100 kWh, inclusive of the inefficiencies in energy generation. With a power plant efficiency of 33% and a transmission and distribution loss of 5%, the energy that would need to be generated at the power plant to supply 100 kWh to the consumer is determined. The total reduction in CO_2 emissions is then calculated by multiplying the adjusted energy requirement by the weighted average emission factor. This methodological approach provides a comprehensive quantification of the reduction in carbon footprint attributable to the saved energy,

Figure 1: Monthly energy consumption of tube lights classroom

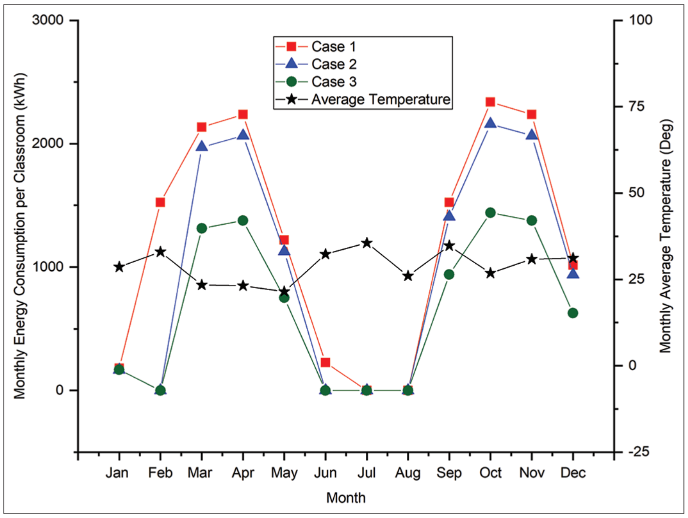
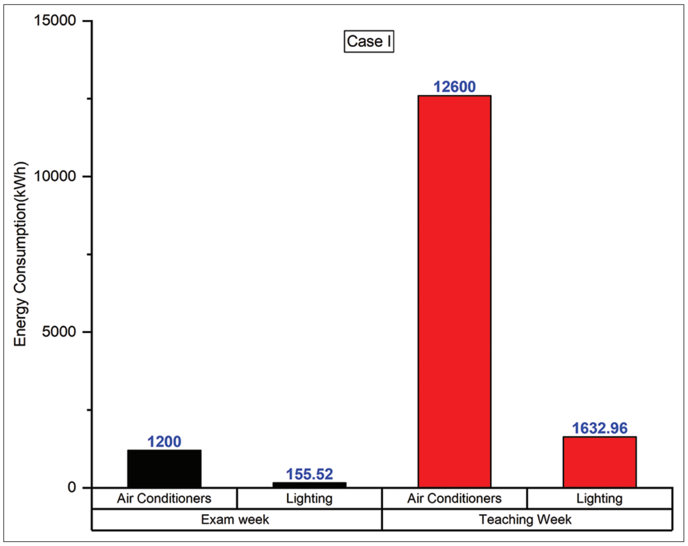


Figure 2: Annual energy consumption per classroom: Case I



encompassing both the efficiency of the power generation process and the carbon intensity of the utilized fuel sources, thereby offering a holistic understanding of the environmental implications of energy conservation initiatives.

3. RESULTS AND DISCUSSION

Figure 1 shows monthly energy consumption of a classroom. It also shows the variation of month wise average temperature in Muscat, Oman. The monthly energy consumption of the classroom is highly dependent on the average ambient temperature. The lowest monthly average temperature of 21.48°C was recorded in January and corresponding energy consumption was measured as 180.736 kWh. The highest monthly average temperature of 35.56°C was recorded in June and corresponding energy consumption was measured as 1016.64 kWh. This energy consumption was recorded only for 4 working days in January and 10 working days in June due to examination. The classrooms remain closed on remaining non-teaching days. Per day energy consumption in January and June was 45.18 kWh and 101.6 kWh. This clearly shows that ambient temperature has a profound effect on daily energy consumption.

Annual energy consumption per classroom in case I is shown in Figure 2. The energy consumption in air conditioning and lighting loads for exam and teaching weeks have been shown separately. By replacing the existing tube lights by energy efficient LED lights as per luminance required for a classroom considerable energy can be saved. This has been implemented in Case 2. Further from the graph it is clearly seen that the air conditioners are the largest energy consuming loads. This depicts that there is a scope to reduce the energy consumption during teaching weeks for air conditioners which has been implemented in Case III using smart controllers.

Figure 3 shows the annual energy consumption per classroom for case II where the energy efficient LED lights of 9 Watts have been

Figure 3: Annual energy consumption per classroom: Case II

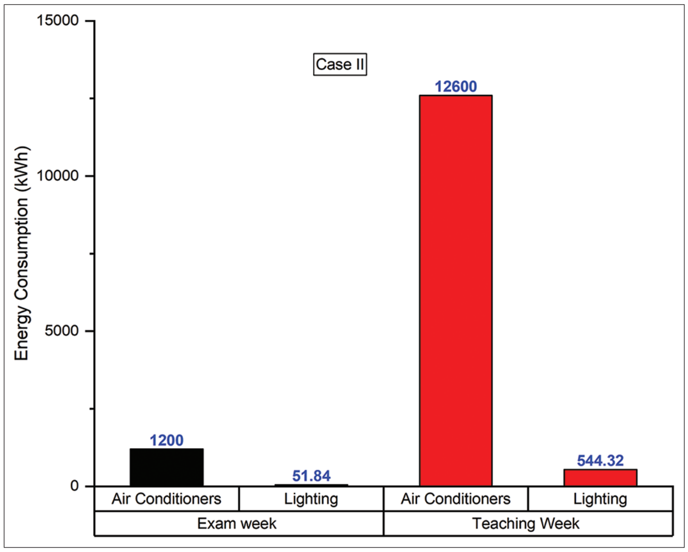


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Figure 4: Annual power consumption per classroom: Case III

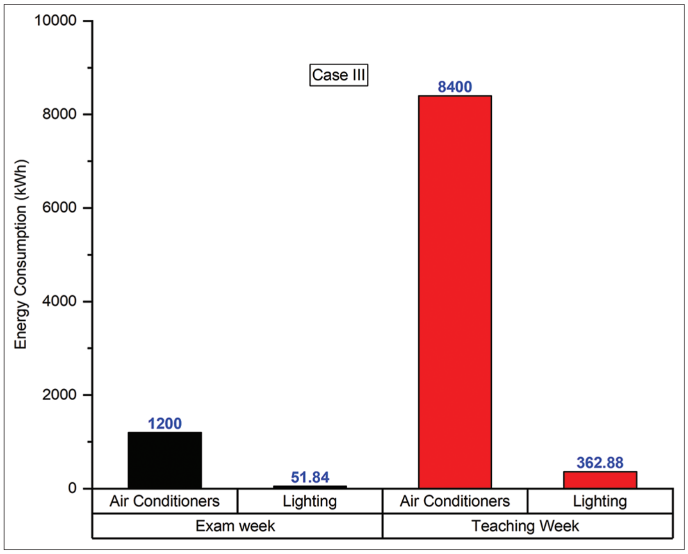


Figure 5: Annual power consumption per classroom: Case IV

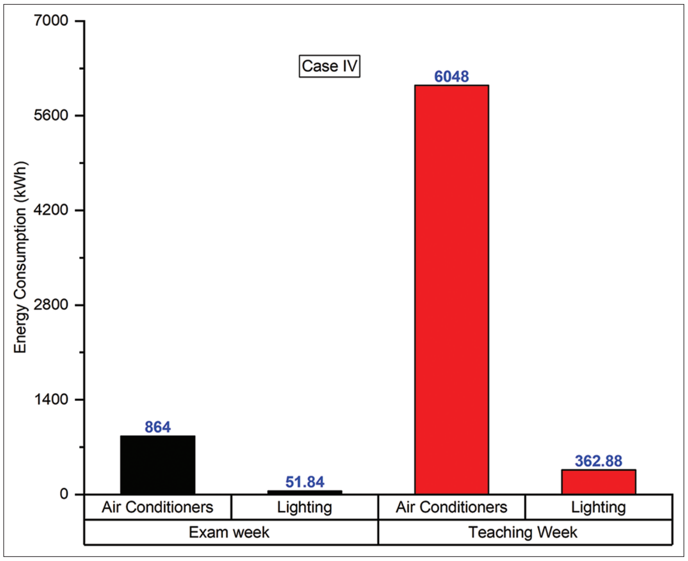
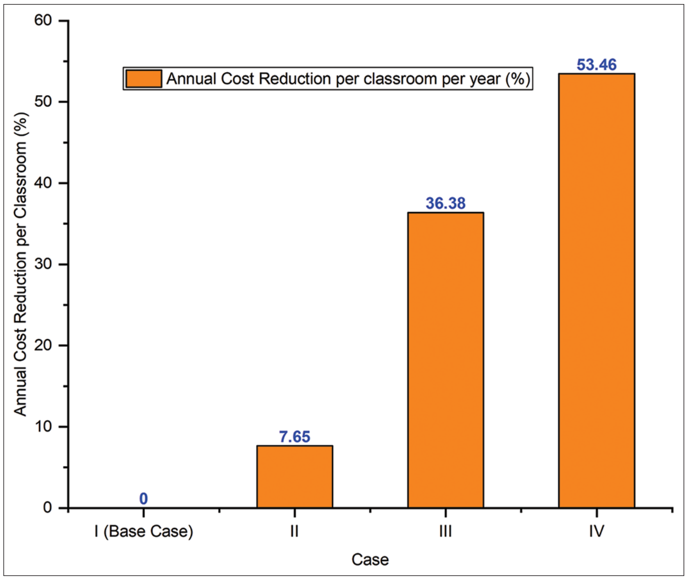


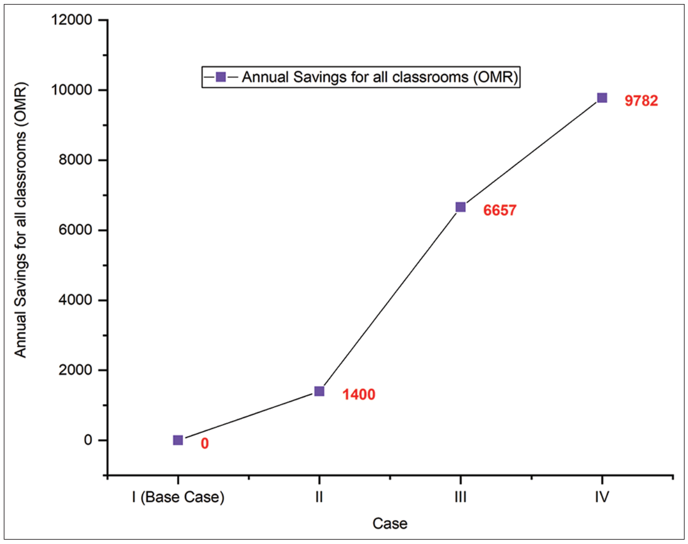
Figure 6: Total annual cost reduction per classroom



used for replacement for existing tube lights of 18 Watts. Due to this change there is an energy saving of 66.67% during teaching weeks and examination weeks.

The effect of programmable smart controllers combined with energy LED efficient LED lights on energy consumption of a classroom is shown in Figure 3. It clearly indicates that due to mapping of smart controllers with a class timetable, there has been a significant energy saving as compared to Case I and Case II. It can be seen that there is 77.78% energy saving during teaching weeks and 66.67% energy saving during exam week for lighting as compared to Case I. Also there is 33.34% energy saving during teaching weeks for air conditioners. Annual power consumption per classroom after installation of energy efficient LED Tube Lights and programmable remote switches is shown in Figure 4.

Figure 7: Annual savings for all classrooms (in OMR)



Based on the results obtained in case III, there is a scope to replace the existing air conditioners with energy efficient 25 SEER air conditioners for further energy savings. With this proposed replacement energy requirement has been estimated and the results are shown in Figure 5. It can be seen from Figure 5 that due to use of more energy efficient air conditioners it is possible to save 52% energy during teaching week and 28% energy during exam week as compared to case I.

Total annual cost of energy usage for each classroom (OMR) has been calculated and the percentage reduction in the cost for case to case is shown in Figure 6. Considering case I as base case, it is found that there is a saving of 29.2 OMR (7.65%) for case II, saving of 138.7 OMR (36.38%) for Case III and saving of 203.80 OMR (53.46%) for Case IV.

If we implement the energy saving techniques for all 48 classrooms on campus, a benefit of 1400 OMR, 6657 OMR and 9782 OMR can be obtained in Case II, Case III and Case IV respectively. This has been shown in Figure 7.

The annual carbon emission is calculated for the current electricity usage on campus for each case. Oman power generation units mainly use two resources namely oil (65%) and natural gas (35%). Crude oil produces 2 lbs of CO_2 for generation of one energy

Table 1: Energy consumption and carbon footprint estimation of case I to case IV

Description	Case I	Case II	Case III	Case IV
Energy Consumption for tube lights per day				
Power of each tube light (Watt)	18	9	9	9
Number of tube lights in each room (Nos.)	72	48	48	48
Total power for all tube lights (KW)	1.296	0.432	0.432	0.432
Energy consumption per day by tube lights (For 9 h) (kWh)	11.664	3.888	2.592	2.592
Energy Consumption by Air conditioners per day				
Power of each air conditioner (KW)	2.5	2.5	2.5	1.8
Number of air conditioners	4	4	4	4
Total power for all air conditioners (KW)	10	10	10	7.2
Energy consumption for 9 h (kWh)	90	90	60	43.2
Total daily energy consumption (KWh) for the classroom	101.66	93.88	62.59	45.79
Total weekly consumption	508.32	469.44	312.96	228.96
Teaching weeks for an academic year	28	28	28	28
Annual Energy consumption (kWh) during teaching weeks	14232.96	13144.32	8762.88	6410.88
Exam weeks in one academic year	6	6	6	6
Energy consumption (kWh) during exam weeks	1016.64	938.88	938.88	686.88
Total Energy consumption (kWh) per year for each classroom	15249.6	14083.2	9701.76	7097.76
Average Energy tariff (0.025 OMR/kWh)	0.025	0.025	0.025	0.025
Total annual cost of energy usage for each classroom (OMR)	381.24	352.08	242.54	177.44
Number of classrooms	48	48	48	48
Total annual energy cost for all classrooms (OMR)	18299.52	16899.84	11642.11	8517.31
Annual carbon emission reduction on campus (lbs)	Base Case	1908	9076	13336
Annual carbon emission at generation end (lbs)	32432	29952	20634	15096
CO_2 emissions at generation end in metric tons of carbon dioxide equivalent (MT CO2e)	14.71	13.59	9.36	6.85
% reduction of CO_2 footprint at Generation end	0	7.61	36.37	53.43
Cost saving (in OMR)	Base Case	29.16	138.7	203.8
Cost saving (%)		8	36	53
Investment for eco-friendly energy efficient classroom				857.6
Payback period (years)				4.21

Table 2: Investment cost to convert energy efficient eco-friendly classroom

Description of items	Amount (OMR)
LED Tube light (48 Tubes*1.2 RO Each)	57.6
Smart Heavy Duty Remote Switch with Timer for 48 light (20 RO*2)	40
Remote operated AC controller with timer (20 RO*2)	40
LG Air conditioner T24ZCA - 2 ton with SEER 25 (180 RO*4)	720
Total Investment cost per classroom	857.6

Figure 8: Annual carbon emission for current electricity usage on campus (lbs)

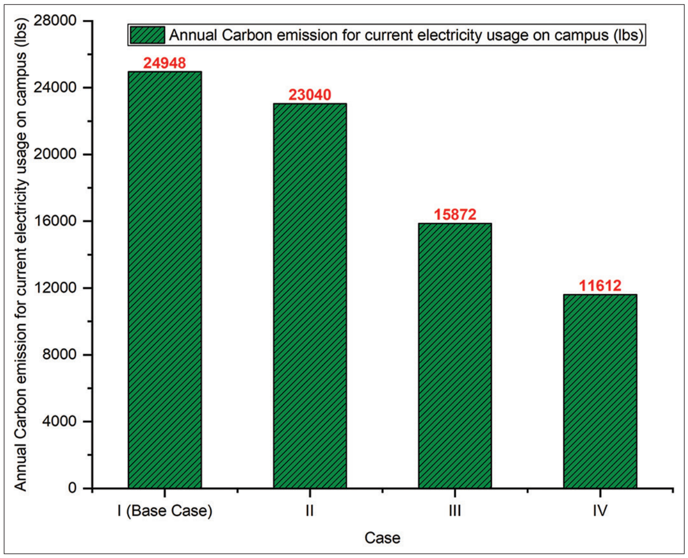
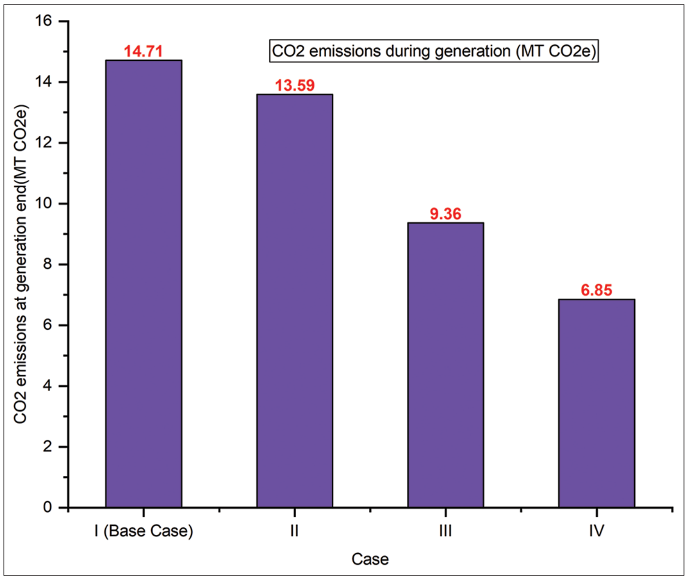


Figure 9: Monthly energy consumption of tube lights per classroom



unit, while natural gas produces 0.96 lbs of CO_2 for the same. Figure 8 shows the annual carbon emission for current electricity usage on campus (in lbs) for each case. It is observed that with the implementation of energy conservation techniques there is a reduction of 1908 lbs CO_2 in Case II, 9076 lbs CO_2 in Case III and 13336 lbs CO_2 in case IV as compared with Case I.

Considering power losses at generation, transmission and distribution phases, 1 unit of energy saving at the distribution end results in approximately 1.33 units of energy saving at the generation end. By considering this, annual carbon emission at the generation end for current electricity usage on campus is estimated in metric tons of carbon dioxide equivalent (MT CO2e) as shown in Figure 9. It can be seen that there is carbon emission reduction of 7.61% for case II, 36.37% for case III and 53.43% for case IV as compared to the base case I.

The Table 1 provides the estimated results obtained for all cases. In the initial stage the cost of energy consumption per day by tube lights was estimated in Case I as 11.664 OMR and is reduced further till 2.592 OMR for Case IV due to replacement of LED Tube lights and smart monitoring. There are total 4 air conditioners installed in each of the classrooms and total energy consumption of all 72 tube lights and 4 air conditioners was estimated which is reduced from 101.66 kWh in Case I to 45.79 kWh in Case IV. The energy cost estimation is done separately for the Teaching and examination weeks as there is only few hours utilization of classrooms during examination time. Average Energy tariff used for the estimation of energy cost is 0.025 OMR/kWh taken from the Muscat Electricity Distribution Co. SAOC (MEDC) website. Annual carbon emission is estimated in university campus and at generation source by considering losses in transmission. Investment cost for LED tube Light and Smart Controllers are based on the material purchased from local suppliers. Energy Efficient ACs cost is calculated based on the data provided by the local suppliers. Based on the costs estimated as shown in Table 2 for eco-friendly energy efficient classroom the payback period is estimated as 4.21 years per classroom.

4. CONCLUSION

The conclusion of this study highlights the remarkable effectiveness of a multi-pronged approach to energy conservation in an academic setting. The implementation of energy-efficient LED lighting (Case II), resulting in a 66.67% energy saving, programmable remote switches (Case III), yielding up to 77.78% energy saving in lighting and 33.34% in air conditioning, and the adoption of 25 SEER air conditioners (Case IV), saving 52% energy during teaching weeks, significantly reduced energy consumption. This approach, validated by smart metering and theoretical calculations, not only improved energy efficiency but also offered substantial economic benefits, including cost savings of 29.2 OMR (7.65%) in Case II, 138.7 OMR (36.38%) in Case III, and 203.80 OMR (53.46%) in Case IV per classroom.

Additionally, this research underscores the environmental impact of these energy-saving measures. The reduction in carbon emissions was substantial, with savings of 1908 lbs CO_2 in Case II, 9076 lbs CO_2 in Case III, and 13336 lbs CO_2 in Case IV compared to the baseline (Case I). These reductions, alongside the calculated 7.61%, 36.37%, and 53.43% decreases in carbon emissions for Cases II, III, and IV respectively, demonstrate the potential of integrated energy management strategies to significantly mitigate the carbon footprint of educational institutions. The study not only contributes to the field of sustainable energy practices in academic environments but also provides a model for cost-effective and environmentally responsible operations.

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