Energy Audit and Management: A Case Study of the UMaT New Administration Building*

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Abstract

The University of Mines and Technology (UMaT) New Administration Building, located in Tarkwa, Western Region, Ghana, faces increasing electricity consumption and expenditures, emphasizing the need for energy management and audit. This study aims to conduct a preliminary energy audit of the building, propose energy-saving strategies, and evaluate their impact on energy efficiency. The preliminary energy audit utilized RETScreen to calculate base case energy consumption, considering equipment quantity, operating hours, electrical load, and duty cycle. Air conditioning was the largest energy consumer (395,405 kWh), followed by desktop computers (23,547 kWh), resulting in substantial total energy use (434,756 kWh). Lighting systems, contributing substantially to the base case scenario, consumed an additional 2,459 kWh. Optimizing the cooling system reduced energy consumption by 26.1%. The optimized lighting system achieved a 54.6% reduction. Collectively, these strategies contributed to a remarkable 24.07% reduction in total energy consumption, yielding both cost savings and environmental benefits. Furthermore, the integration of a solar car park yielded an 18% reduction in electricity costs and carbon dioxide (CO_2) emissions. It was discovered that generating the monthly required energy of 147,116 kWh through the solar car park produced approximately 273 tCO_2, resulting in a reduction of 63.6 tCO_2 compared to the overall emissions of 336.6 tCO_2. This integration not only improved reliability but also significantly enhanced environmental sustainability by reducing CO_2 emissions by approximately 62.13 tCO_2. The study demonstrates that implementing energy-saving strategies can substantially improve energy efficiency, lower costs, and reduce carbon emissions. It aligns with prior research, indicating consistent energy savings across different contexts. This research contributes valuable insights into enhancing energy efficiency in buildings, reducing costs, and promoting environmental sustainability through energy management and audit practices. The findings emphasize the importance of optimizing cooling and lighting systems, as well as integrating solar solutions, to achieve significant energy and environmental benefits.

Keywords: Building energy consumption, Energy efficiency, Energy saving solutions

1 Introduction

Global energy consumption in various sectors of the world's economy has increased in recent years as a result of rapid population growth and a high standard of living (Aldhshan *et al*., 2021; Avtar *et al*., 2019). In comparison to other sectors of the economy, the building sector, which includes residential and commercial end-use, consumes the most energy (Wang *et al*., 2017). Buildings account for 30 to 45% of global energy consumption, though percentages vary by country (Berardi 2017; Gul and Patidar 2015). According to a study conducted by (Peacock *et al*., 2007), the energy consumption of buildings in the United Kingdom tops the chart with the highest consumption among others. The primary areas of energy use in buildings include but are not limited to lighting, ventilation and air-conditioning, heating, and main appliances such as dryers, water heaters, freezers, refrigerators, etc. (Gul and Patidar 2015).

The aforementioned projections indicate that there is the need to critically analyze our energy systems making it essential to optimize energy use in buildings in order to minimize losses as well as provide alternative solutions to help stabilize the energy sector and reduce costs to building owners, realtors, and other occupants. Building efficiency must be considered when improving the performance of a complex building designed to provide comfort and safety to occupants (Galiano-Garrigós *et al*., 2021). This includes superb architecture and engineering designs, proper building practices, as well as smart operation of the edifice. More and more, operations will involve the incorporation of advanced electricity grids; this can range from the distribution of electricity through transmission lines to the end user. In order to properly manage a building's energy consumption, first, an energy audit comes to mind. Energy auditing is the process of inspecting, and evaluating the electrical energy flow of a building under inspection and designing it to reduce the amount of energy used (Darshan *et al*., 2022). The main goal of an energy audit is to assess a building's energy consumption and examine effective solutions that enhance energy efficiency as well as provide energy conservation, without negatively affecting the operation of the building. This process gives an account of the system used, and the appliances used and performs an analysis on the distribution during the day (Kabir *et al.*, 2010). The energy auditing process also tackles issues of leakage in ventilation

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cooling systems, illumination systems, and sound systems just to mention a few (Kazem, *et al*., 2012). Also, in order to reduce the emission of greenhouse gasses such as carbon dioxide (CO_2), and carbon monoxide (CO) emanating from the consumption of energy in buildings (Lu, 2017), owners and occupants of buildings can implement energy audits and management strategies to find out the amount of greenhouse gases released into the air as a result of the operation of the buildings and to propose suitable actions to reduce these emissions.

In view of the high energy consumption in most buildings, science, and technology are playing key roles in order to minimize losses through Building Energy Management Systems (BEMS) (Ozturk, *et al.,* 2013). Through BEMS, a building's energy needs can be monitored and controlled while still ensuring a high standard of living within the building (Mohamed, *et al.,* 2016). Some of the known strategies for BEMS are; model predictive control, demand side management, optimization, and fault detection and diagnoses. (Mariano-Hernández, *et al*., 2020). Among these, the demand-side management strategy is suitable for energy efficiency on the users' side (Palensky and Dietrich, 2011). Demand Side Management (DSM) is a model that controls the demand of consumers by adjusting their energy patterns of electricity usage (Mariano-Hernández *et al*., 2020). This model is usually on the consumers' premises and is incorporated with incentives that reduce the energy consumed by the user. It spans from improving energy efficiency through the utilization of better materials, over smart energy tariffs coupled with special motivations for certain consumption patterns, up to the state-of-the-art control of distributed energy resources (Palensky and Dietrich, 2011). DSM approaches are grouped into energy efficiency and demand response. The main aim for optimizing equipment operations such as lighting, heating, cooling, ventilation, and other appliances, is to reduce the energy requirements of such facilities. The post-occupancy evaluation of the spaces' utilization, occupants' attitudes, and their perception of overall comfort served as the foundation for optimization. Rearranging the schedule of integrated electric equipment is a key component for improving energy and environmental performance. Post-occupancy evaluations of the building's effective occupants' weekly attitudes are then implemented as a result of this rescheduling (Pisello *et al*., 2012). Optimization strategies are grouped into stochastic and robust approaches. The fault detection and diagnostics (FDD) strategy is the process of automatically detecting and restricting faults for the protection of the system from damages or losses in BEMS (Hannan *et al*., 2018). In order to achieve energy management in buildings, the use of sensors and other devices to determine faults that develop within the energy system is detected, diagnosed, and further addressed by a technician or the system itself through a recalibration system, and has also been estimated that wastages recorded in commercial building energy use are (5-30) % due to the lack of control of energy systems (Lin, *et al*., 2020). Fault detection and diagnostics strategy is grouped into data-driven-based and knowledge-driven-based FDD.

Several studies on BEMS have been conducted, with an emphasis on novel ideas and building characteristics that can be used to address energy efficiency and management issues in buildings, using various modeling and control strategies. For instance, Jomoah *et al*. (2013) installed an energy management system in the buildings of King Abdulaziz University in Saudi Arabia which resulted in a decrease in electrical energy consumption using the demand-side management strategy. It was found that the energy consumption in the building during holidays could be hugely decreased with BEMS. Also, a 14.3% reduction in energy consumption of the building in the month of August 2012 was accomplished after implementing DSM on cooling and lighting systems, when compared to that of August 2011 without BEMS. One drawback of the system is its high cost. Furthermore, Ashaj and Erçelebi (2018) have also utilized monitoring and control systems for the design and control of energy management systems for buildings. A remote monitoring system was used in this study to analyze environmental factors such as CO_2 concentration. The monitoring system is unique to Linux systems and is dependent on the type of processor. Yang (2013) has developed a multi-objective particle swarm optimization (MOPSO) to integrate building control systems and coordinate activities in building system components in his dissertation. This algorithm performs exceptionally well in solving multi-objective problems in building automation. Through a smart energy management approach, Nadimuthu and Victor (2021) have improved the energy efficiency of medicine manufacturing systems. Foroughi *et al*. (2021) have proposed a genetic algorithm-based optimization model in conjunction with the EnergyPlus software package to achieve the optimal window-to-wall ratio (WWR), aspect ratio, and window positions in commercial structures in the United States of America. Furthermore, Wang *et al*. (2017) have presented a mixed integer linear programming-based strategy for scheduling a collection of constant air-conditioning loads in order to alleviate the ambiguities associated with some stochastic variables, such as wind energy and ambient temperatures, which ultimately improves wind energy use and lowers operational costs. A new method for optimizing heating, ventilation, and air conditioning (HVAC) energy consumption is proposed, which is based on load prediction and energy flexibility. A thorough assessment of uncertainty analysis in building energy analysis has been presented (Tian *et al*. 2018). The review proposed some feasible future directives for a more appropriate and meticulous building energy uncertainty analysis.

Furthermore, the construction industry typically consists of a number of stages and procedures, beginning with the creation of the client's brief or prerequisites and progressing inexorably to development, erection or establishment, and life cycle operation and maintenance (Yüksek and Karadayi, 2017). The aspect of energy conservation and maintenance has received little attention in the life cycle and maintenance of a building. Building energy consumption is a significant issue that must be efficiently managed and reduced. Building industry issues include the use of old devices, outdated building designs, and human negligence, among others (Yüksek and Karadayi, 2017).

Energy efficiency and management is a severe problem for campus structures as it is linked to students' comfort and indoor air quality. In this regard, quite a number of research have been conducted. Quite recently, Osorio *et al*. (2022) have proposed a research direction succeeded by two private higher education institutions in Columbia for net-zero carbon emissions, and they found that higher education institutions can improve carbon neutrality while also promoting adequate cultural awareness of sustainability for their students. Marrone *et al*. (2018) have also used cluster analysis to assess the stock of Italian school buildings, proposing a strategy to examine the optimal energy retrofit interventions from a cost-benefit standpoint and match them up with the specific properties of the educational buildings. Furthermore, a retrofit strategy to improve energy efficiency in some selected higher educational buildings in Egypt has been proposed (El-Darwish and Gomaa, 2017). Some building envelope features can be retrofitted to provide comfort without compromising functional needs. Moreover, Sapri *et al*. (2016) presented a paper that investigates the implementation of energy management strategies in six public higher education institutions in Ghana in order to examine the presence of energy-saving opportunities. It was concluded that energy management is an underutilized opportunity to reduce energy costs in Ghanaian higher education institutions.

Through the planned study using the University of Mines and Technology (UMaT) New Administration Building as a case study, we intend to explore how energy management and auditing can help differentiate energy consumption in the building into elements such as ventilation and air-conditioning, lighting, and other office equipment. This aspect, which has received less attention, will be the focus of our investigation. Additionally, as electricity consumption continues to rise throughout the day, the university's annual expenditure on electricity consumption has become a significant concern. Consequently, estimating energy consumption at the UMaT New Administration building, determining the extent of energy loss, and providing energy management solutions for optimization are critical tasks. In line with these objectives, the primary goal of this study is to conduct a preliminary energy audit of the University of Mines and Technology New Administration Building and propose feasible ways to achieve energy savings or identify areas for potential optimization. To accomplish this, we have outlined the following objectives: Investigating the potential for energy consumption in the UMaT Administration Building;

i. Investigating the prospect of energy savings in various energy-consuming equipment through energy audits;

ii. Identifying energy conservation opportunities (ECO) within the most energy-consuming equipment; and

iii. Establishing economic assessments for those energy conservation opportunities.

2 Materials and Methods

In this section, we outline the methodology used to assess the UMaT New Administration building's energy characteristics and performance. The general characteristics, technical characteristics, electrical characteristics, and thermal characteristics of the UMaT New Administration building are presented in this section. In terms of electrical characteristics, a preliminary energy audit of the building's four floors is presented. The energy performance assessment criteria used are included here.

The energy audit process for the UMaT New Administration building includes the following steps:

i. Data Collection: Comprehensive data gathering included building specifications, utility bills, and historical energy usage.

ii. Site Inspection: Assessment of physical condition, energy systems, and building envelope.

iii. Interviews and Surveys: Occupant and facility manager insights, surveys for behavior.

iv. Instrumentation: Basic tools for energy and environmental monitoring.

v. Software Simulations: RETScreen is used for energy modeling.

vi. Analysis: Data and simulations were analyzed for energy hotspots and baseline.

vii. Energy-Saving Strategies: Evaluation of lighting, cooling, and solar car park options.

viii. Recommendations: Formulation of energy-efficient suggestions.

ix. Cost-Benefit Analysis: Preliminary financial implications estimation.

Report Generation: Comprehensive energy audit report creation.

2.1 General Characteristics of the Building

The UMaT Administration Building, located in Tarkwa, Ghana, was completed in 2020. It is a four-story structure facing east and surrounded by adjacent buildings within a 5-meter radius, including the Mechanical Engineering Department Building, the Environmental and Safety Engineering Department Building, the Renewable Energy Engineering Department Building, and the Security post.

2.1.1 Technical Characteristics of the Building

The building consists of 65 rooms distributed across different floors, serving various purposes such as administrative offices, storage, and meeting spaces. Fig. 1 provides floor plans detailing the layout of each floor. The building consists of 65 rooms distributed across different floors, serving various purposes such as administrative offices, storage, and meeting spaces. The ground floor houses a parking lot and a reception area, while the basement houses a storage room. Administrative offices, server rooms, and a kitchenette are on the first floor, with individual offices and a conference room on the second and third floors. The Registrar's Office, the Finance Office, the Pro-Vice Chancellor's Office, the Vice Chancellor's Office, and a large conference room are on the top floor.

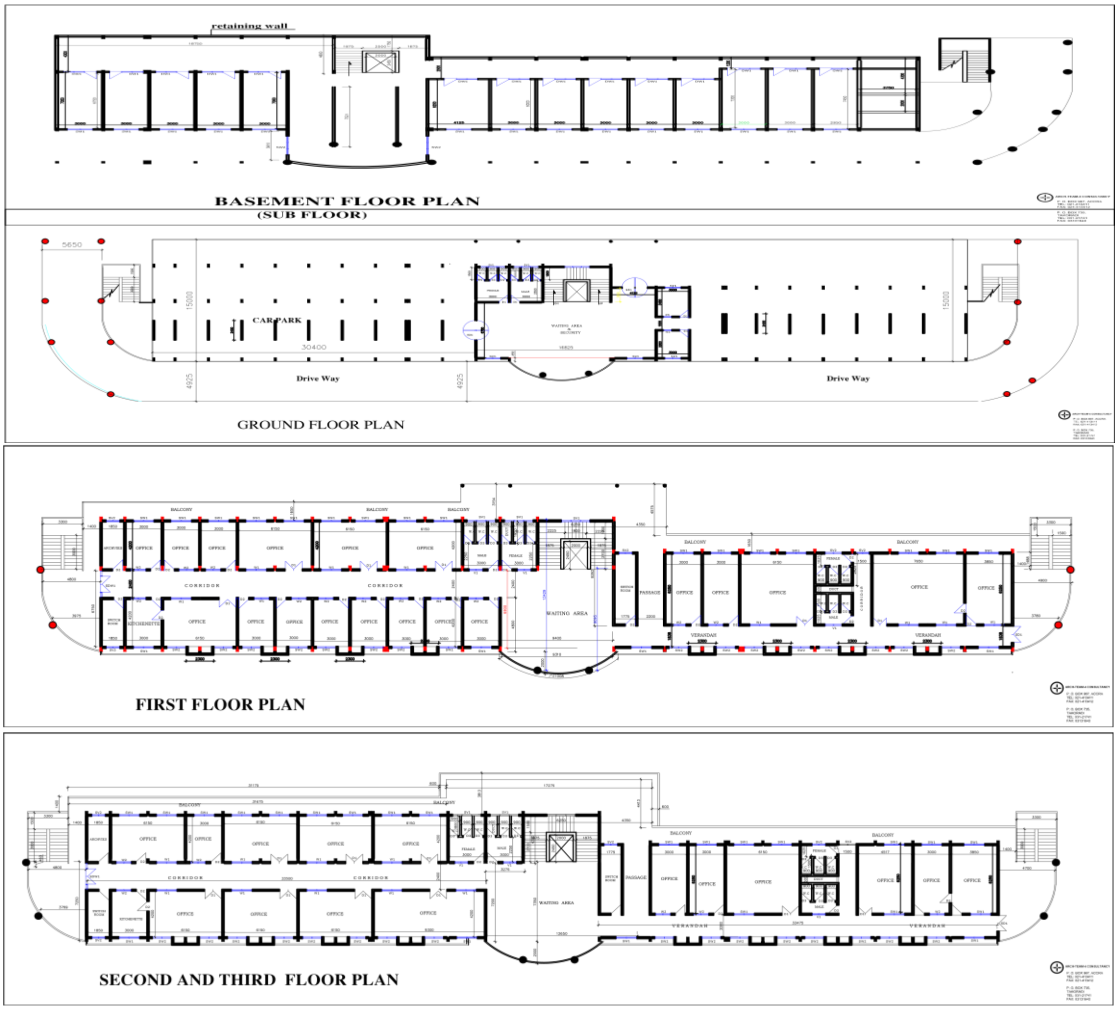

Fig. 1 Floor Plans for the Building

2.1.2 Electrical Characteristics of the Building

The electrical characteristics of the building are essential for our energy audit. We consider various electrical systems, including cooling systems, heating systems, electrical appliances, lighting systems, and miscellaneous electronic devices. These systems are assessed in terms of their quantity, daily operating hours, and power ratings.

The general formula to calculate the amount of energy consumed (E_C) by a building's electrical system is based on several key parameters, including quantity of appliances (Qty), power rating (P), and daily operating hours (T) of the i^{th} appliance, and is given as:

$$E_C = \sum_{i=1}^{n} P \times Qty \times T \qquad (1)$$

2.1.2.1 Assessment of Cooling System Load

Table 1 provides detailed information about the types of ventilation and equipment on each floor, including quantity, daily operating hours, and power rating.

Table 1 Floor-wise Ventilation and Equipment Details

Floor	Type of Ventilation	Quantity (Qty)	Operating Hours (T) (hr/day)	Power Rating (P) (W)
GROUND	LG 2hp AC	2	2.00	200
FIRST	Crompton Ceiling Fan	20	0.50	200
	LG 1.5hp AC	7	8.00	1000
	LG 2hp AC	6	7.00	2500
	LG 2.5hp AC	7	8.00	3000
SECOND	Crompton Ceiling Fan	19	0.50	200
	LG 1.5hp AC	7	8.00	1000
	LG 2hp AC	6	7.00	2500
	LG 2.5hp AC	6	8.00	3000
THIRD	Crompton Ceiling Fan	19	0.50	200
	LG 1.5hp AC	7	8.00	1000
	LG 2hp AC	6	7.00	2500
	LG 2.5hp AC	6	8.00	3000
FOURTH	Standing Fan	2	0.50	0.03
	LG 2.5hp AC	9	10.00	3000

2.1.2.2 Assessment of Lighting System Load

We conducted an evaluation of the energy consumption of the building's lighting system, taking into account specific parameters including the number of bulbs installed throughout the building, the power rating of these bulbs, and the daily operating hours of individual office spaces. Despite the presence of transparent windows designed to enhance ventilation and visibility, the building receives limited natural light, leading to reduced visibility. Table 2 presents a comprehensive overview of the load assessment for the lighting systems, including lamps and related components, on different floors of the building. This table provides detailed information about the types of bulbs used for lighting on each floor, including quantity, daily operating hours, and power rating.

Table 2 Floor-wise Lighting System Details

Floor	Type of Bulb	Quantity (Qty)	Operating Hours (T) (hr/day)	Power Rating (P) (W)
GROUND	Inside light (LED)	11	8.00	24
	Outside light (LED)	32	11.00	38
FIRST	Inside light (LED)	68	8.00	24
	Outside light (LED)	17	0.00	38
SECOND	Inside light (LED)	68	8.00	24
	Outside light (LED)	16	11.00	38
THIRD	Inside light (LED)	68	8.00	24
	Outside light (LED)	117	11.00	38
FOURTH	Inside light (LED)	32	8.50	24
	Outside light (Flood Light)	3	11.00	38

2.1.2.3 Assessment of Desktops and Associated Accessories Load

In consideration of the building's primary administrative functions, desktop computers and their associated accessories hold a significant role within the electrical systems.

To provide a detailed overview of their energy consumption, we have compiled a load assessment, as outlined in Table 3. This table provides detailed information about desktops and accessories on each floor, including quantity, daily operating hours, and power rating.

Table 3 Floor-wise Desktops and Accessories Details

Floor	Desktops and Accessories	Quantity (Qty)	Operating Hours (T) (hr/day)	Power Rating (P) (W)
FIRST	Desktop	6	8.00	280
	Laptop	4	6.00	65
	Printer	5	17.00	40
	Scanner	1	0.02	15
	Server Room	1	24.00	400
	Photocopier	3	0.083	183
SECOND	Desktop	10	8.00	280
	Laptop	3	5.00	65
	Printer	11	0.17	40
	Scanner	1	0.02	15
	Shredder	2	0.02	200
	UPS	3	0.50	300
	Photocopier	3	0.083	183
THIRD	Desktop	12	8.00	280
	Laptop	2	6.00	65
	Printer	3	0.17	40
	Scanner	5	0.02	15
	UPS	7	0.50	300
	Photocopier	4	0.083	183
FOURTH	Desktop	4	8.00	280
	Laptop	3	2.00	65
	Printer	3	0.17	40
	Scanner	1	0.02	15
	Shredder	2	0.02	200
	UPS	4	0.50	300
	Photocopier	1	0.083	183

2.1.2.4 Assessment of Other Electrical Loads

A comprehensive evaluation of additional electrical loads within the building, including items such as refrigerators, kettles, microwaves, coffee machines, and sound systems, has been conducted. The energy consumption of these various building loads is outlined in Table 4.

Table 4 Load Assessment of Other Electrical Loads in The Building

Floor	Type of Load	Quantity (Qty)	Operating Hours (T) (hr/day)	Power Rating (P) (W)
FIRST	Double door fridge	1	6.00	450
	Kettle	2	0.05	1400
SECOND	Double door Fridge	4	6.00	450
	Kettle	1	0.05	1400
THIRD	Double door fridge	1	6.00	450
	Table Top Fridge	3	2.00	350
FOURTH	Double door fridge	2	6.00	450
	Table Top Fridge	1	2.00	350
	Kettle	1	0.05	1400
	Coffee machine	1	1.50	1.35
	Microwave	1	0.33	1500
	Sound system	1	0.50	120

2.1.3 Determination of Thermal Characteristics

The thermal characteristics of the building, crucial for energy conservation analysis, were assessed without the use of thermal sensors due to resource constraints. Herein, we selected thermal insulation materials based on factors like compressive strength and thermal conductivity. These materials affect heat transfer within and outside the building. We considered insulation thickness, accounting for climate, energy costs, material properties, and wall characteristics. While no specific tools were used, our approach relied on industry standards and material specifications to enhance thermal characteristics.

While a detailed thermal sensor-based assessment would have been ideal, this approach provided valuable insights given the limitations. As shown in Fig. 2, the arrangement of insulating material, brick, and other types of concrete are the primary building materials for outside walls.

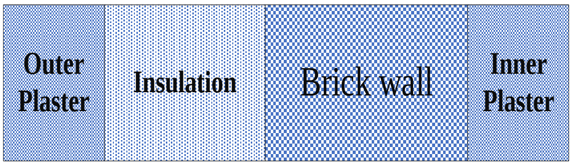

Fig. 2 Configuration of Insulating Material

2.2 Energy Performance Assessment of the Building

The assessment of the building's energy efficiency is conducted following guidelines and standards for building energy efficiency, including measures proposed by the European Union Council. The assessment primarily relies on design data, measurement of actual performance, and extrapolations from short-term, in-situ measurements (Economidou *et al*., 2020).

2.3 Energy Audit Using RETScreen

An energy audit was performed using RETScreen software to summarize the building's load profile, simulate energy consumption, and design energy-saving strategies. While this audit was not detailed, it leveraged RETScreen's capabilities for energy modeling in various building types. Due to the lack of specialized tools and detailed measurements, certain parameters, such as heat gain, were estimated based on assumed values for the duty cycles of electrical components.

2.3.1 Assumptions and Parameters for RETScreen Simulations:

To ensure transparency and provide readers with a comprehensive understanding of our methodology, we present the following assumptions and parameters considered in the RETScreen simulations:

i. Weather Data: We utilized local weather data specific to the Tarkwa, Ghana region to accurately model external environmental conditions, including temperature, humidity, and solar radiation.

ii. Building Envelope: The building envelope characteristics, such as insulation materials, wall construction, roof construction, and window properties, were based on the actual specifications of the UMaT New Administration building.

iii. Lighting Systems: The lighting systems within the building were characterized by the type of bulbs used, their wattage, and the number of hours they were operated daily.

iv. Cooling Systems: We considered the type and capacity of air conditioning units, fans, and ventilation systems installed in the building.

v. Internal Heat Gain: Internal heat gain factors, including occupancy levels, equipment usage, and lighting intensity, were integrated into the simulations. These factors were derived from occupancy schedules, appliance specifications, and typical office activities.

vi. Energy Tariffs: We incorporated local energy tariffs and utility rates to calculate the cost implications of energy consumption, particularly in relation to the proposed strategies.

2.4 Boundaries and Assumptions

In this section, we outline the boundaries and assumptions considered during the energy audit of the UMaT New Administration building. These aspects provide essential context for the interpretation of our findings.

2.4.1 Boundaries

Our study is bounded by specific criteria to maintain a focused and accurate assessment of the building's energy characteristics. These boundaries include the following:

i. We primarily focused on the energy consumption of electrical systems within the UMaT Administration Building, including lighting, cooling, heating, and electronic devices. Other energy sources, such as renewable energy generation, were not included in this audit.

ii. The audit is confined to the UMaT New Administration building located in Tarkwa, Ghana, and does not extend beyond its geographical boundaries.

2.3.2 Assumptions

Several assumptions were made to facilitate the audit process and calculations:

i. We assumed that building conditions, occupancy patterns, and equipment usage remained relatively constant throughout the assessment period.

ii. Power ratings, operating hours, and other technical details of electrical equipment were assumed to align with manufacturer-provided specifications; unless observed data suggested otherwise.

iii. We assumed uniform thermal performance and energy efficiency characteristics across different areas of the building.

3 Results and Discussion

3.1 Assessment of Baseline Energy Performance

The preliminary energy audit's base case energy consumption was determined using RETScreen by taking into account the quantity of equipment, operating hours, electrical load, and duty cycle. Fig. 3 depicts the building's base case energy profile.

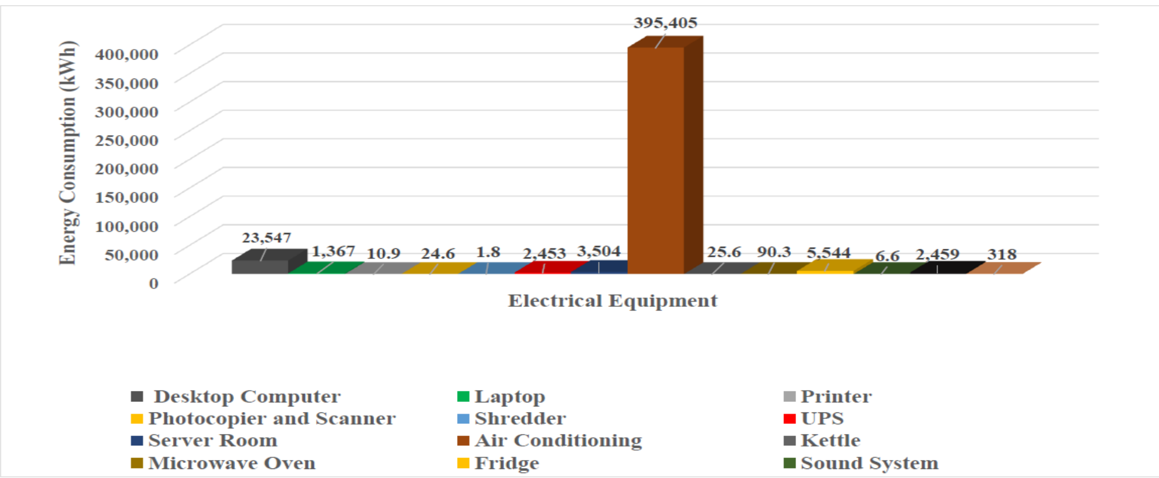

Fig. 3 Base Case Energy Profile in the Building

According to Fig. 3, air conditioning consumed the most energy (395, 405 kWh), followed by desktop computers (23, 547 kWh), with the least being shredders (1.8 kWh), resulting in a very high total energy consumption (434, 756 kWh). Other loads, such as refrigerators, lighting systems, refrigerators, server rooms, UPS, and laptops, consumed a significant amount of energy, ranging from 1,367 to 5,544 kWh. In recent literature, Mohamed *et al*. (2022) have presented an energy audit and conservation for educational buildings, using Princess Sumaya University for Technology as a case study, and they reported that air conditioners are the building's highest electricity-consuming devices.

Based on the building's base case energy performance, it is clear that energy-saving solutions are required to improve the building's overall energy efficiency. Implementing energy-saving solutions serves multiple crucial purposes. Firstly, it promotes energy conservation, preserving valuable resources and reducing reliance on fossil fuels. Second, it ensures compliance with energy efficiency regulations and standards, avoiding penalties and legal complications. Additionally, these solutions lead to substantial long-term savings, enhance climate change mitigation efforts by reducing emissions, bolster building resilience, and improve indoor comfort for occupants.

Despite the fact that the majority of energy-saving measures will increase the building's energy efficiency, their viability must be considered in order to select the best options. Various energy-saving strategies are proposed and researched, and their financial savings in terms of energy use, fuel use, and CO_2 emissions are calculated in this regard. According to Dong *et al*. (2023), in order to determine the effectiveness of each plan, a feasibility analysis for all proposed energy-saving methods must be performed.

3.2 Energy Saving Strategies

To avoid any potential ambiguity in the picture of building efficiency, this study proposes two energy-saving strategies: strategy one (1) includes reducing consumption associated with cooling systems (air conditioners) and lighting systems. As previously stated, air conditioners are the most energy-consuming devices in the building, hence they are selected. Lighting systems are also included because they are one of the most important electrical systems in buildings for improving security at night. The second proposed strategy (2) is based on incorporating a solar car park into the building's supply.

3.2.1 Proposed Strategy 1: Optimized Cooling and Lighting Systems

In the pursuit of energy-saving solutions, this study focused on optimizing both the cooling and lighting systems of the building.

3.2.1.1 Optimized Cooling System

The cooling system was simulated with specific duty cycles to accurately represent real-world conditions and energy consumption patterns. For the proposed strategy, the following duty cycles were applied: 70% for 1.5 HP A/Cs; 65% for 2.0 HP Acs; 70% for 2.5 HP ACs; and 100% for 2.5 HP Ceiling Fan. Because servers require constant cooling, the server room's duty cycle was set to 100%. The last floor, the Vice Chancellor's zone, was also left at 100%. In contrast, the base case scenario featured different duty cycles, reflecting the initial conditions of the building's cooling system: 90% for 1.5 HP A/Cs; 80% for 2.0 HP A/Cs; 85% for 2.5 HP A/Cs; 95% for 2.5 HP Ceiling Fan; and 100 % for Server Room A/Cs.

Fig. 4 depicts the cooling system simulation for the proposed strategy (the optimized cooling systems).

According to Fig. 4, the energy consumed after implementing the proposed cooling system strategy was 292,146 kWh, which is 103,259 kWh less than the energy consumed by base case cooling systems, which was 395,405 kWh in Fig. 3. This equates to 26.1 % energy savings. This demonstrates that implementing an optimized cooling system strategy can help improve building efficiency.

3.2.1.2 Optimized Lighting System

The energy saved, emissions, and cost savings on energy were simulated based on the lighting system measures proposed. Fig. 5 depicts the lighting system simulation for the proposed strategy.

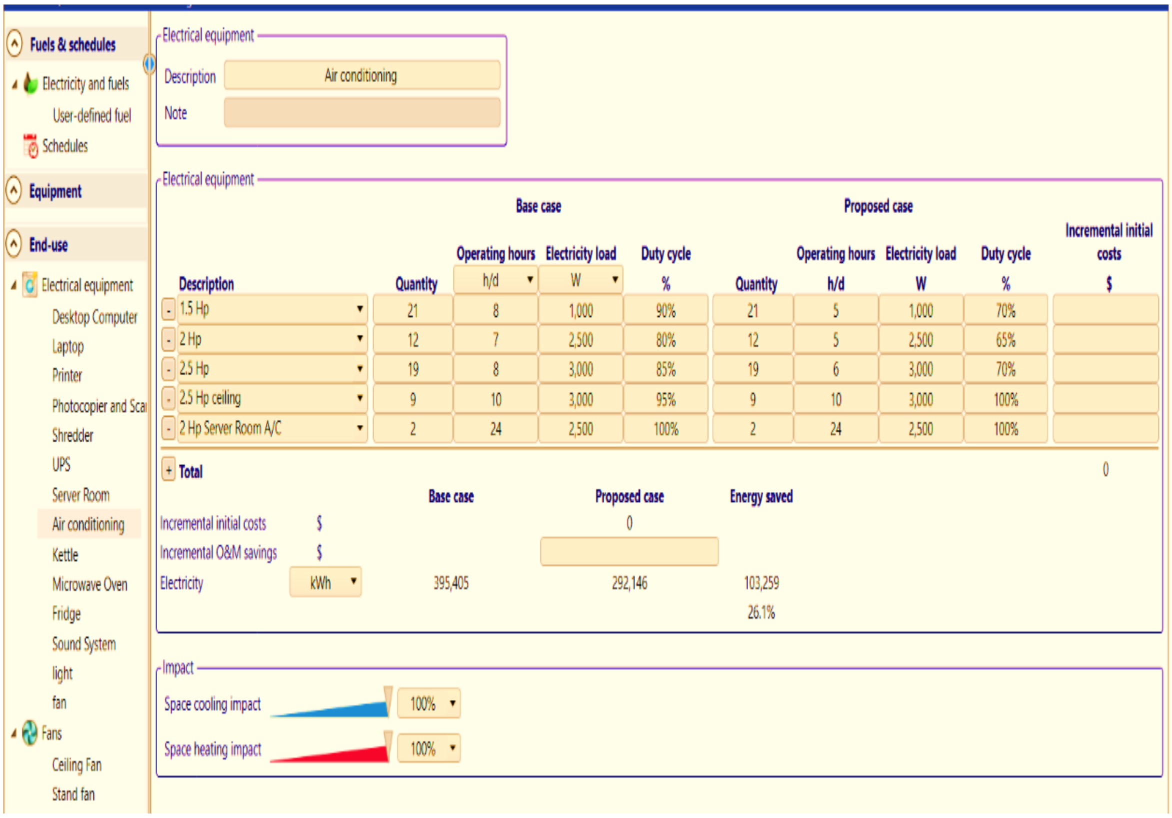

Fig. 4 Proposed Cooling System Strategy Simulation

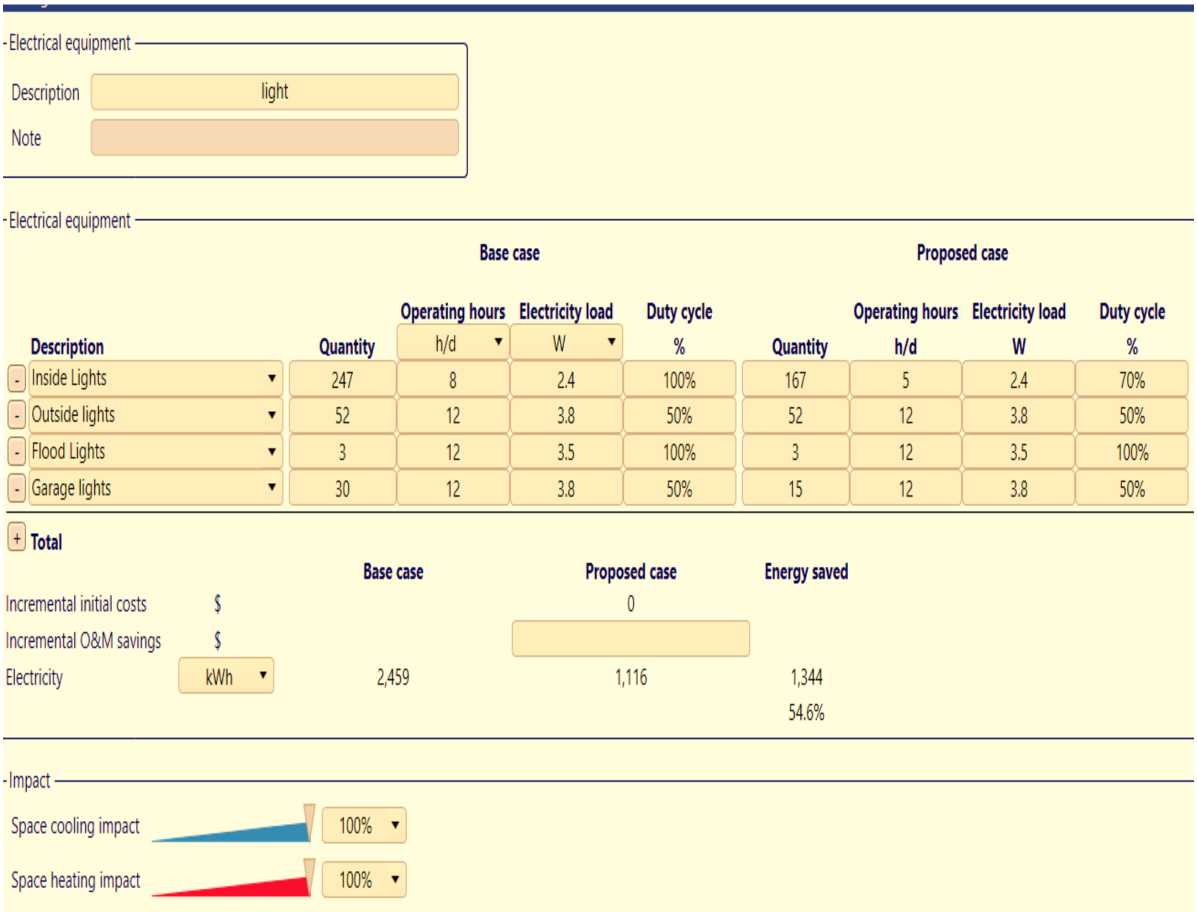

Fig. 5 Proposed Lighting System Consumption

According to Fig. 5, the energy consumed after implementing the proposed strategy (optimized lighting system) was 1,116 kWh, which was 1,344 kWh less than the 2,459-kWh energy consumed by the base case lighting system in Figure 3, implying a 54.6% energy savings in terms of lighting systems. This demonstrates that implementing an optimized lighting system strategy can improve building efficiency, as shown in Fig. 6.

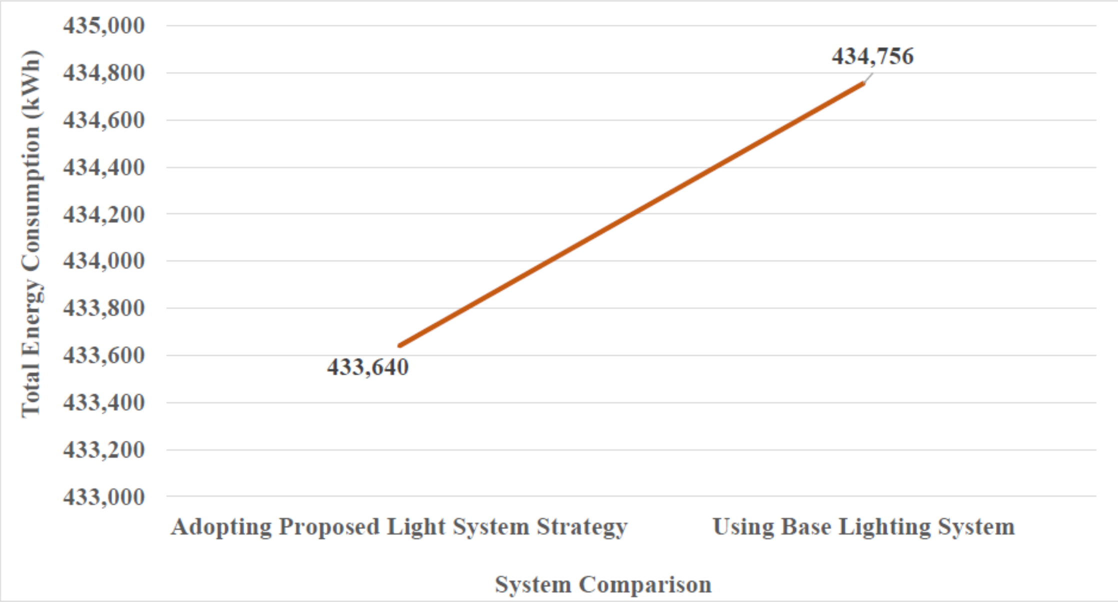

Fig. 6 Comparison of Energy Consumption Between Base Case and Optimized Lighting System Scenarios

Fig. 6 implies that the energy consumption after implementing the optimized lighting system strategy was 433,640 kWh, which is 3% less than the base case energy consumption of 433,756 in Fig. 4. Moreover, according to Fig. 7, replacing only light loads results in a negligible change in the consumption trend. Furthermore, a comparison with the total base case energy consumption can be made by combining the energy consumption from both simulations (the optimized cooling system and the optimized lighting system) in Figs. 6 and 7.

While we have elaborated on the energy savings achieved, it is pertinent to delve into the components and strategies that constituted the optimized lighting system and how it compares with the base case scenarios. The key component of the optimized lighting system was the transition from traditional lighting to energy-efficient LED lighting fixtures. This transition is a well-established method for reducing energy consumption in lighting systems and played a pivotal role in achieving significant energy savings (Mariano-Hernández *et al*., 2020).

Additionally, the optimization process involved the implementation of advanced lighting control strategies (Füchtenhans *et al*., 2021; Wagiman *et al*., 2020). These strategies included the use of occupancy sensors that automatically turn off lights in unoccupied areas and daylight harvesting systems, which adjust lighting levels based on available natural light. These measures not only conserved energy but also improved lighting efficiency.

While specific details about energy management systems were not provided, it is plausible that such systems were utilized to optimize lighting energy consumption. These systems may have included central control systems for real-time monitoring and adjustments of lighting levels.

Energy-efficient lighting technologies, such as dimmable lighting controls and efficient ballasts, might have been incorporated into the optimized lighting system to further enhance energy efficiency. This holistic approach to lighting optimization significantly contributed to the overall energy-saving efforts.

Fig. 7 shows visual representation of the results obtained when both optimized systems, namely the optimized cooling system and the optimized lighting system. It illustrates the combined effect of implementing these two energy-saving strategies on the building's energy consumption.

Proposed Strategy 1 (Fig. 7) achieved a significant reduction in total energy consumption, lowering it from 432,184 kWh in the Base Case Scenario (Fig. 1) to 330,153 kWh, representing a reduction of approximately 24.07%. This reduction demonstrates the effectiveness of optimizing cooling and lighting systems in Proposed Strategy 1. This outcome aligns with Gomes, Coelho, and Valdez's (2011) study, which reported a 28% reduction in annual electricity bills, closely mirroring the results of this investigation. Similarly, El-Darwish and Gomaa (2017) realized an average energy consumption reduction of 33% through retrofit strategies in educational buildings in Egypt, focusing on enhancing thermal comfort. Conversely, Taleb's 2014 study achieved a noteworthy total annual energy consumption reduction of up to 23.6% in a residential building in Dubai by employing passive cooling strategies.

The primary reason behind this substantial energy reduction is the effective optimization of cooling and lighting systems in Proposed Strategy 1. By enhancing the efficiency and performance of these critical building systems, energy wastage was minimized, leading to significant savings. Specific measures taken to optimize these systems, such as the implementation of more energy-efficient technologies, better control systems, or improved insulation, played a pivotal role.
Lowering energy consumption not only contributes to sustainability but also translates into tangible financial savings for the building's owner or operator. These savings can be substantial over time and may offset any initial investment in energy-efficient upgrades.

Additionally, the agreement between the 28% reduction reported by Gomes, Coelho, and Valdez (2011), the 24.07% reduction in this study, the 33% reduction achieved by El-Darwish and Gomaa (2017), and the 23.6% reduction in Taleb's (2014) research implies a degree of consistency in the impact of energy-saving measures across different contexts. This consistency enhances the validity and reliability of the findings and implies that similar strategies can be applied to other buildings to achieve similar results.Beyond cost savings, it is crucial to emphasize the environmental and sustainability implications of reduced energy consumption. Furthermore, in terms of CO_2 emissions, Fig. 8 depicts a carbon emission for the base case scenario, as well as the adopted proposed strategies used.

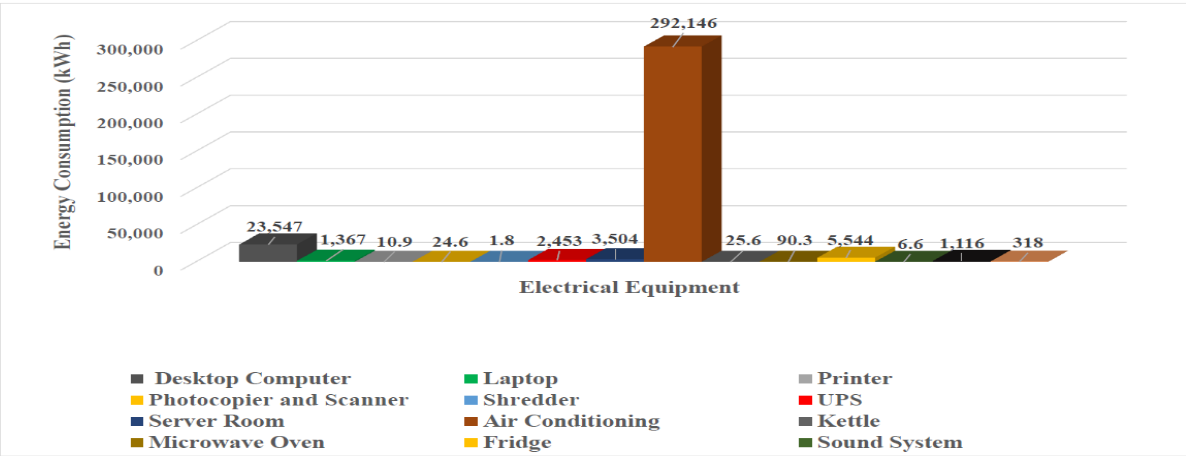

Fig. 7 Combined Impact of Optimized Cooling and Lighting Systems on Building Energy Consumption

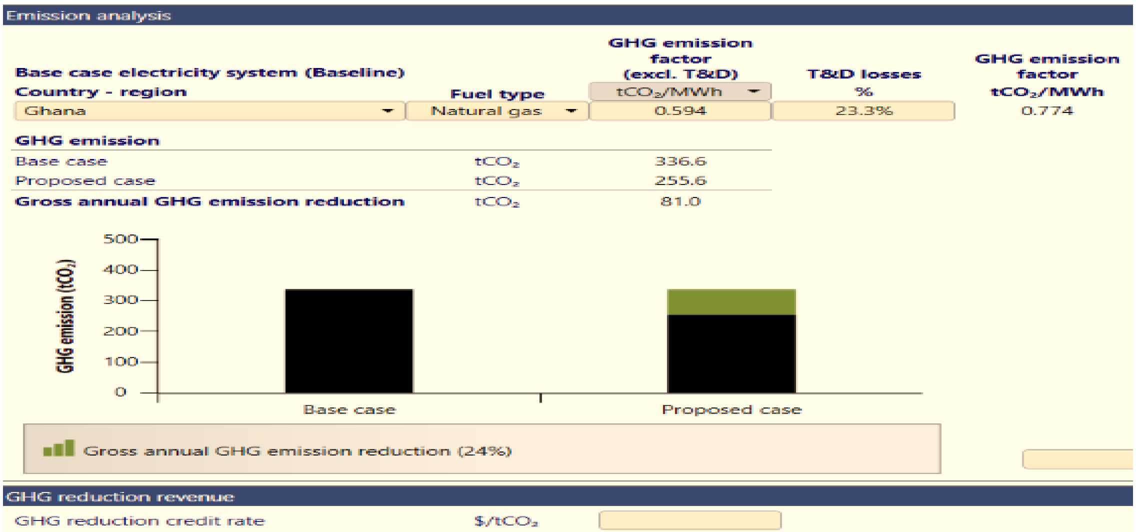

Fig. 8 Carbon Emissions of Base and Combined Proposed Strategies (Optimized Cooling and Lighting System

According to Fig. 8, the base case generated approximately 336.6 tCO_2, whereas implementing the combined proposed strategy generated approximately 255.6 tCO_2, implying that implementing the two proposed strategies (optimized cooling and lighting systems) will help reduce carbon dioxide emissions by 24%. This result is consistent with a previous study by Owolabi *et al*. (2020), which reported a 2.71 tCO_2 reduction. It also agrees with the findings of Salih, Ledesma, and Saeed (2020), who found that passive energy-saving measures saved 49% more energy than active energy-saving measures. Gomes, Coelho, and Valdez (2011) have also reported a similar reduction in carbon emission of 16.12 tCO_2. Similarly, El-Darwish and Gomaa (2017) achieved a significant reduction in CO_2 emissions through retrofit strategies in educational buildings in Egypt. Taleb (2014) reported a substantial reduction in CO2 emissions in a residential building in Dubai using passive cooling strategies. These findings underscore the consistent and substantial reduction in CO2 emissions achieved through energy-saving measures across various building types and climates, highlighting their crucial role in promoting environmental sustainability.

Lower energy use leads to a decrease in carbon dioxide emissions, aligning with global efforts to combat climate change. The reduction in greenhouse gas emissions is a positive contribution to environmental conservation and the mitigation of climate-related challenges. This clearly supports the claim that the proposed strategies are sustainable and environmentally friendly, and should thus be implemented.

3.2.2. Proposed Strategy 2: Integration of a Solar Car Park

This strategy involves the integration of a solar car park into the building's supply. The parameters considered are:

i. Area of the region designated for the installation is 30m x 15m;

ii. Sizing of grid-tied solar car pack to supply power for light loads (loads aside from AC) during the day.

An energy conservation opportunity in the form of an intervention is established under the proposed Strategy 2. The average daily electricity consumption was calculated using the base load established in Case 1 (see Fig. 3). The solar array sizing and the number of panels required for installation are calculated using the Omni solar panel Calculator. As shown in Fig. 9, a bill offset rate of 10% was established, which is the amount of money saved by using solar. Furthermore, the factors influencing solar panel performance were determined to be 85%, with all of these factors taking into account 5.5 hours of solar irradiance per day.

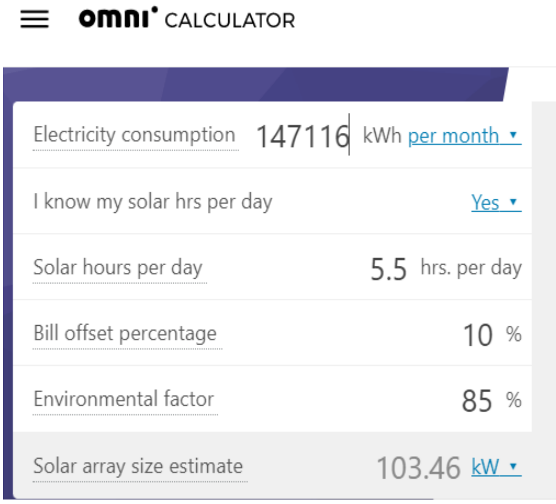

Fig. 9 Solar Array Size Estimation

Moreover, as shown in Figure 10, the area under consideration was determined to be 450 m2 using a standard 1.4 m^2 solar panel with a power output of 350 W. Also, 296 panels were determined, which will cover approximately 414.4 m^2 or approximately 92% of the considered area. Table 5 presents a summary of the market value of the solar system and its components.

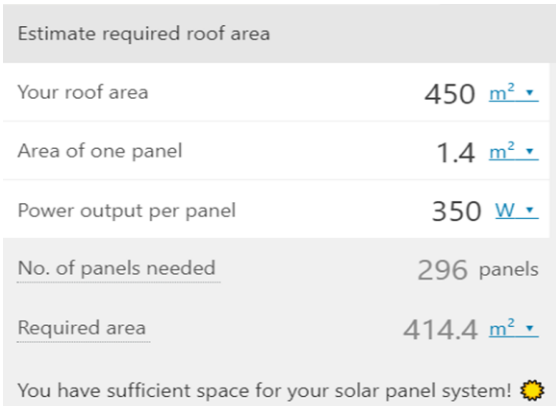

Fig. 10 Number of Solar Panels Required

Table 5 Total Number of the Solar System Components Required for the Design of the Solar Car Park

System Component	Total Number Required	Unit Price (US$)	Total Price (US$)	Manufacturer
Solar PV	296	65	18,944	Trinar solar
Inverter	1	550	550	NOCHESKI SOLAR
Cost of cable, design, labor, metering, installation, etc.			3, 547.975	NOCHESKI SOLAR
OVERALL SYSTEM COST			23,041.755	

3.2.2.1 Proposed Solar Car Park Design

Fig. 11 depicts the proposed solar car park design. The system will provide several advantages, including significant cost savings on electricity, increased reliability, and lower CO_2 emissions.

Fig. 11 Proposed Solar Car Park Design

Using the United States Environmental Protection Agency Greenhouse Gas Equivalencies Calculator, it was discovered that using the solar car park to produce the monthly required energy of 147,116 kWh will reduce CO_2 emissions from 336.6 tCO_2 to 273 tCO_2 (i.e., an 18% reduction), as shown in Fig. 12. This clearly supports the claim that the proposed strategy is environmentally friendly and should thus be implemented.

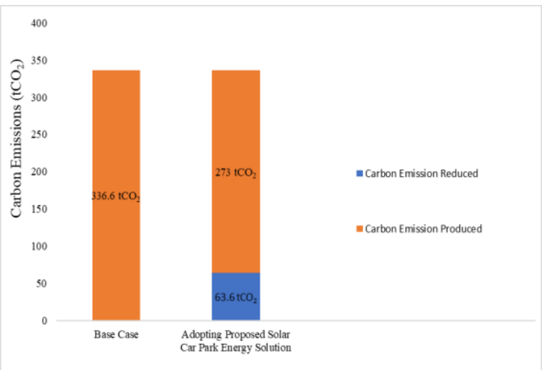

Fig. 12 Carbon Emission Comparison Between Base Case Scenario and Energy-Saving Solution Utilizing Solar Car Park Energy

Moreover, by applying a standard calculation (Anon., 2020), it was found that 1 kWh of solar PV electricity is equivalent to a reduction of approximately 0.846 lbs (0.383 kg) of CO_2 emissions. Consequently, the 147,116-kWh electricity generated by the proposed solar car park resulted in a reduction of approximately 56,364.578 kg (62.13 tCO_2) of CO_2 emissions, a value consistent with the simulation findings in this study.

3.3 Limitations of the Study

Despite our efforts to provide an accurate assessment, certain limitations are inherent in our study:

i. The accuracy of our findings depends on the quality and precision of the data collected, which may be subject to measurement errors.

ii. Dynamic factors, such as changing weather conditions and fluctuating occupancy, could influence energy consumption but were not extensively considered.

iii. Our audit does not account for external factors that may affect energy usage, such as utility rate changes, policy shifts, or unforeseen events.

iv. While our findings are specific to the UMaT New Administration building, they may not be directly transferable to other buildings or regions with different characteristics.

4 Conclusions

Based on the preliminary identification of energy-consuming systems used in the building, as well as prioritization and classification of consumption, a simplified energy audit of the UMaT New Administration Building was conducted. Following a detailed energy performance assessment, air conditioning was discovered to consume the most electrical energy (395, 405 kWh), followed by desktop computers (23, 547 kWh), and shredders (1.8 kWh), resulting in a very high overall energy consumption of 434, 756 kWh. Energy-saving solutions such as optimizing air conditioning and lighting usage, as well as installing a solar car, were suggested to reduce energy consumption. It was found that using a combination of the optimized lighting system and optimized cooling system resulted in a rapid reduction of overall energy consumption by nearly 24% and eventually reduced CO_2 emissions by 24%. Furthermore, by using the proposed solar car park as an alternative energy-saving solution, CO_2 emissions were reduced by 63.6 tCO_2 (18%), or from 336.6 tCO_2 to 273 tCO_2. As a result of the findings, proposed low-cost energy-saving methods may become strategic in the future. In particular, if the strategies are implemented, the efficacy increases; the same proposed strategy could represent an important solution in order to control and re-schedule the overall energy equipment of the buildings, as well as economic gains related to cost savings from reduced energy use.

4.1 Recommendations

Based on the findings of this study, several recommendations can be made to improve the energy efficiency of the UMaT New Administration Building and similar structures:

i. To enhance energy efficiency, consider upgrading cooling and lighting systems with energy-efficient technologies, better control systems, and improved insulation. LED lighting fixtures and advanced controls, like occupancy sensors and daylight harvesting, can reduce energy consumption.

ii. Before implementing energy-saving measures, assess their cost-effectiveness and practicality in your specific building context through a feasibility analysis.

iii. Leverage Solar Solutions: Explore solar solutions like solar car parks to offset electricity costs and reduce carbon emissions. Ensure proper planning and sizing of solar arrays to meet energy needs.

iv. Regularly maintain energy-consuming equipment to maximize efficiency and minimize energy wastage.

v. Consider using energy management systems for real-time monitoring and control of energy usage, enabling adjustments and optimizations as needed.

4.2 Future Research Direction

To enhance the comprehensiveness of this study, future research efforts may explore the financial aspects of the proposed solar car park integration. Specifically, the inclusion of financial metrics such as Net Present Value (NPV) and Internal Rate of Return (IRR) will be considered to evaluate the economic viability of the solar car park project. This financial analysis will provide valuable insights into the cost-effectiveness and long-term sustainability of the proposed energy-saving strategy.

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