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Solar Powered Lighting System for Educational Institutions: Assessing Efficiency and Sustainability

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Abstract

Electricity wastage from lighting systems in educational institutions is a prevalent issue, with classroom lights often left on unnecessarily when unoccupied. This project addresses this problem by developing an Automatic-Lighting-Control-System that aims to save electricity through efficient management of classroom lighting. The system utilizes an IR motion sensor to detect human presence and a relay control to switch lights on or off accordingly, illuminating only occupied areas of the classroom. A counter-bidirectional approach using two IR sensors at entry/exit points counts the number of occupants to control lighting levels based on the density of people present. The system is powered by a solar-photovoltaic unit, comprising solar panels, a charge controller, and batteries, making it an eco-friendly solution. Experiments were conducted to analyze the solar panel's performance under varying temperatures and weather conditions in the local climate. Findings revealed the solar panel's efficiency reached up to 80% during peak sunshine hours, with temperature inversely affecting voltage output. In classrooms with lower student counts, significant energy savings of up to 3.19W/h were achieved compared to conventional lighting systems. This system presents a sustainable solution for minimizing electricity wastage in classroom lighting by intelligently managing illumination levels through occupancy sensing and solar-powered operation.

Keywords: Automatic Lighting Control System, Electricity Wastage, Solar, Classroom Lighting

Introduction

Every year, the growth of energy consumption accelerated quickly. The dramatic growth in energy use necessitated government intervention in energy efficiency by guaranteeing minimal waste. The term energy refers to, specifically electricity. There is a lot of energy waste in educational sector. In term of the energy waste in lighting system, the scenario happens in the classroom where the class is be used from 8am to 5pm. If the student forgets to switch off the light of after class session, there will electricity waste happen. As energy conservation becomes a popular topic these days, one of the issues that is usually brought up is how to save energy through lighting system (Choubey et al., 2024; Yu et al., 2021).

The primary problem addressed in this study is the inefficient energy consumption in educational buildings, especially by outdated lighting systems that operate without regard to actual usage. This inefficiency not only increases energy costs but also leads to unnecessary environmental degradation. The introduction of smart lighting systems, which adjust based on real-time occupancy, coupled with the use of solar energy, can significantly reduce energy consumption. However, the efficiency of such systems, especially under varying weather conditions, requires detailed analysis to ensure reliability and sustainability.

The implementation of LED technology in educational institutions has been a focal point of several studies, with a consensus on its benefits for energy efficiency and sustainability. For instance, Seyitoglu et al. conducted a study at Hitit University that demonstrated a 68.2% reduction in electricity consumption after converting traditional lighting to LED systems (Seyıtoglu et al., 2023). This significant decrease in energy usage underscores the potential of LED lighting systems to enhance sustainability in educational buildings. Additionally, José Carlos Pereira de Morais et al. emphasized the economic advantages of LED technology, highlighting its role in institutional planning for sustainability in higher education (Pereira de Morais et al., 2024). These findings support the objective of designing a microcontroller-based counting system that optimizes LED usage, ensuring that lights operate only when classrooms are occupied, thereby maximizing energy savings.

Further supporting the benefits of LED systems, Nurindah Wiji Sejati and Ova Candra Dewi (Zublie et al., 2023)explored sustainable lighting design strategies in educational buildings, focusing on enhancing both lighting quality and energy efficiency (Sejati & Dewi, 2024). Their research demonstrated that the integration of LED technology with automation systems significantly reduces energy consumption. This aligns with the current research's goal of creating a smart lighting system that adapts to real-time occupancy, ensuring lights are used efficiently and only when necessary.

The increasing demand for sustainable energy solutions within educational institutions is driving significant interest in solar-powered lighting systems. Traditional lighting methods, primarily relying on grid electricity, not only contribute to higher operational costs but also pose environmental challenges due to carbon emissions. Solar-powered lighting systems, integrated with advanced technologies such as microcontrollers for usage-based control, present a viable alternative to address these issues.

Transitioning from LED systems to photovoltaic (PV) technology, several studies have explored the feasibility and efficiency of solar-powered systems in educational institutions.

Zublie et al. conducted a feasibility analysis of a hybrid solar power generation system in a Malaysian educational institution, focusing on lighting, air conditioning, and laboratory equipment (Zublie et al., 2023). Their findings revealed substantial energy savings and demonstrated the viability of rooftop solar installations for sustainable energy production. Similarly, Shklyar and Havrylenko's research on solar systems in educational institutions highlighted the effectiveness of these systems in reducing both electricity consumption and greenhouse gas emissions, with their analysis showing a payback period of 4.3 years for photovoltaic systems (Dubrovska & Havrylenko, 2023).

Furthermore, Ravindra Jatav et al. analyzed the energy and economic viability of a 1kW solar PV system for a heritage building, emphasizing the potential for self-sustainability through off-grid solar power (Jatav et al., 2023). This research complements the current study's objective of analyzing the impact of various weather conditions on solar energy production, as it underscores the importance of environmental factors in determining the efficiency of solar PV systems.

Another study by Nor Hazlina Md Khairi et al. assessed the suitability of rooftop solar PV systems in educational buildings in Malaysia, highlighting significant energy savings and emission reductions (Md Khairi et al., 2022). This study's results, which show a potential for high PV generation and energy savings, reinforce the importance of integrating solar PV systems in educational institutions as part of a comprehensive approach to sustainable energy management. Additionally, the design of solar cell-based street lighting by Azriyenni Azhari Zakri et al. demonstrates the practical application of PV technology in educational settings, meeting national standards and providing a reliable source of energy (Zakri et al., 2023).

In addition to lighting systems, solar system has been explored in various applications, demonstrating its versatility in powering small, remote devices (Md Yusop et al., 2022). Moreover, many researches highlight the extensive application of Arduino technology across various domains, particularly in smart automation and management systems. For instance, Bhagyasri developed a smart billing system utilizing RFID technology integrated with Arduino (Bhagyasri et al., 2023). This system not only accelerates the billing process but also enhances customer satisfaction by introducing a mobile application for bill payments. The study confirms that using RFID with Arduino can produce an efficient and user-friendly billing system, potentially reducing the time required for billing processes in the hospitality industry.

In addition to billing systems, Arduino technology has also been applied in home automation, as explored by (Kalpana et al., 2024). In their study, the integration of OpenCV with Arduino was used to create a home automation system capable of image processing for security and energy efficiency. The findings indicate that this system not only has the potential for future technology integration but also significantly enhances home security and energy efficiency. The modular approach used in this study allows for greater flexibility and scalability in the development of home automation systems.

Furthermore, Ajagbe et al. developed an Arduino-based home automation system that leverages IoT technology for remote device control (Ajagbe et al., 2024). This study introduced a low-cost and reliable smart home system, where devices such as lights and water pumps were successfully controlled through an Android application. The study also found that using

Arduino with Bluetooth IP connectivity enables reliable remote control of devices, thereby reinforcing the relevance of this technology in practical home automation applications.

Sharkawy et al. demonstrated how the Arduino and Android platforms can be integrated to develop efficient and cost-effective smart home applications (Sharkawy et al., 2022). The system developed in this study includes various smart home applications such as lighting control, temperature and humidity monitoring, and fire and toxic gas alarms. The study confirms that the system is both effective and fully functional, and findings emphasize the potential of Arduino technology in providing affordable and practical home automation solutions for the general public.

Overall, these studies underscore the effectiveness and versatility of Arduino technology in various automation applications, from smart billing systems to home automation, and highlight the significant potential of this technology to enhance efficiency, security, and convenience in everyday use.

In conclusion, the systematic review of existing research underscores the significant potential of both LED and PV technologies in enhancing energy efficiency and sustainability in educational institutions. By integrating smart control systems with solar power, educational buildings can achieve substantial energy savings, reduce their environmental footprint, and move towards a more sustainable future. This study aims to build on these findings, offering practical solutions tailored to the unique needs of educational environments.

This paper aims to design a system that controls LED lights using a microcontroller based on the number of users in a classroom. The effect of various weather conditions on energy production by solar panels are also analysed at the end of this paper. This study's significance lies in its potential to offer a blueprint for energy-efficient lighting in educational institutions, contributing to reduced operational costs and a lower environmental footprint. The findings will be particularly relevant for policymakers and administrators seeking sustainable energy solutions in the education sector. This research aims to assess the efficiency and sustainability of implementing solar-powered lighting systems in educational institutions, focusing on both design and environmental impact.

Methodology

Control strategy is given for the smart classroom light control project. According to the suggested arrangement in Figure 1, the counter system will turn on the light in the class based on the number of students. The system consists of two IR sensor that will be used as counter sensor. Each sensor is place at door A and door B. For this system block diagram consists of four main block diagram that is detection unit, light control unit, output unit and power storage. Each block diagram has its own function, and all these functions is listed in Table 1.

Table 1
Bock Diagram Function

Block Diagram	Function
Detection unit	Detect the person the entering to the class or exits the class
Light control unit	Control the supply to output unit, acts as the switch
Output unit	Three LED as lighting system
Power storage unit	Store energy from solar unit to battery.

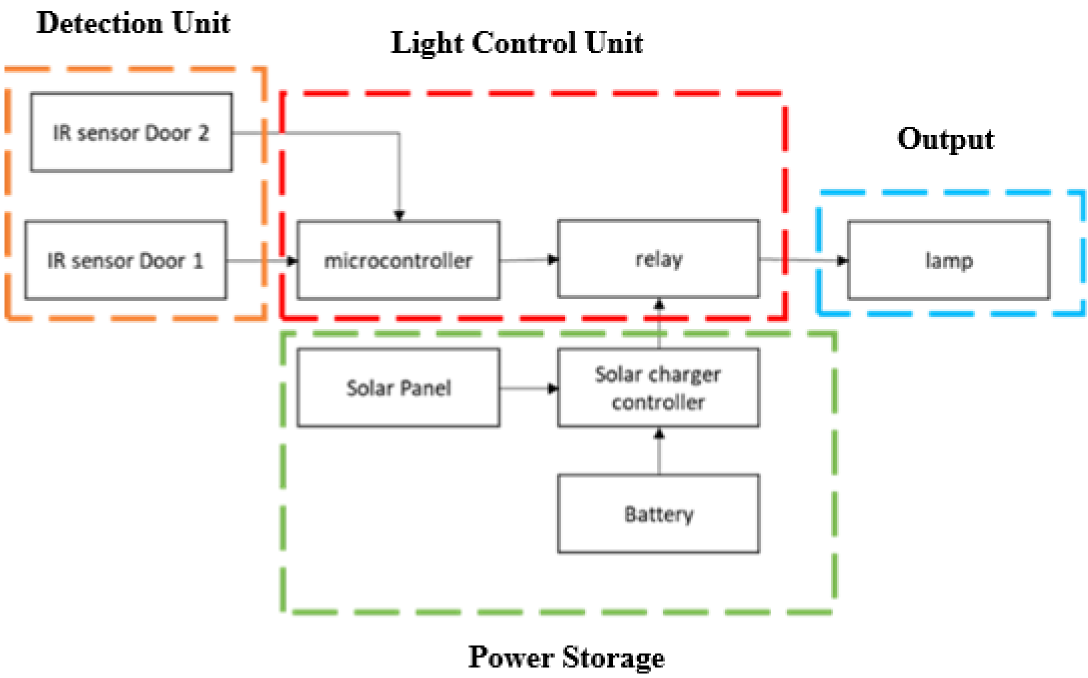

Figure 1 Block diagram of the system

The IR sensor is initialized by Arduino when the system program begins to run, according to the Figure 2 system flowchart. Upon detection of the infrared entrance, the counter will increase by one and be stored at the counter system. Based on the number of counting systems, the relay will act as the switch to control three lightning system. If the IR exit detect person at the exit, the counter will decrease by one and will switch off the lamp based on the number students that exist the classroom.

The hardware model system consists of three relays for turning on and off the lights and three output 5-Watt lamps for use as classroom lights. The IR sensor utilized as sensors to detect the number person entering and exiting classroom. Each IR sensor is installed on the A and B sides of the doors. The ESP32 and relay module are housed in a plastic box, with the solar charger and battery attached on the exterior. A PV module comprises many photovoltaic cells integrated into an installation system. Direct current (DC) electricity is generated by photo-voltaic cells using sunlight as a source of energy. An array is a system of panels, and a PV panel is a collection of PV modules that can be joined.

The solar array's power input to the battery bank is managed by a solar charge controller. As a result, the deep cycle batteries are not overloaded during the day and the electricity does not drain the batteries by flowing backwards to the solar panels at night. A battery is a gadget consisting of at least one electrochemical cell with external ESP 32 power-up connections and a water quality monitoring sensor. The cathode is the positive terminal at the point where a battery provides electrical force, and the anode is its negative terminal. The terminal stamped negative is the electron wellspring that will pass to the positive terminal via an outside electrical circuit.

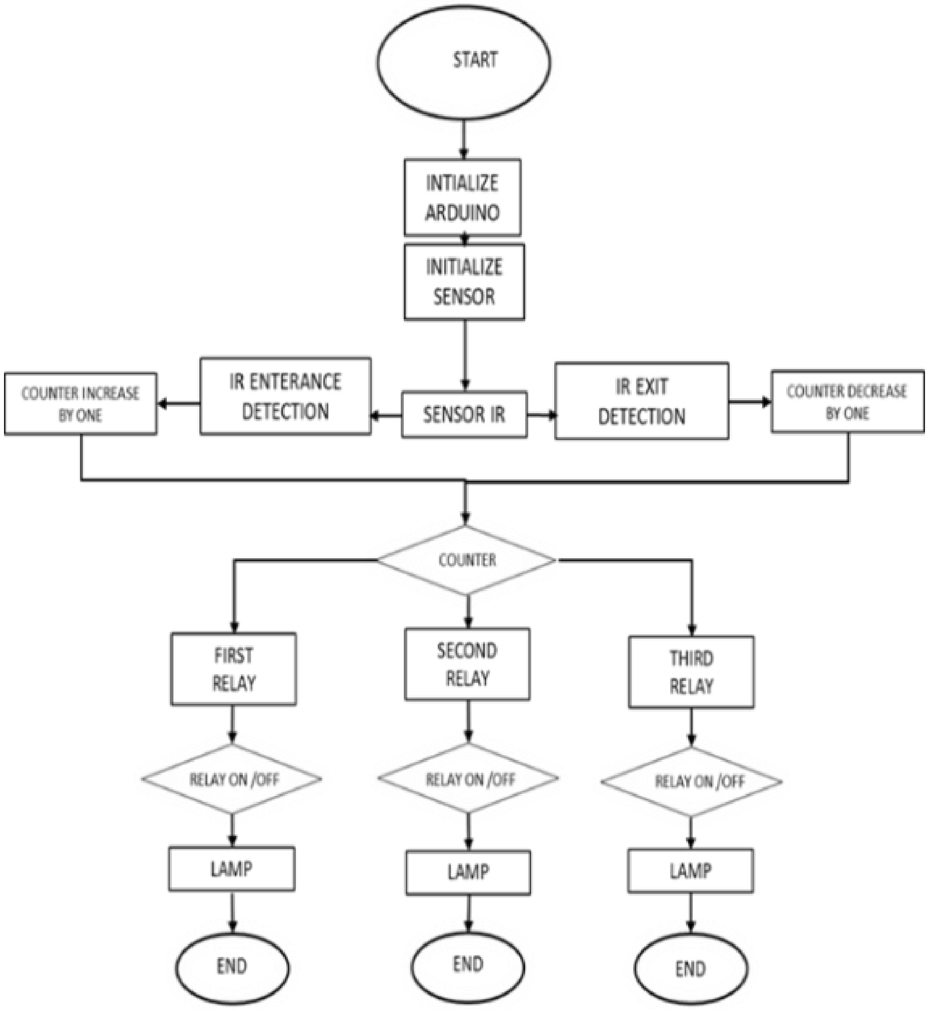

Figure 2 System flowchart

The hardware in Figure 3 illustrates how the system is set up in a model classroom and how the two IR sensors are arranged to evaluate the bidirectional counting system's performance.

Figure 3 Prototype system

Results and Discussion

This project aims to investigate the effectiveness of solar photovoltaic cell applications under different weather and temperature conditions. We also carried out experiments to determine the solar panel's characteristic curves between temperature and PV voltage in order to achieve this goal, similar to the typical switch-based lighting system utilized at Universiti Teknikal Malaysia Melaka. This system will use an automated light-switching mechanism to analyze energy savings. The primary functional domain of energy consumption and related statistics is showcased. We can observe the effectiveness and possible savings for the classroom lighting system from this point on. Three primary findings emerged from the investigation of the performance of the solar-powered classroom light: the impact of temperature on voltage, current, and solar cell efficiency under the meteorological conditions of Durian Tunggal.

Figure 4 illustrates how the temperature varies from 29°C to 46°C. The maximum temperature ever recorded was 46°C with an output voltage of 18.2 V at 14.00. Next, the solar panel's output voltage is measured in the range of 21.4 V to 18.2 V in sunny weather conditions. The output voltage ranges from 16.3 V to 15.3 V while it's raining. Over time, the voltage and power recorded by the solar panel diminish as its temperature rises. As the panel temperature rises, the output voltage decreases, indicating a link between the two variables. The band gap in the silicon layer of the solar module contracts, which is the origin of this phenomenon.

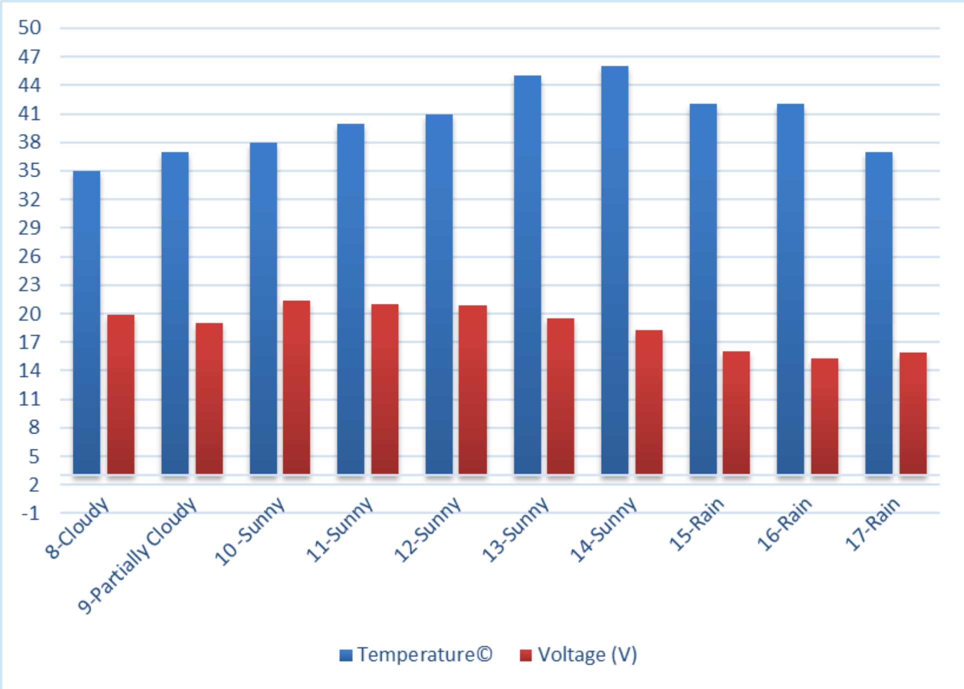

Figure 4 Temperature and voltage

The impact of temperature on current is displayed in Figure 5. At 46 °C, the maximum current ever recorded was 1.55 A. Due to the cloudy weather that prevented sunlight from reaching the ground, the current measured decreased steadily between the hours of 15.00 and 17.00. The output current that the solar panel generates at 29 °C is 0.56 A. The temperature has less of an impact on the solar panel's output current than its output voltage, according to the results. A significant effect of rising solar panel temperature was a linear decrease in open circuit voltage and a slight rise in current [7]. Elevated heat provides energy to the intrinsic carrier in the semiconductor, increasing the dark saturation current.

The effectiveness of solar cells is highest in bright weather and lowest in rainy weather, based on the data computation shown in Table 2. At 11:00, the efficiency level that was recorded was at its maximum, 80%. The efficiency rises steadily between 8:00 and 11:00. The efficiency starts to fall around 11:00 and continues to do so until 17:00.

Table 2
Solar Cell Efficiency and Time to Full Charge

Current (A)	**Voltage (V)**	**Solar Cell Efficiency** $\eta = \frac{FF(V)(I)}{30}$	**Maximum Time to Full Charge** $h = \frac{7100}{I}$
0.56	19.9	26.74	17.75
1.02	19.05	46.63	9.74
1.47	21.4	75.5	6.27
1.6	21	80.64	5.32
1.55	20.9	77.75	5.95
1.49	19.5	69.73	6.19
1.43	18.2	62.46	6.95
0.25	16	9.6	39.76
0.15	15.3	5.50	66.26
0.03	15.9	1.14	331.33

The amount of time it takes to charge a battery is determined by the weather condition where is rainy, sunny, or cloudy, as well as the state and type of battery. When a battery is entirely depleted, a solar panel can usually charge it in four to 5 hours based on calculation of the 40 % depletion rate. Depending on the state of a battery, the overall charging time will vary. By referring to the Table 3, the time for full charge battery is dependent on the charging current rate. The amount of time it takes to charge a battery is determined by the weather condition where is rainy, sunny, or cloudy, as well as the state and type of battery.

When a battery is entirely depleted, a solar panel can usually charge it in 4 to 5 hours based on calculation of the 40 % depletion rate. Depending on the state of a battery, the overall charging time will vary. The speed at which a solar panel charges is influenced by the position of the sun in the sky. In the middle of day, PV panel produced energy around 21 Watt when sunshine shines directly on a panel where the battery level is increase around 2.1 volt. Because of that, the charging pace will be faster. On cloudy day and rainy-day PV panel produces energy around 0.5 Watt and 3.4 Watt.

Table 4 displays the output power produced by a solar panel under various weather conditions, including clear, overcast, and rainy days. When the battery is fully charged, the counter system can run for 9 hours without requiring a charge. The battery charging time without the counter system turned on is displayed in Table 3. While the system is operating, the counter system can be charged. The battery recharge times for 7.6 Ah and 12 V batteries are also displayed in this table. It demonstrates that the system requires a 6-hour battery change every time the battery needs to be recharged, and that a full 14-hour charge takes place in inclement weather.

Table 3
Time to Full Charge Battery

Weather condition	Time to recharge full charge battery (hour)
Sunny	6
Cloudy/rain	14

The lighting system's on-time is determined by how many hours it runs without requiring a solar charge. Prior to the study of the operation in real time, the battery has been fully charged. Table 4 shows that the three LED lighting system ran for about 9 hours, with a twenty percent battery depletion rate. One LED lasts 13 hours, compared to 11 hours for the two light LEDs. The output of the lamp determines how much power it uses.

Table 4
The Time Operation

Counter Number	Lamp ON	Time Operation (Hour)	Power Consumption (Watt)
0 – 20	Lamp A	13	2.41
21 - 40	Lamp A and B	11	4.28
41 - 60	Lamp A, B and C	9	5.60

Table 5 displays counter systems with energy saving features and counter systems without them, categorized by the number of students in classes A, B, and C. There is a total energy savings of around 3,19 W/h for the 17-student class, compared to 1.32 W/h for class B. When the counter system is not used, all of the lights in the class which has between 40 and 20 students are on, wasting a lot of energy.

Table 5
Energy Saving

Class	Number of students	Energy saving counter system	Energy saving without counter system
A	17	3.19	0
B	32	1.32	0
C	48	0	0

The counter system is intended to be an independent system that uses solar panels to supply the energy it needs, as per the results of the study that was conducted. One of this system's benefits is that it can do without the costly wiring to the main DB board. The LED bulb reduces battery depletion and solar panel energy, allowing the system to operate with the least amount of energy feasible. The main goal of the system's control programming is to avoid wasting energy. The number of students can be counted at a speed of one second interval using both the enter and exit door IR sensors. The inability of the IR sensor to count accurately in outdoor environments with high levels of brightness is a drawback.

Subsequently, the study's findings indicate that significant parameters like current and voltage are influenced by high temperatures and affect the output's efficiency. Every day from 8 a.m. to 5 p.m., the system is analysed. The findings indicate that temperature affects output voltage and current. When considering the current generated by the solar panel, temperature has less of an effect on the output voltage. At 40°C, the output voltage recorded is approximately 21.5 V, the output current is 1.43 A, and the output voltage is approximately 14.63 V. At 46 °C, the output voltage recorded is approximately 14.63 V.

Additionally, the solar panel's analytical efficiency is dependent on its output current. There is a direct proportionality between the energy that a solar panel captures and the efficiency of its solar cells. When the solar panel has the highest solar cell efficiency, the maximum time for charging the battery is shortened.

Conclusion

The aim of this project was to develop the solar LED for classroom-based number of students to switch on and off lamp. The system is consisted of the IR block, activation relay block and microcontroller block. The IR sensor will counter the number of student and turn on the light based of the number of students in classroom. The lighting system is powered up by the solar panel that integrates new technologies and offers ease of maintenance and energy savings. The energy consumption of three LED lights and the energy savings achieved by employing a counter system are the basis of this project's analysis. The temperature and total solar radiation both affect how efficiently solar panels produce energy. It is advised to install the solar panel in an area with plenty of solar radiation and a comfortable, cool temperature.

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