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Smart energy conservation system for study rooms

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ABSTRACT

Most individuals in public and private sector offices are uninterested in turning off electronic equipment like fans and lamps while they are not present. For example, most students fail to turn off the fans and lighting in their classrooms, study rooms, residence halls, and so forth. As a result of this attitude, power usage in these places tends to rise. Several automation systems have been designed and implemented to decrease power waste in these locations, but the majority of these systems are either inefficient or inappropriate for their intended use. This study presents a proposed smart energy conservation system in a study room that employs an infrared remote-control mechanism to turn on or off an energy system in the absence of humans. Embedded technology was used to create an energy-saving solution. The testing was done with a range of scenarios and key performance indicators. The test results showed that the proposed system was effectively implemented, and a comparison of the system to a case study system demonstrated that it had a better design, lower cost, and higher operational efficiency. The findings of this study will be essential to a wide variety of stakeholders.

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1. INTRODUCTION

The demand for efficient electrical energy consumption in Ghana is growing as the country’s population grows and the government’s ambition to build more businesses grows. Demand growth is more than twice as fast as economic growth [1]. Ghana’s use of electrical energy is still poorly managed, and as a result, Ghana is one of Africa’s most wasteful countries in terms of power use. Electricity waste is more common in offices or public buildings. Most of these buildings lack sufficient windows in the skylights to avoid using lights during the day, as well as adequate ventilation to prevent using fans and air conditioners in cold weather [2]. Furthermore, the successful use of energy efficiently is significantly impacted by behavior, habits, and energy-saving knowledge. Examples of energy-efficient habits or behaviors include adopting light-emitting diode (LED) bulbs instead of incandescent lamps, which may reduce energy use by up to 40% while producing the same light intensity, turning off lights, fans, and other appliances when leaving a room [3], adopting the generation and use of renewable energy [4], [5]. Unfortunately, humans have a propensity of forgetting, ignoring, or failing to turn off lights and fans while leaving a room. As a result, a significant amount of energy is wasted if lights and fans are kept on in the absence of humans, resulting in power over-utilization [6].

The automated system is rapidly evolving due to the rapid advancement of technology [7]. It ensures the comfort, convenience, and security of its residents at all times [8]. Using an automation system to switch the home or office lighting system saves a significant amount of energy, which saves money on power bills. Furthermore, by using automatic switching, people will not pay attention to turning off the lights while leaving the room, therefore reducing power waste when lights, fans, and other electric appliances are left on in the absence of a person.

With Ghana's fast population expansion, economic growth, and increased building, the use of technology to ensure energy efficiency in buildings has become critical. According to Opoku *et al.* [9], buildings in Ghana consume the most energy for the air system (60-80%), lighting systems (45-70%), elevators and escalators (2-7%), office equipment and electronics (2-7%), and other purposes (2-10%). Energy-intensive buildings and residences are not only expensive, but they also emit greenhouse gases that harm the environment. As a result, it is imperative to include technology to assist minimize electrical energy usage, particularly in lighting and air conditioning in Ghanaian buildings. Several automation systems have recently been designed and installed [10]–[12] to reduce the amount of power waste in places where electrical appliances such as lights, fans, and air conditioners are always on regardless of need. Parking lots, libraries, garages, schools, stairwells, restrooms, lawns, public toilets, and labs are examples of such locations. Some of these systems employ the use of a passive infra-red (PIR) detector module to detect the presence or absence of a person in the room, Arduino microcontroller, and relay switches to process the signals and control the appliances, respectively.

For example, Caldo *et al.* [13] suggested an automated lighting system capable of dimming and switching off and on lights and other electrical equipment and integrating interior and outdoor natural light to adjust the illuminance of lamps and minimize resource waste. The system is composed of an Arduino microcontroller, lamp, occupancy sensors, and fuzzy logic algorithm. Two membership functions of the fuzzy logic algorithm were utilized as inputs for light sources, one from outside lighting and the other from inside illumination, while one membership function was used as output. The occupancy sensors were utilized to detect occupancy inside the area for automated lighting switching, and the output of the control system's membership function was used to calculate the dimming percentage of lamps. The intended input and output membership functions of the fuzzy logic controller, however, were set arbitrarily and utilized to benchmark the system's performance.

Furthermore, people use lights needlessly, especially during the day, when the intensity of sunshine around us is sufficient. As a result, another smart approach to use lights is automated self-controllable light intensity based on the user's preferences. Kilari *et al.* [14] presented an automated lighting system that adjusts the amount of light intensity required for vision in a certain location or for a certain job. The system comprises of light-dependent sensors (LDRs) positioned throughout the room to obtain the needed intensity of light and compare it to the user-specified reference intensity. The data is then sent into a microprocessor, which adjusts the intensity as needed. The proposed system was successful in controlling light intensity based on the presence of natural light in the surrounding region; however, various people have varied preferences for light intensity; hence, this system may cause conflict in a room when more than one person is using it.

Similarly, Li *et al.* [15] proposed an Arduino-based intelligent office lighting system that monitors and tracks power supply in real-time, automatically and smoothly adjusts the voltage and current amplitude of the electric circuit and reduces the additional power consumption caused by the unbalanced load in the lighting circuit. The system was also developed to increase the power factor, lower the operating temperature of the lights and lines, and accomplish the lighting control system for optimizing the power supply. The system's components included a clock module that keeps track of its operations, a communication module for transmitting and receiving data, an illumination module, a human body infrared module for detecting human body movement, a controller for transmitting data collected by each node to the system and the user via the communication network, and an execution device consisting of an execution LED light and a liquid crystal display (LCD) to indicate the system's operation. The intelligent lighting system includes an automated controller that opens and shuts the lights, as well as a brightness adjustment function that allows the user to modify the brightness of the indoor light at any moment in order to obtain the most comfortable lighting effect. At the same time, users may use their mobile phones to manage the indoor lighting switch, brightness adjustment, and scenario pre-sets. The authors used a complicated system design architecture, which raises the operating costs.

Suresh *et al.* [16] presented another intelligent automated street light management system that uses an internet of things (IoT) framework to decrease electricity waste. The proposed system has three major stages: maintenance, automated adaptive ON/OFF management, and prediction of power usage. A Wi-Fi module, an LDR, an accelerometer, and ultrasonic sensors were used to make the system work effectively. The accelerometer sensor was used to determine the tilt of the street lighting pole and alert the emergency situation to the control room or user. Then, an LDR sensor was used to switch on and off the streetlights based on the intensity of the atmosphere. This switching might be accomplished with an LDR-based Wi-Fi module. An ultrasonic sensor was used to detect the presence of any vehicle or person within a set range, causing the light to shine with full brightness if a vehicle or person was detected, otherwise the light was lowered to glow with just 60% intensity. Furthermore, a prediction model based on an improved Bayesian neural network (IBNN) model was used to report power usage over a given time period. The suggested method minimizes electricity waste at night when no vehicle or trespasser is present. The suggested design has the ability to reduce street light power consumption, identify failures early, and alert the control room of the time length of those failures; however, its performance was not evaluated and reported.

The standard lighting system, with a switch to regulate the lighting, is used by the majority of schools and institutions. However, students and staff members have a propensity of leaving the classroom without turning off the lights, fans, air conditioners, and so on. In some situations, only a few pupils are spotted sitting in one corner of the classroom or lab, while all the fans, lights, and air conditioners are left turned on. All this adds up to needless power waste and exorbitant electricity bills. To address this issue, Suresh *et al.* [17] created an automated lighting and control system based on Arduino for the efficient use of energy in schools. The system was developed to regulate lighting in specific sections of the classroom depending on the presence of humans utilizing relay control and mobility, as well as remote voice command execution through Bluetooth using the android mobile app. To do this, the classroom was split into grids, and one PIR sensor was installed at the entrance and another within the classroom. The system was tested in a classroom for one week and was found to save 50% of the energy. Similarly, an IoT-based home automation systems that switch on room appliances only when PIR sensors detect occupancy had been developed [18]–[23]. The systems also collect room characteristics via different sensors, analyze the data with an ARM-7 controller, and transfer the data to the cloud over Wi-Fi. The android application, however, utilizes manual control of the appliances.

Due to the variety of classroom contexts, the diversity of user groups of any energy management solution and the complexity of their response to such a solution, a flexible lighting control system is highly preferred for the minimization of electrical energy consumption and acceptance by the users for different conditions. Such a system should meet the following requirements: i) the choice of design should aim at minimizing the implementation cost; ii) the design should minimize the operational energy consumption and enhance its control accuracy; iii) can be installed based on the context of lighting space to control/classroom learning context to make it appropriate for any intended use; iv) can control based on zones in the classroom.

In the current study, we designed and implemented an innovative automatic room lighting system (ARLS) in order to meet these requirements. The remainder of the paper is organized. Section 2 describes the design methodology and the technical details of the proposed system. Section 3 explains the findings, and Section 4 concludes the study.

2. RESEARCH METHOD

2.1. Description of the system

The proposed ARLS is powered by 5 V, 1.5 W DC which is sourced from the Arduino microcontroller. It features two infrared sensors that are linked to the Arduino Uno and an LCD screen that is interfaced to display the number of people that enter the room. The infrared (IR) sensors detect the movement of people entering and exiting the room and send a signal to the Arduino Uno to trigger the relay to turn on or off the lamp when the first person enters or the last person departs the room, respectively. For example, when a person enters the study room, the infrared signal bounces back and is detected by the infrared receiver, indicating an entry. As a result, the count is increased. Similarly, when a person leaves the room, the count is decremented. When the count is more than zero, the relay goes high, causing the room lights to turn on; when the count is less than or equal to zero, the relay goes low, causing the lights to turn out. The system was built using appropriately sized components. It has four primary components: a sensor unit, a processing unit, a control unit, and a counting unit. The block diagram of the proposed system is shown in Figure 1.

The sensing unit is primarily concerned with the parameters required for automation. The sensing unit's components were chosen based on dynamic human motion, component cost, and operating cost. Consequently, an IR sensor was chosen to detect the presence of humans in the study room. An infrared sensor gives out an infrared signal, which bounces back from the surface of an object and is picked up by an infrared receiver. IR sensors detect movement whether it is within or outside of the range. These sensors are small, inexpensive, low-power, easy to use, and do not wear out easily [24]. Figure 2 shows an example of an IR sensor.

When human motion is recorded, the input parameters are evaluated, processed, and the associated actions are triggered by the processing unit. The Arduino Uno board was chosen for this unit based on its low cost and ease of use. Arduino is a microcontroller that utilizes the C programming language to control its functions. It is based on the ATmega 328P and has 14 digital I/O pins, 6 analog inputs, a 16 MHz quartz crystal, a universal serial bus (USB) connection, a power jack, an in-circuit serial programming (ICSP) header, and a reset button [25]. Figure 3 depicts an Arduino board.

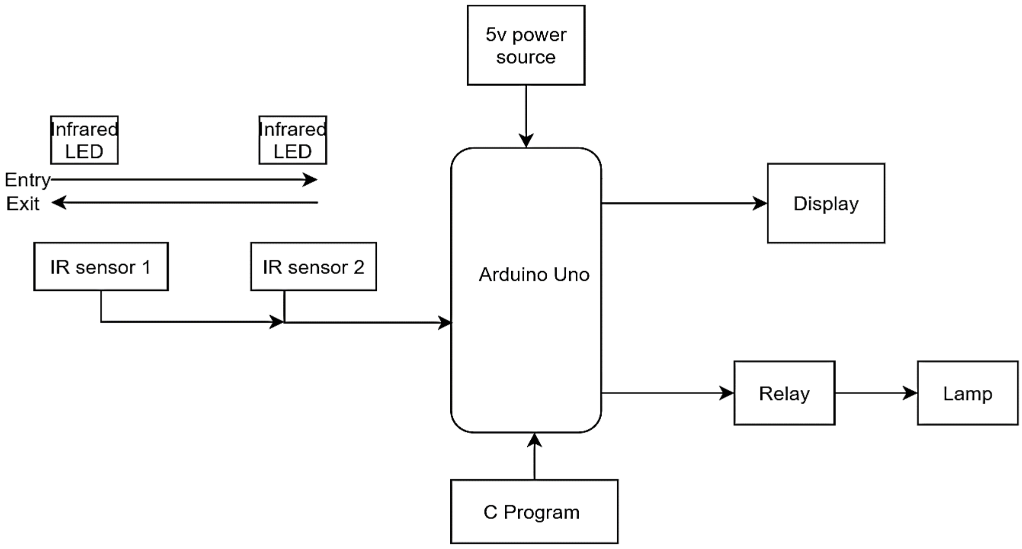


Figure 1. Flowchart of automatic room light controller

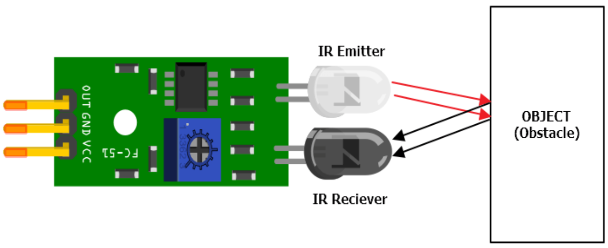


Figure 2. Operation of IR sensor

Figure 3. Arduino Uno microcontroller board

The control unit consists of a relay module and a lamp. A relay is an electrically powered switch that employs an electromagnet to activate a switch mechanically. Relays are employed in appliances where a low-power signal is required to control a circuit or where many circuits must be controlled by a signal. The relay module controls the lamp by turning it on or off. It is controlled by the Arduino microcontroller. To operate, this relay module required 5 V from the microprocessor [26]. We selected a 4-channel relay module because of its inexpensive cost and compatible voltage with a microcontroller. Figure 4 depicts an example of a relay module.

Figure 4. A 4-channel relay module

2.2. Design procedure for the system

Following a review of the literature to identify the shortcomings of existing automation systems, the requirements of the proposed system were specified. Based on these specifications, a circuit was constructed and analyzed using Proteus 8.1 software, in which a 16×2 LCD was interfaced with the Arduino Uno and two IR sensors were attached to digital input pins 5 and 6 of the Arduino Uno (Pin 5 for entry and pin 6 for exit). The relay module was wired to Arduino Uno pin 2, and the bulb and switch were also connected to the relay module. The program code as shown in Figure 5 was then uploaded to the Arduino Uno microcontroller and simulated in the Proteus 8.1 software to ensure that everything worked properly. On a breadboard, the design was reviewed, prototyped, and tested. The final design was created using the same proteus circuit design software after adjusting the values of the resistors and other components utilized. The design was constructed on the breadboard once more, and continuity testing was performed. Following the completion of the continuity testing and adjustments, a cardboard box was constructed. The different pieces of the case were assembled using super glue adhesive. The system was then installed inside the packaging, and a sticker was applied to it. After that, the circuit was ready for final testing and analysis.

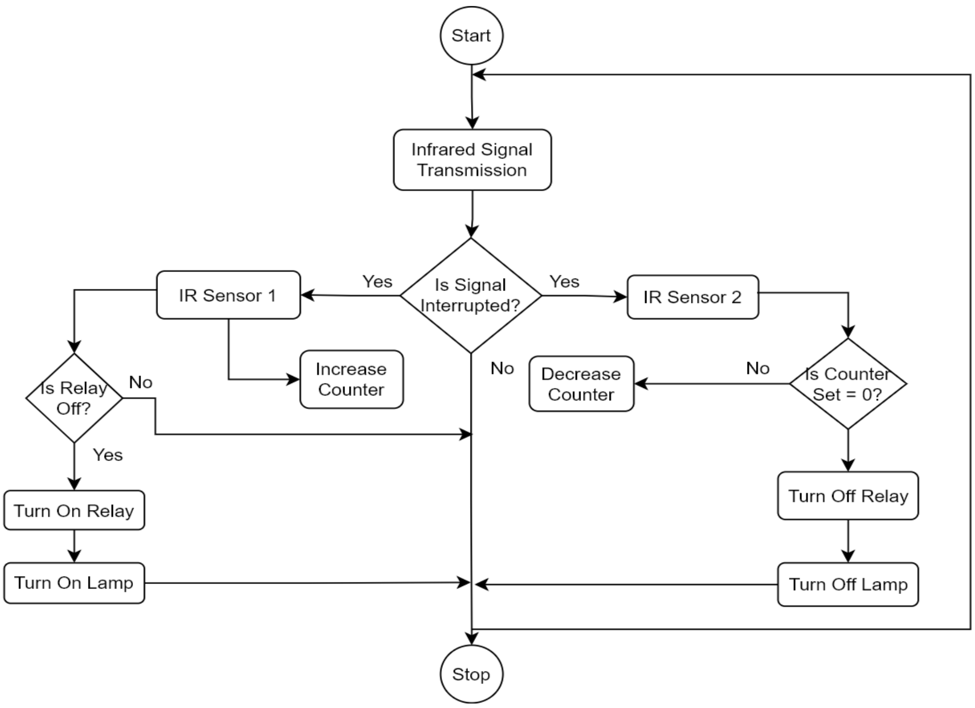


Figure 5. Flowchart of automatic room light controller

3. RESULTS AND DISCUSSION

The entire automatic room lighting system was designed using the Proteus 8.1 software. The device was tested after being powered by a bench AC power supply. It was able to perform as it was designed and programmed. When the first person entered the study room, the lamp turned on automatically, and it turned off when the last person left. The system's performance was evaluated in the following scenarios:

3.1. Power consumption test

The overall power of the device is calculated as the product of voltage and current. The lowest and highest voltages and currents were measured, and the power consumption was computed and shown in Table 1. When powered by the 7 V power source, the system became extremely unstable, causing the microcontroller to restart. The device operated smoothly and without hiccups at the 9 V power source and the device's operating current was efficient. The Arduino microcontroller became hot as a result of the 12 V. This occurred due to the Arduino's 5 V voltage regulator, which runs at an optimal value of 7 V. Although the technical specifications state that it can take up to 20 V, heating will result in wasteful operating power consumption. As a result of examining the voltage range, the 9 V power supply was recommended for its availability and lower heating.

Table 1. Power consumption analysis

Voltage (V)	Current (mA)	Power (mW)
7	87	609
9	100	900
12	120	1,440

3.2. The view angle and range test

The purpose of this test was to determine the system’s view area. As illustrated in Figure 6, the sensors are mounted halfway between the entry and exit doors of a study room. The device was able to identify human movement at the room’s entry and exit and maintain track of the number of individuals in the room. This enabled the device to toggle the light on and off.

Figure 6. View angle and view range test results

3.3. System sensitivity test

The system’s sensitivity is a measure of how quickly it responds to a change in its condition. The IR sensors were positioned in such a way that for one to enter the room, the entry sensor must be cut first, followed by the exit sensor, in order to track the number of people who used a single door to access the study room. This advances the counter indicating that someone has entered the monitored room. When the exit sensor is cut before the entry sensor, the counter status is decremented by one. When the first person enters the room, the lights turn on. When the final person exits the room, the lights stay on for 5 seconds before turning off. The system is designed in such a way that the counter state must be equal to or greater than one for the lights to be turned on.

Two approaches were employed to test the system:

a. Proteus virtual system modeling (VSM) simulation, in which the source code file obtained from the development environment was uploaded to the Arduino program memory and the simulation was started. When logic gate 1 was pressed, followed by logic gate 2, the status of the counter was increased and decremented in reverse, and this count was shown on the liquid crystal display, as shown in Figure 7.

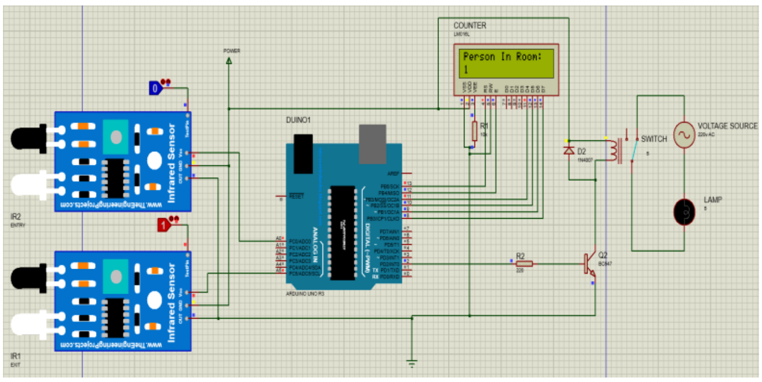
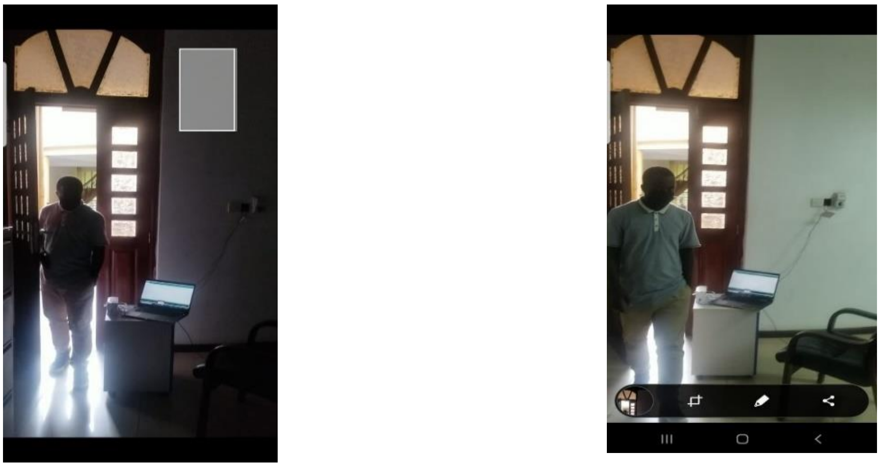


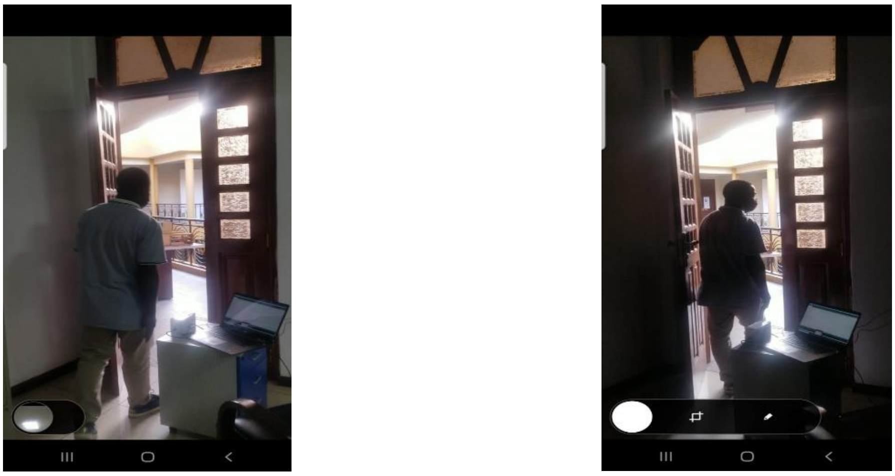
Figure 7. System response using simulation

b. The second technique entailed burning the source code into the microcontroller program memory once the prototype was built and putting the device in a room with five persons randomly entering and exiting the room, as illustrated in Figures 8 and 9. The system turned on the lamp as soon as the first person entered the room (see the difference of before and after he entered in Figure 8(a) and (b)) and kept it turned on until the last person left. After the last person exited, the system turned off the lamp after 5 seconds, just as intended (see the difference of before and after he entered in Figure 9(a) and (b)).



(a) (b)

Figure 8. System response using actual sensors (a) before first person entered and (b) after first person entered



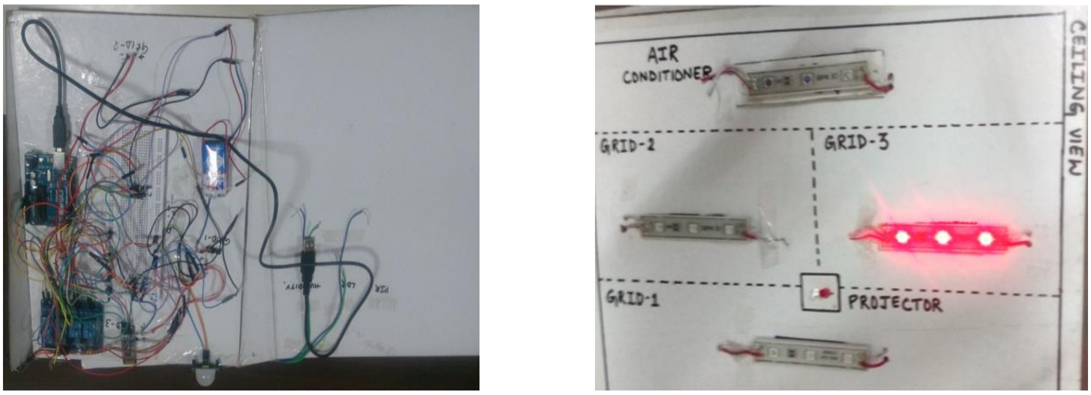
(a) (b)

Figure 9. System response using actual sensors (a) before last person exited and (b) after last person exited

3.4. Cost analysis

Following a comprehensive review of the literature to identify the shortcomings of existing automation systems, a case study system was chosen and utilized to benchmark the proposed system. Suresh *et al.* [17] developed and implemented the case study system for grid-divided classrooms. To detect the presence of a human, the authors utilized one PIR sensor at the classroom’s entrance and another PIR sensor within the classroom, which was split into grids. The major rationale cited for arranging the sensors in a grid pattern is that ceiling-mounted sensors are costly and have a limited range for sensing objects/people. This implies that a single sensor may not cover an entire room, necessitating extra wiring in the case of wired sensors. The authors also included a mobile application for regulating the lighting as on or off based on voice input transmitted through Bluetooth, noting the system's ability to switch on or off electrical equipment in a specific area of the classroom based on human presence as an advantage. Figures 10(a) and 10(b) depict the design and operation of the case study system, and the advantages and shortcomings of this system are evaluated and compared with the proposed system.

The cost of implementing the proposed system was GHS 303.00, which is 61% less than the cost of implementing the case study project. Table 2 depicts the comparison of the implementation costs and Table 3 presents the cost savings of installing the proposed system. To determine the cost savings, a sub-meter was installed in the study room to measure the consumed kilowatts for a period of one month each with and without the energy conservation system.



(a) (b)

Figure 10. The (a) construction and (b) operation of the case study system

Table 2. Cost of proposed and case study systems

Material/item	Quantity	Amount (GHS)	
		Proposed System	Case Study System
IR sensor /PIR sensor	2/4	20	40
Relay Module	1/4	11	44
Solderless Breadboard	1	10	10
LCD Screen	1	15	15
Arduino Uno	1	69	69
Circuit components		10	20
Shipping		35	35
Workmanship		100	100
Bluetooth Module	0/1		56
Mobile Application	0/1		100
Total		303	489

Table 3. Monthly electricity consumption

	Period	Sub-meter measurement in kWh	Computation based on ECG charges	Monthly electricity cost in Ghana cedis
Without the system installed	July 1-31, 2021	30.575	30.575×0.796	24.3377
With the system installed	August 1-31, 2021	25.595	25.595×0.796	20.37362
Cost savings in monthly consumption		24.3377-20.37362		3.96408

Without installing the device, the previous month's energy usage in kilowatt hours was 30.575. This value was multiplied by GHS 0.796, the electricity of Ghana's tariff per kWh consumed. The monthly cost of electricity is shown to be GHS 24.3377. After one month of installing it, the energy consumption was measured to be 25.595 kWh, and the monthly cost of energy was calculated to be GHS 20.37362, which is much cheaper. The operation of the energy conservation system resulted in a cost reduction of GHS 3.96408 throughout the month period. We then projected the annual cost savings of using the device by multiplying the monthly findings by 12, which yielded GHS 292.0524 (30.575×0.796×12) cost when the device was not installed, GHS 244.48344 (25.595×0.796×12) cost when the device was installed, and a cost savings of GHS 47.56896 ((24.3377-20.37362)×12). Figure 11 depicts the annual energy cost projection for the proposed system. Energy measurements for the case study system were not available for comparison.

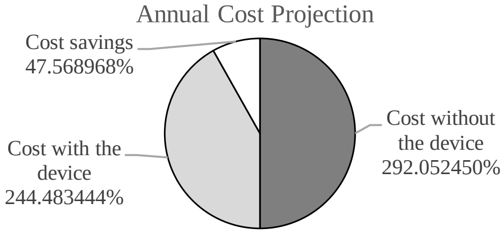


Figure 11. Annual energy cost projection

4. CONCLUSION

A simple, low-cost, portable microcontroller-based automated room light controller was designed and built for energy waste management. An entry/exit sensing unit that employs infrared sensors to detect the number of people entering and exiting the controlled room has also been developed. The Arduino integrated development environment (IDE) was used to write, develop, and debug code for the Arduino microcontroller, and Proteus was used to simulate the designed circuits. IR sensors, an Arduino microcontroller, a relay control circuit, and an LCD output module are the main parts of the system. The proposed system was able to receive two sensor inputs and, using the code loaded in the microcontroller's program memory, turn on or off electrical appliances in a study room while also keeping count of people entering and exiting. If the pulse from the entrance sensor is interrupted first, the microcontroller processes it and triggers an inward count. The microcontroller waits 5,000 milliseconds before turning on the controlled lights. On the other hand, when the exit sensor is interrupted first, an outward count is recorded. If the counter's status is zero, the lights switch out; otherwise, they remain on. When the counter is equal to or greater than one, the appliances remain on, and the exit IR sensor output pin is monitored. When the last person in the room leaves, the sensor's output is about 0 V, which the microcontroller interprets as logic 0. In this condition, the microcontroller waits 5,000 milliseconds before turning off the lights. The proposed system's time delay transitions may also be changed in the application code to accommodate varied user preferences. To increase efficiency, the space may be partitioned, and the system replicated with a few logic combinations to control lights in different areas of the same room or preferred areas of a monitored room. Furthermore, it may be expanded to operate all gadgets and appliances in the room by connecting them to the system's control unit. With the achievement of all the study objectives, we can conclude that the system is reliable, cost-effective, compact, and portable, and thus can be used in light energy management operations to assist in minimizing electricity waste, particularly in public places.

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