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Development and Evaluation of Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology

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ABSTRACT: Conventional lighting systems still rely on manual switching and grid electricity, contributing to unnecessary energy use and limited remote-control capabilities. Despite advances in automated lighting, the integration of solar photovoltaic power, GSM communication, and automatic switching in affordable, small-scale systems remains insufficiently explored. This study developed and evaluated a mobile phone-enabled, solar PV-powered lighting control system with GSM/3G/4G Temperature, Humidity, and Power Status Monitoring T200 module automatic switching technology. A developmental-evaluative research design was employed involving 100 respondents comprising 65 students, 25 faculty members, and 10 community users, selected through purposive and convenience sampling. Data were gathered using a survey questionnaire and prototype performance tests, and descriptive statistics and F-tests were used for analysis. Results indicated 96% functionality, 95% reliability, and 95% accuracy, with average response times of 5.30 seconds for ON commands and 8.40 seconds for OFF commands. Respondents reported high perceived usefulness (M = 4.62) and ease of use (M = 4.49), alongside favorable acceptability ratings for user-friendliness, innovativeness, durability, and service efficiency. Age, respondent type, and educational attainment differed significantly in usability and acceptability assessments ($p = 0.001$), whereas sex did not. The findings support the system's potential for accessible, renewable-energy-based lighting management while highlighting opportunities to improve communication reliability and long-term performance.

KEYWORDS: solar photovoltaic system, GSM-based automation, lighting control system, energy efficiency, usability, acceptability

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INTRODUCTION

Lighting systems are an important component in many areas, including community facilities, commercial settings, and residential spaces. Conventional lighting systems often rely on manual switching, which can lead to unnecessary energy consumption, higher electricity costs, and inefficient energy management. According to an International Energy Agency report, lighting in buildings and outdoor applications accounts for most overall electricity demand. In 2024, around 8% of global electricity demand, or about 2 200 terawatt hours (TWh), was attributed to lighting in buildings and outdoor applications. It is estimated that electricity consumption for lighting, including industrial lighting, was 2,500 and 3,500 TWh in recent years (Delmastro et al., 2026). One major problem with conventional lighting systems is their dependence on manual switching. Users must physically turn lighting devices on or off, which often leads to forgetting to turn them off after leaving the room or facility. Lights are still on when not in use, resulting in high energy consumption. Energy wastage is another important concern for conventional lighting systems, as some lighting devices remain on or operational without corresponding benefit to the users. The IEA has previously identified situations in which lighting is supplied to spaces where people are not present as a significant source of lighting-related energy waste (Delmastro et al., 2026). Lack of monitoring and remote-control capabilities are another cause of this problem. Users can't determine the status of lighting devices without physically checking the location. Without remote monitoring and control, users may accidentally leave lights on because they forget to turn them off, increasing electricity consumption.

According to a study by Bisht and Borah (2018), batteries in solar street-lighting systems under actual field conditions lasted only about one to two years, with field conditions contributing to faster degradation than laboratory conditions. Another study evaluated the reliability and performance of solar-powered street-lighting systems over an extended monitoring period and reported performance ratios ranging from 70% to 89%, while also identifying charge-controller overheating as a factor affecting system components (Fashina et al., 2017). Recent research has shown that a GSM-based home automation system using an Arduino Uno microcontroller and a GSM SIM900 module allows users to switch electrical appliances on and off through SMS commands, receive SMS notifications, and improve remote appliance control. The authors also discussed its potential to reduce energy wastage (Okubanjo et al., 2021). By integrating solar panel technology with GSM functionality, the system ensures efficient energy use, reduces dependence on conventional electricity, and allows users to receive notifications or control the lighting system remotely (Gubbi et al., 2013). Solar energy is one of the most abundant and environmentally friendly energy sources available today. In a tropical country like the Philippines, where sunlight is available year-round, solar-powered systems offer a practical, sustainable solution to rising electricity costs and frequent power interruptions. Automation plays a crucial role in improving energy efficiency and reducing human effort. With GSM communication, users can monitor system performance, receive status alerts, and control lighting remotely when needed. This capability enhances safety, convenience, and system reliability, especially during emergencies or unexpected power outages (Qiang et al., 2023). Islam (2026) found strong quantitative support for ML-based intelligent lighting, with an overall support score of 4.42 out of 5.00 and 86% of reviewed studies supporting ML- or AI-based streetlight control and monitoring systems. Energy-saving patterns ranged from 25% to 60%, with an estimated average saving of 38.7%. The study implies that smart cities can reduce energy waste, improve lighting reliability, lower operational costs, and support predictive maintenance and monitoring. The researcher aims to provide a practical and affordable solution that can be implemented in schools, residential areas, homes, and public infrastructure. The device is designed to be simple, cost-efficient, and easy to maintain, making it suitable for communities seeking sustainable energy alternatives. In today's rapidly advancing technological era, automation and renewable energy integration are essential for building smarter, more sustainable communities (Rajaperumal & Columbus, 2025). The development of a Mobile Phone-Enabled and Solar PV-powered Lighting Control System with GSM-Based Automatic Switching Technology represents a step toward efficient energy management, environmental sustainability, and improved quality of life. By combining automation, solar energy, and mobile communication, this study offers a practical solution that benefits people and the environment while supporting the transition to a cleaner, smarter future.

Although GSM-based automation systems have proven effective for remote control and monitoring, many rely on conventional grid electricity as their primary power source. During power outages or in off-grid locations, these systems may lose functionality. Integrating renewable energy sources, such as solar photovoltaic power, into GSM-based automation remains relatively underexplored, especially for small-scale community applications. The proposed system is different from other technologies in that it must be controlled and monitored by many users, whereas the system used in this study allows only the admin to control and monitor the GSM system. Existing integrated systems are often designed for industrial or commercial applications, making them too expensive or complex for widespread adoption in rural and low-income communities.

To address these gaps, this study proposes developing a low-cost, solar photovoltaic-powered automated lighting system with GSM-based remote monitoring and control capabilities. By integrating renewable energy, automation, and wireless communication into a single platform, the proposed system aims to provide an efficient, reliable, and sustainable solution for both urban and rural communities in the Philippines. Beyond improving energy access and operational efficiency, the proposed system combines renewable energy generation, automatic lighting switching, GSM-based communication, and mobile-phone accessibility in one practical architecture. The system is therefore intended to address several limitations simultaneously: unnecessary energy consumption from manual operation, limited remote monitoring, dependence on conventional grid electricity, and delayed awareness of lighting-system operating conditions. Existing studies have demonstrated smart lighting, solar lighting, GSM communication, and predictive monitoring as individual or partially integrated technologies, but there is still room for a practical system that integrates solar PV power, automatic switching, GSM/mobile-phone that controls all the system by the admin only, and operational monitoring into one platform and empirically evaluates its energy, operational, and maintenance performance.

Objective of the Study

This study aimed to develop and evaluate a mobile phone-enabled, solar PV-powered lighting control system with GSM/3G/4G Temperature, Humidity, and Power Status Monitoring T200 module. It examined respondents' perceptions of the existing lighting management system; the system design, pictorial, and wiring diagram; evaluated the developed system's performance in terms of functionality, reliability, accuracy, response time, and energy efficiency; and assessed its usability based on perceived usefulness and perceived ease of use, as well as its acceptability in terms of user-friendliness, innovativeness, durability, and service efficiency. Furthermore, the study determined whether significant relationships

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existed between respondents' demographic profiles and their assessments of the developed system's usability and acceptability to identify areas for further technological enhancement and practical implementation.

METHODOLOGY

Design

This study used the developmental-evaluative design, also known as the Developmental Evaluation (DE) research design, which guides the entire process of developing and evaluating the Mobile Phone-Enabled and Solar PV-powered Lighting Control System with GSM-Based Automatic Switching Technology. This will help the researcher build and shape a dynamic program as it evolves. It is also an evaluation approach that can help social innovators develop social change initiatives in complex or uncertain environments by enabling real-time feedback and a continuous development loop. The researcher maintains full control of the procedures to ensure accurate, consistent results. It objectively measures the device's functionality, efficiency, responsiveness, and reliability when operated through GSM-based control and solar energy utilization.

Respondents

The study employed a combination of purposive and convenience sampling techniques to select respondents who could provide relevant assessments of the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology. Purposive sampling selected individuals with specific knowledge, expertise, and experience relevant to the research objectives, while convenience sampling recruited accessible, willing community participants (Etikan et al., 2016). Specifically, purposive sampling was used for Mechatronics students and faculty members of Cebu Technological University–Danao Campus, while convenience sampling recruited community users who primarily relied on conventional or manually operated lighting systems in their households. Mechatronics students were selected for their foundational knowledge of GSM communication, microprocessors, and microcontrollers, while faculty members specializing in Mechatronics, Electrical, and Electronics Technology were included for their technical expertise in evaluating the system's functionality, usability, and operational performance. Community users were included to provide practical perspectives on household lighting management, particularly regarding the convenience of remote switching, energy conservation, and the potential benefits of automated lighting control.

A total of 100 respondents participated in the study, comprising 65 Mechatronics students (65.00%), 25 faculty members or instructors (25.00%), and 10 community users (10.00%), representing individuals with varying levels of technical knowledge and experience. As presented in Table 1, most respondents were aged 20 years and below (65.00%), followed by those aged 21–30 years (23.00%), 31–40 years (10.00%), and 41–50 years (2.00%), while females (70.00%) outnumbered males (30.00%). Regarding educational attainment, the majority were at the college level (73.00%), followed by master's degree holders (11.00%), college graduates (8.00%), doctoral degree holders (6.00%), and high school graduates (2.00%). Including students, faculty members, and community users enabled the collection of diverse perspectives on the developed system's usability, acceptability, functionality, and potential applications in educational and residential settings. Nevertheless, because the respondents were selected through non-probability sampling techniques, the findings primarily reflected the assessments of the participating individuals and could not be statistically generalized to the broader population of potential users.

Table 1. Profile of the Respondents (N=100)

Profile	Variables	Responses	
		f	%
Age	20 years old and below	65	65.00
	21-30 years old	23	23.00
	31-40 years old	10	10.00
	41-50 years old	2	2.00
Sex	Male	30	30.00
	Female	70	70.00
Type of Respondent	Student	65	65.00
	Faculty/Instructor	25	25.00
	Community Expert	10	10.00
Highest Educational Attainment	High School	2	2.00
	College Level	73	73.00
	College Graduate	8	8.00
	Master's Degree	11	11.00
	Doctoral Degree	6	6.00

Instruments

This study used an adapted questionnaire with four parts to gather the data needed to evaluate the developed system. Part 1 collected the respondents' demographic profiles in terms of age, sex, type of respondent, and highest educational attainment. Parts 2 to 4 employed a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), to measure the respondents' perceptions, assessments, and evaluations of the lighting management system. Part 2 assessed the respondents' perceptions of the existing lighting management system in terms of six constructs: familiarity with automated lighting systems (Lui et al., 2021), awareness of energy management practices (DeWaters & Powers, 2011; DeWaters et al., 2013), convenience of operation (Davis,, 1989; Venkatesh et al., 2003), reliability (Rafi et al., 2025), energy efficiency (Williams

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et al., 2012), and the need for automated monitoring and control (Venkatesh et al., 2003). This section consisted of 30 items, with five items allocated to each construct. Part 3 evaluated the system's usability using two constructs: perceived usefulness and perceived ease of use. This section consisted of 12 items designed to determine the extent to which the system was useful and easy for respondents to operate, adapted from the study of Ghani et al. (2019). Part 4 assessed the acceptability of the developed system in terms of four constructs: user-friendliness (Davis, 1989), innovativeness (Bruner et al., 2007; Moore & Benbasat, 1991), durability (Rafi et al., 2025), and service efficiency (Parasuraman et al., 2005). This section consisted of 20 items intended to determine the respondents' level of acceptance of the developed system based on these criteria.

Data Gathering Procedures

The researcher secured official permission from the Dean of the College of Technology at Cebu Technological University–Danao Campus and coordinated with the concerned authorities before conducting the study. Following authorization, the developed mobile phone-enabled and solar PV-powered lighting control system with GSM-based automatic switching technology was demonstrated to the selected students, faculty members, and community users to familiarize them with its features, functionality, and operation, while pilot testing was conducted to identify technical issues and improve the research instrument and prototype. After incorporating the necessary revisions, the validated questionnaire was administered to the respondents, who were provided sufficient time to observe and evaluate the developed system in terms of its performance, usability, and acceptability. Before participation, the researcher explained the study's objectives and procedures, obtained informed consent, emphasized the voluntary nature of participation, and assured respondents of their right to withdraw without penalty or negative consequences. To ensure confidentiality and compliance with Republic Act No. 10173, or the Data Privacy Act of 2012, the researcher collected no personally identifiable information, identified respondents only by their respective categories, and securely stored all gathered data, accessible only to the researcher for academic and research purposes. Finally, the researcher retrieved the completed questionnaires, checked them for completeness, organized, tabulated, and analyzed them using appropriate statistical procedures to determine respondents' assessments of the developed lighting control system and identify areas for further improvement.

Data Analysis

The collected data were systematically analyzed using appropriate descriptive and inferential statistical tools to ensure accurate and reliable interpretation of the findings. Frequency and percentage were employed to summarize the demographic profiles of the respondents, including students, faculty, and community users. Mean and standard deviation were used to assess respondents' perceptions of the existing lighting management system in terms of familiarity with automated lighting systems, awareness of energy management practices, convenience of operation, reliability, energy efficiency, and need for automated monitoring and control; the usability of the developed system in terms of perceived usefulness and perceived ease of use; and its acceptability in terms of user-friendliness, innovativeness, durability, and service efficiency. Finally, the analysis of variance (ANOVA) was employed to determine the statistical significance of the relationships between respondents' profile variables and their assessments of the developed system's usability and acceptability.

RESULTS AND DISCUSSION

Respondents' perceptions of the Existing Lighting Management System

Table 2 presents the respondents' perceptions of the existing lighting management system, which obtained an overall mean of 4.40 and a standard deviation of 0.74, interpreted as Strongly Agree, indicating generally favorable perceptions across the six constructs. Among these, energy efficiency recorded the highest mean, suggesting that respondents strongly recognized the importance of minimizing energy consumption in lighting operations, followed by awareness of energy management practices and the need for automated monitoring and control, reflecting their awareness of energy conservation and the potential benefits of automated lighting technologies. Reliability and convenience of operation were likewise rated Strongly Agree, indicating favorable assessments of these operational characteristics, whereas familiarity with automated lighting systems received the lowest mean, interpreted as Agree, suggesting comparatively limited familiarity with automated lighting technologies. These findings aligned with Wagiman et al. (2020), who emphasized the importance of intelligent lighting control strategies in improving energy efficiency, and Aussat et al. (2022), who demonstrated the potential of adaptive lighting systems to reduce electricity consumption while maintaining user comfort. Similarly, Chiradeja and Yoomak (2023) highlighted the role of smart lighting controls and Internet of Things technologies in improving lighting management, while Zocchi et al. (2024) underscored the contribution of advanced lighting controls and connected technologies to sustainable building operations. The findings indicated that respondents valued energy efficiency, operational reliability, and automated monitoring, providing empirical justification for developing a mobile phone-enabled and solar PV-powered lighting control system with GSM-based automatic switching technology to address emerging demands for convenient, accessible, and energy-conscious lighting management, although its actual effectiveness and energy-saving performance required experimental verification.

Table 2. Respondents' perceptions of the Existing Lighting Management System

Constructs	Mean	SD	Interpretation
Familiarity with Automated Lighting Systems	4.18	0.86	Agree
Awareness of Energy Management Practices	4.53	0.70	Strongly Agree
Convenience of Operation	4.32	0.79	Strongly Agree
Reliability	4.33	0.77	Strongly Agree
Energy Efficiency	4.61	0.59	Strongly Agree
Need for Automated Monitoring and Control	4.45	0.70	Strongly Agree
Average	**4.40**	**0.74**	**Strongly Agree**

Legend: *1.00-1.79 (Strongly Disagree); 1.80-2.59 (Disagree); 2.60-3.39 (Neutral); 3.40-4.19 (Agree); 4.20-5.00 (Strongly Agree)*

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System Design

Figure 1 shows the study's system design. The developed system provides an efficient, convenient lighting management solution by integrating solar photovoltaic technology, GSM communication, and an automated switching mechanism. It utilizes a solar panel to convert sunlight into electrical energy, which is regulated and stored in a rechargeable battery. The stored energy supplies the electrical requirements of the control circuit and lighting load. The GSM/3G/4G Temperature, Humidity, and Power Status Monitoring T200 module serves as the communication interface between the user's mobile phone and the developed system. When an authorized user sends a programmed command, the GSM module receives the message and forwards the corresponding instruction that activates or deactivates the relay module, thereby controlling the lighting load. This design allows users to remotely operate the lighting system while using renewable solar energy as its power source.

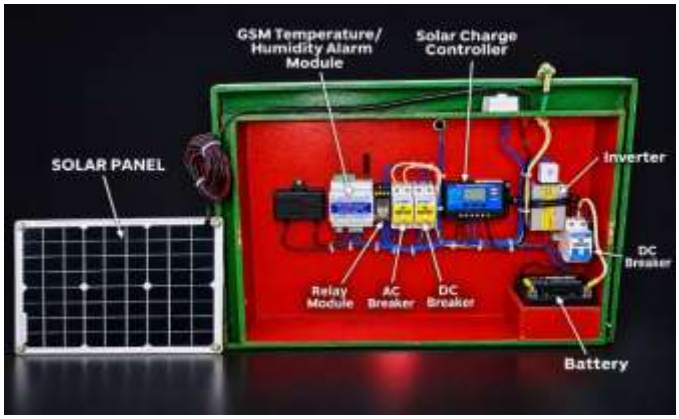


Figure 1. The System Design of the Study

The electrical control panel serves as the main control and protection unit of the solar-powered lighting system. The GSM Temperature/Humidity Alarm Module monitors conditions and sends alerts, while the relay module enables automatic switching of electrical connections. The Solar Charge Controller regulates the power from the solar panel to charge the battery, while the inverter converts DC power to AC power when needed. The yellow AC breaker protects the AC circuit, while the adjacent yellow DC breaker and the blue DC breaker on the right protect the DC circuits against electrical faults and overloads. Finally, the battery stores the solar-generated energy, ensuring a continuous power supply for the lighting system when sunlight is unavailable.

Pictorial Diagram

Figure 2 presents the pictorial diagram of the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology, illustrating its physical structure, component arrangement, and overall assembly from different perspectives, including the front, back, top, left, and right-side views. The front view shows the lighting fixture and its supporting structure, while the back view without the cover reveals the internal components, including the GSM module, solar charge controller, relay module, circuit breakers, inverter, battery, and electrical connections that manage power distribution and automated lighting control. The top and side views show the positioning of the solar photovoltaic panel, external wiring, and structural enclosure, while the back view with the cover shows the protective housing designed to secure the electrical components against physical damage and external interference.

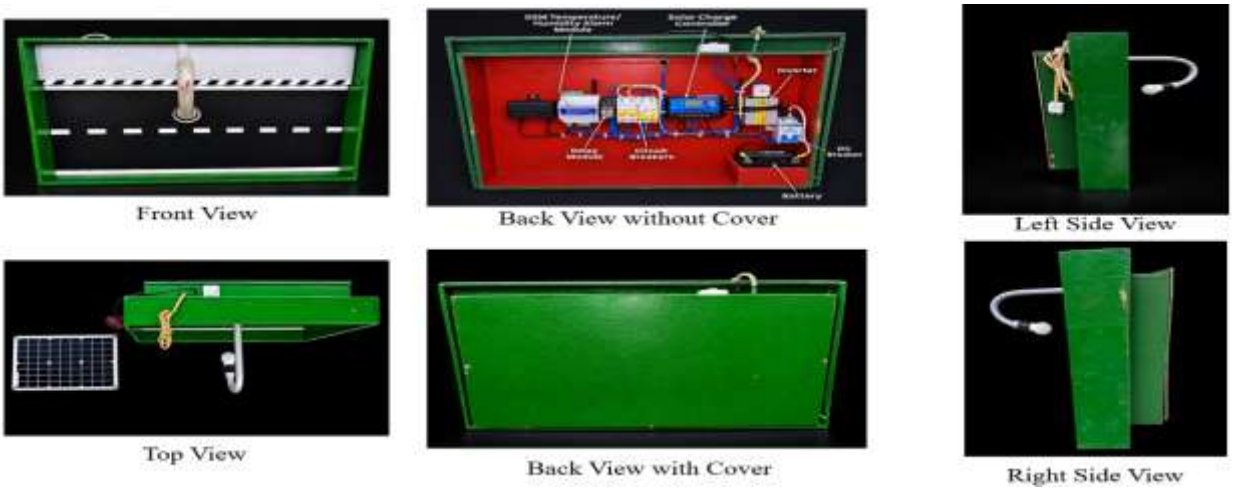


Figure 2. Pictorial Diagram

Wiring Diagram

The wiring diagram in Figure 3 shows the electrical connections and control components of the solar PV-powered lighting system with GSM-based monitoring and automatic switching technology. The solar panel converts sunlight into electrical energy, which passes through the first DC circuit breaker (DC Breaker 1) before reaching the solar charge controller, which regulates the charging process and protects the battery from improper charging. The battery stores the generated electrical energy and supplies power to the system when sunlight is unavailable. The second

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DC circuit breaker (DC Breaker 2) protects the DC supply line connected to the inverter, while the AC circuit breaker protects the AC output circuit against electrical faults and overloads. The GSM temperature and humidity alarm module enables remote monitoring and alerts, while the relay module serves as the switching component that controls the lighting load. The manual switch provides an additional means of controlling the lighting system, while the inverter converts DC power from the battery into AC power for compatible electrical loads. Finally, the color-coded wiring identifies the electrical connections: red represents positive or live conductors, black represents negative or neutral conductors, and green represents grounding connections, helping ensure organized installation and easier system troubleshooting.

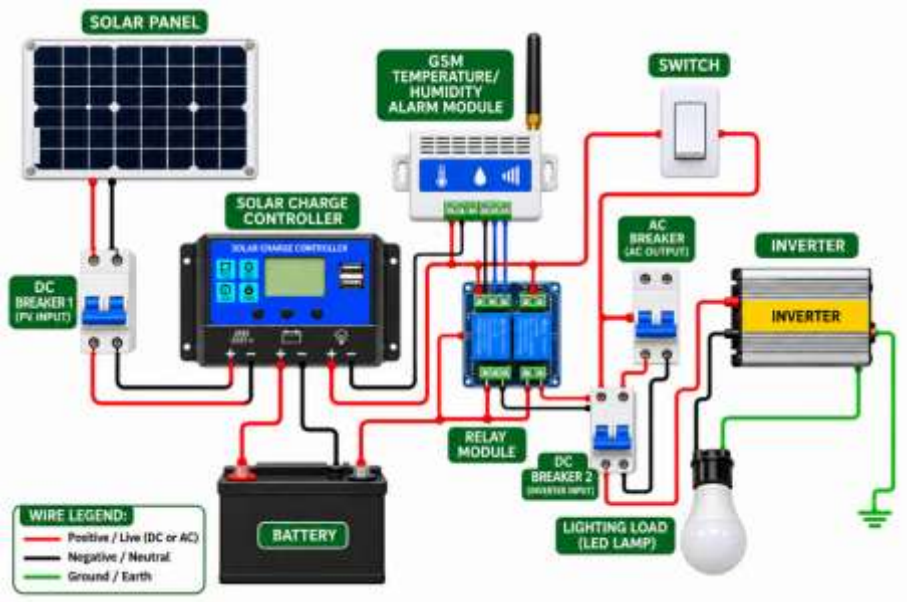


Figure 3. Wiring Diagram

Level of Performance of the Developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-based Automatic Switching Technology

Functionality

Table 3 presents the functionality performance of the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology, which achieved an overall success rate of 96.00%, equivalent to 48 successful operations out of 50 illustrative functional tests. This result indicated that the developed system performed satisfactorily under the specified testing conditions, reflecting its capability to perform the intended lighting control operations. Specifically, the mobile phone ON command, mobile phone OFF command, and solar-powered operation each achieved a 100% success rate, demonstrating consistent execution across all recorded trials. However, GSM communication and automatic switching each recorded a lower success rate of 90.00%, indicating occasional failures that may have resulted from signal instability, communication interruptions, or switching-mechanism limitations, although testing did not establish the specific causes. These findings aligned with Tamakloe and Kommey (2022), who demonstrated the feasibility of controlling electrical appliances through GSM-based mobile phone commands, and Goswami et al. (2022), who developed an Arduino-controlled smart street lighting system incorporating GSM communication, automatic switching, and environmental sensors, supporting the practical application of automated lighting technologies.

Table 3. Functionality

Functional Test	Successful Tests	Total Tests	Success Rate (%)
1. Mobile phone ON command	10	10	100.00
2. Mobile phone OFF command	10	10	100.00
3. GSM communication	9	10	90.00
4. Automatic switching	9	10	90.00
5. Solar-powered operation	10	10	100.00
Overall	**48**	**50**	**96.00**

Furthermore, Alias and Salimin (2023) demonstrated the feasibility of integrating solar photovoltaic power with wireless control and illumination monitoring in a smart classroom lighting system, reinforcing the potential of renewable energy technologies in automated lighting applications. The overall functionality success rate of 96.00% suggested that the developed system possessed promising capabilities for remote lighting management and solar-powered operation, although the illustrative test results required verification through actual experimental measurements. Nevertheless, the comparatively lower success rates for GSM communication and automatic switching highlighted the need to enhance signal reception, communication stability, and switching mechanisms to minimize operational failures. Therefore, additional functional testing under varying cellular network conditions, weather conditions, and operating environments was recommended to determine the system's

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consistency, reliability, and adaptability during prolonged operation. The findings suggested that the developed lighting control system offered a potentially practical approach to automated and sustainable lighting management, provided that its functionality was further validated through repeated experimental testing before wider implementation.

Reliability

Table 4 shows that the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology achieved an overall reliability rate of 95.00%, with 76 successful operations out of 80 illustrative attempts, indicating high operational consistency under the specified testing conditions. Automatic switching cycles recorded the highest reliability rate of 100.00%, demonstrating successful operation in all 20 trials, while ON switching cycles and GSM command execution each achieved 95.00%, reflecting generally consistent performance. Conversely, OFF switching cycles had the lowest reliability rate of 90.00%, suggesting occasional failures that may be associated with communication delays, switching components, or command execution, although further investigation is needed to determine the actual causes.

Table 4. Reliability

Test Condition	Successful Operations	Total Attempts	Reliability Rate (%)
1. ON switching cycles	19	20	95.00
2. OFF switching cycles	18	20	90.00
3. GSM command execution	19	20	95.00
4. Automatic switching cycles	20	20	100.00
Overall	**76**	**80**	**95.00**

These findings are supported by Tamakloe and Kommey (2022), who successfully developed and tested a GSM-based remote-control system for switching electrical appliances ON and OFF, demonstrating the feasibility of reliable mobile phone-enabled operations. Similarly, Goswami et al. (2022) developed a GSM-based smart street lighting system integrating mobile phone commands, sensors, and automatic switching, supporting the practical application of automated lighting control mechanisms. However, Askola et al. (2022) showed that repeated adaptive switching and dimming can contribute to LED luminaire aging under intensive operating conditions, emphasizing the need for extended testing when evaluating long-term lighting system reliability. The findings suggest that the developed lighting control system shows promising operational reliability, particularly in automatic switching, although the illustrative results require confirmation through experimental testing. The lower reliability rate for OFF switching cycles highlights the need to investigate possible communication failures, switching delays, and component-related problems to improve operational consistency. Furthermore, extended reliability testing under varying GSM signal strengths, solar power availability, and repeated switching conditions is recommended to establish the system's long-term dependability and suitability for practical implementation.

Accuracy

Table 5 shows that the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology achieved an overall switching accuracy of 95.00%, with 57 correct actions out of 60 illustrative test attempts, indicating high accuracy under the specified testing conditions. The ON commands recorded the highest accuracy rate of 100.00%, demonstrating that all 20 commands produced the expected switching responses, while OFF commands achieved 95.00%, reflecting one unsuccessful or incorrect operation. Conversely, automatic switching conditions obtained the lowest accuracy rate of 90.00%, suggesting occasional discrepancies between expected and actual switching behavior that may be associated with GSM signal instability, control-circuit limitations, or system configuration issues, although these possible causes require further verification.

Table 5. Accuracy

Switching Test	Correct Actions	Total Actions	Accuracy (%)
1. ON commands	20	20	100.00
2. OFF commands	19	20	95.00
3. Automatic switching conditions	18	20	90.00
Overall	**57**	**60**	**95.00**

Gbadega et al. (2024) developed a GSM-based remote-control system for smart home energy management that enabled users to switch electrical appliances ON and OFF through mobile phone commands, demonstrating the feasibility of GSM technology for remote switching operations. Similarly, Poza-Lujan et al. (2021) evaluated a street lighting control system using receiver operating characteristic (ROC) analysis to assess pedestrian detection and lighting control decisions, emphasizing the importance of measuring correct responses and identifying errors in automated lighting operations. These studies support the feasibility of automated lighting control while highlighting the need to verify switching accuracy, communication performance, and system responsiveness through repeated experimental testing. The findings suggest that the developed lighting control system shows promising switching accuracy, particularly for mobile phone ON commands, although the illustrative results must be verified through actual experimental testing. The relatively lower accuracy of automatic switching conditions highlights the need to improve control-circuit configuration, GSM communication stability, and command-processing mechanisms to minimize incorrect or missed operations. Furthermore, repeated accuracy testing under varying signal strengths, power conditions, and operating environments is recommended to enhance system precision and establish its suitability for residential, educational, and industrial applications.

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Response Time

Table 6 shows that the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology recorded an average response time of 5.30 seconds for ON commands and 8.40 seconds for OFF commands, indicating that the system responded faster when activating than deactivating the lighting. The 3.10-second difference suggests that OFF commands experienced longer processing or communication delays, although the recorded response times alone cannot determine the underlying causes. ON commands showed relatively consistent response times (5.1-5.5 seconds), whereas OFF commands showed greater variability (5.6-10.4 seconds), indicating less consistent responsiveness during deactivation.

Table 6. Response Time

Trial	ON Command (seconds)	OFF Command (seconds)
1	5.1	10.3
2	5.4	9.5
3	5.2	10.4
4	5.3	6.2
5	5.5	5.6
Average	**5.30**	**8.40**

This finding is supported by Olusakin et al. (2025), who reported an average switching response time of about 10 seconds in an SMS-controlled home automation system, showing that GSM-based switching can involve delays of several seconds. Furthermore, Gbadega et al. (2024) evaluated the responsiveness of a GSM-based smart home energy management system to remote commands, reinforcing the importance of response-time assessment in determining the operational performance of automated electrical control systems. The findings suggest that the developed system has potential for convenient remote lighting control, although longer and more variable OFF-command response times indicate opportunities to improve operational responsiveness. Improving GSM signal reception, optimizing command-processing procedures, and enhancing communication stability may help reduce switching delays and provide more consistent system performance. Furthermore, repeated response-time testing under varying network conditions and signal strengths is recommended to verify the illustrative findings and establish the system's suitability for practical lighting management applications.

Energy Efficiency

Table 7 presents the energy efficiency performance of the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology, showing an illustrative total average power consumption of 8 W, comprising a 3 W lighting load and a 5 W control circuit. Based on a 12-hour operating duration, the system's calculated energy consumption was 96 Wh, while the solar photovoltaic system generated 150 Wh, resulting in a theoretical energy surplus of 54 Wh before accounting for battery charging losses, conversion inefficiencies, and other operating conditions. These findings suggest that the solar PV system can meet the lighting and control circuit's energy requirements during the specified operating period, although comparative measurements are needed to establish actual energy efficiency and savings.

Table 7. Energy Efficiency

Parameter	Illustrative Measurement
Lighting load power	3 W
Control circuit power	5 W
Total average power	8 W
Operating duration	12 hours
Total energy consumption	96 Wh
Solar PV energy generated during the period	150 Wh

These findings are supported by Alias and Salimin (2023), who developed a solar PV-powered smart classroom lighting system integrating battery storage, wireless lighting control, and illumination monitoring, demonstrating the feasibility of using renewable energy for automated lighting applications. Similarly, Belloni et al. (2024) reported that an optimized solar-powered street lighting system substantially reduced dependence on grid electricity compared with conventional lighting, highlighting the potential energy benefits of photovoltaic-powered illumination. Furthermore, Aussat et al. (2022) demonstrated approximately 40% lower energy consumption through adaptive lighting control compared with conventional LED lighting, but also identified circumstances in which controller and sensor power consumption could offset energy savings, emphasizing the importance of evaluating total system energy demand. The findings imply that the developed lighting control system could operate using solar-generated electricity, reducing dependence on conventional electrical power sources under favorable operating conditions. However, the control circuit's 5 W consumption represents 62.5% of the total 8 W load, highlighting the need to optimize electronic components, minimize standby consumption, and improve battery charging and storage efficiency. Furthermore, extended energy monitoring under varying solar irradiance, weather conditions, and operating schedules, together with comparisons against conventional lighting systems, is recommended to establish actual energy savings and long-term sustainability.

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Level of Usability of the Developed System

Table 8 presents the level of usability of the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology, which obtained an overall mean of 4.56, interpreted as Strongly Agree, indicating that respondents perceived the system as highly useful and easy to operate. Among the two constructs, perceived usefulness obtained the higher mean, suggesting that respondents strongly recognized the system's potential to improve lighting management through remote operation, automated switching, and the integration of solar photovoltaic technology. Meanwhile, perceived ease of use recorded a slightly lower mean, although still interpreted as Strongly Agree, indicating that respondents generally found the system understandable and manageable, while the comparatively higher standard deviation suggested greater variation in their assessments of operational simplicity. These findings were consistent with Blut et al. (2022), who established through a meta-analysis of the Technology Acceptance Model that perceived usefulness and perceived ease of use were important determinants of technology acceptance, and Pal et al. (2018), who emphasized the influence of perceived usefulness, ease of use, and user-related factors on the adoption of smart home technologies. The findings suggested that the developed system demonstrated a high level of perceived usability, particularly in its practical usefulness for automated lighting management, while highlighting the importance of further simplifying user interactions, providing clear operating instructions, and improving accessibility to accommodate users with varying levels of technological familiarity.

Table 8. Perceived Usefulness

Statements	Mean	SD	Interpretation
Perceived Usefulness	4.62	0.57	Strongly Agree
Perceived Ease of Use	4.49	0.66	Strongly Agree
Average			

Legend: *1.00-1.79 (Strongly Disagree); 1.80-2.59 (Disagree); 2.60-3.39 (Neutral); 3.40-4.19 (Agree); 4.20-5.00 (Strongly Agree)*

Level of Acceptability of the Developed System

Table 9 presents the level of acceptability of the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology, which obtained an overall mean of 4.53 with a standard deviation of 0.64, interpreted as Strongly Agree, indicating a high level of acceptability among the respondents across all evaluated constructs. User-friendliness and innovativeness obtained the highest mean ratings, suggesting that respondents perceived the developed system as easy to operate and technologically innovative, particularly through the integration of mobile phone-based control, solar photovoltaic power, and GSM-based automatic switching technology. Service efficiency was likewise rated Strongly Agree, reflecting favorable perceptions of the system's ability to facilitate convenient and efficient lighting operations, while durability obtained the lowest mean (M = 4.39, SD = 0.70), although still interpreted as Strongly Agree, indicating comparatively greater opportunities for improving the system's structural robustness and long-term operational stability. The relatively low standard deviations (0.58–0.70) further suggested reasonably consistent assessments among respondents across the four constructs. These findings were consistent with Chiradeja and Yoomak (2023), who emphasized that integrating smart lighting controls with communication technologies could improve operational flexibility, remote monitoring, and energy management, supporting the favorable assessments of the developed system's innovativeness and service efficiency. Similarly, Aussat et al. (2022) showed that adaptive lighting control systems could improve energy efficiency while maintaining user comfort, highlighting the importance of intelligent, user-oriented technologies in modern lighting applications. The findings indicated that the developed system achieved a high level of perceived acceptability, particularly in user-friendliness and innovativeness, while the comparatively lower durability rating underscored the need for further improvements in component protection, structural integrity, and sustained operational reliability before wider implementation.

Table 9. Level of Acceptability of the Developed System

Constructs	Mean	SD	Interpretation
User-Friendliness	4.63	0.59	Strongly Agree
Innovativeness	4.63	0.58	Strongly Agree
Durability	4.39	0.70	Strongly Agree
Service Efficiency	4.48	0.70	Strongly Agree
Average	**4.53**	**0.64**	**Strongly Agree**

Legend: *1.00-1.79 (Strongly Disagree); 1.80-2.59 (Disagree); 2.60-3.39 (Neutral); 3.40-4.19 (Agree); 4.20-5.00 (Strongly Agree)*

Respondents' Profile and Their Assessment of the Usability and Acceptability of the Developed System

Table 10 presents the significant differences in respondents' assessments of the usability and acceptability of the developed Mobile Phone-Enabled and Solar PV-Powered Lighting Control System with GSM-Based Automatic Switching Technology when grouped according to their demographic profiles. The results revealed significant differences in usability (F = 9.908, p = 0.001) and acceptability (F = 5.697, p = 0.001) across age groups, indicating that respondents of different ages evaluated the developed system differently. Similarly, significant differences were observed across respondent types in usability (F = 16.060, p = 0.001) and acceptability (F = 12.405, p = 0.001), as well as educational attainment in usability (F = 8.780, p = 0.001) and acceptability (F = 7.017, p = 0.001), suggesting that respondents' educational backgrounds and user classifications were associated with variations in their assessments. Conversely, sex showed no statistically significant differences in usability (F = 0.704, p = 0.404) or acceptability (F = 3.008, p = 0.086), indicating comparable evaluations between male and female respondents, although post hoc comparisons were necessary to identify which specific age, respondent-type, and educational groups differed significantly. These findings were supported by

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de Deursen et al. (2025), who identified age and educational attainment as factors associated with differences in digital skills, and Sovacool et al. (2021), who emphasized the influence of demographic characteristics, technological knowledge, and familiarity on users' perceptions and acceptance of smart home technologies.

Table 10. Respondents' Profile and Their Assessment of the Usability and Acceptability of the Developed System.

Independent Variable	Dependent Variable	f-value	p-value	Interpretation
Age	Usability of the Developed System	9.908	0.001	Significant
	Acceptability of the Developed System	5.697	0.001	Significant
Sex	Usability of the Developed System	0.704	0.404	Not Significant
	Acceptability of the Developed System	3.008	0.086	Not Significant
Type of Respondent	Usability of the Developed System	16.060	0.001	Significant
	Acceptability of the Developed System	12.405	0.001	Significant
Highest Educational Attainment	Usability of the Developed System	8.780	0.001	Significant
	Acceptability of the Developed System	7.017	0.001	Significant

Furthermore, Tural et al. (2021) reported that age, educational attainment, perceived usefulness, and perceived ease of use were associated with older adults' intentions to adopt smart home technologies, although their findings concerning sex differed from the present study, as female respondents demonstrated greater intentions to use home automation systems. In contrast, Chang and Nam (2021) found no statistically significant age or gender differences in their reported technology adoption measure, while educational attainment and prior experience showed significant differences, suggesting that demographic influences may vary by technological application and user population. The significant differences observed across age groups, educational attainment levels, and respondent types highlighted the importance of considering users' demographic characteristics when designing automated lighting technologies, particularly in developing intuitive interfaces, providing appropriate technical orientation, and incorporating accessible control features. Meanwhile, the lack of significant differences by sex suggested that male and female respondents rated the system's usability and acceptability similarly, indicating its potential suitability for diverse users in educational, residential, and industrial environments. These findings underscored the importance of adopting a user-centered approach to further system enhancement, ensuring that the developed lighting control technology remained accessible, convenient, and responsive to users with varying levels of technological familiarity and experience.

CONCLUSION AND RECOMMENDATIONS

The study successfully developed and evaluated a mobile phone-enabled and solar PV-powered lighting control system with GSM-based automatic switching technology to improve lighting management through remote control, automatic switching, and renewable energy utilization. The findings showed that the prototype demonstrates strong usability and acceptability in terms of user-friendliness, innovativeness, durability, and service efficiency. Performance testing demonstrated the system's functionality, reliability, accuracy, response time, and energy efficiency. Moreover, the prototype provided a practical application of automation and control concepts. Overall, the findings support the system’s potential as a practical lighting management solution that combines mobile phone control, GSM-based automation, and solar energy, while continued refinement and long-term testing are recommended to strengthen its reliability, responsiveness, and energy performance.

Based on the findings, it is recommended that the developed and evaluated mobile phone-enabled and solar PV-powered lighting control system with GSM-based automatic switching technology be further enhanced by increasing solar panel and battery capacities to ensure a stable power supply, particularly during periods of limited sunlight. Improvements in GSM communication should also be considered to strengthen signal reliability, minimize communication failures, and reduce response times, particularly in areas with weak cellular network coverage. Future researchers are encouraged to integrate real-time monitoring through mobile or web-based applications and incorporate intelligent automation features, such as microcontrollers, light sensors, and programmable scheduling, to optimize energy consumption and operational efficiency. Furthermore, conduct extensive testing under varying environmental conditions and comparative evaluations against conventional lighting systems to establish the system's long-term reliability, durability, energy efficiency, and cost-effectiveness. Finally, the developed system may be considered for practical implementation in residential, educational, and industrial settings, subject to appropriate safety and performance evaluations, while ensuring that future improvements address user accessibility, ease of operation, and adaptability to different lighting management requirements.

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