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Smart Energy Saving Lamp with Ambient Light Detection for Automatic Brightness Adjustment

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Abstract

This project aims to develop a smart energy-saving lamp that automatically adjusts its brightness based on ambient light levels, providing an energy-efficient lighting solution for residential and commercial spaces. The standard lighting systems operate at full strength hence consuming exorbitant amounts of surplus energy. While further, such actions decrease the lamp's life. The proposed system integrates a Light Dependent Resistor (LDR) to sense ambient light intensity and an Arduino Uno microcontroller to process sensor data. An AC dimmer module was used for tuning the brightness level of a 220–240V dimmable LED lamp during system testing and calibration. The system is designed for relatively small rooms or office spaces, usually between 15 and 20 square meters. The recommended illumination level here is 500 lux. With minimum daylight, the lamp will be in full brightness. Increase in light level causes proportional dimming of the lamp so as to give adequate light and simultaneously save on energy cost. On the software level, an algorithm to control the brightness (easing out and in to the desired value in order to not produce sudden changes that could cause visual discomfort) has been used by the Arduino software. Tests and analysis show a potential energy saving up to 45%-50% with the proposed system in medium light conditions with respect to alternative light sources. The new system also can extend the lamp life by decreasing a thermal stress, while adjusting the brightness according to an actual light environment in real time. This project demonstrates the feasibility of adoption of smart control systems in lighting design in actual installations to conserve energy in residential and commercial buildings, and ensure sustainable development.

1. Introduction

As Malaysian cities grow and more people move into urban areas, there is an increasing need for energy-efficient solutions. Many people use standard lighting systems, which keep running at maximum brightness even in the presence of lots of natural sunshine. This raises the cost of power and wastes a lot of energy. In Malaysia, buildings consume a total of 48% of the electricity generated in the country. Commercial buildings consume up to

38,645 Giga watts (GWh) while Residential buildings consume 24,709 Gwh. Demand for electricity in the country is expected to rise from 91,539 GWh in the year 2007 to 108,732 GWh in 2011. By the year 2020, the energy demand in Malaysia is expected to reach 116 Million tons of oil equivalents (Mtoe). Carbon dioxide (CO2) emission in the country has increased by 221% ,which lists the nation at 26th among the top 30 greenhouse gas emitters in the world [1].

To tackle this issue, this project proposes the development of a Smart Energy-Saving Lamp with Ambient Light Detection for Automatic Brightness Adjustment. This innovative lamp will use sensor technology to detect the level of natural light in a room and adjust its brightness accordingly. When there's enough sunlight streaming in, the lamp will automatically dim or turn off, helping to conserve energy and extend the lifespan of the light source. Artificial lighting is one the most energy consumer is many non-residential buildings in which energy efficient measure such as dynamic simulation should be promoted to reduce the load of consumption [2].

This project is especially relevant in Malaysian cities like Kuala Lumpur and Selangor, where rapid development is driving up energy demand. This project can produce a dynamic lighting system that reacts to current lighting conditions by including an ambient light sensor into the lamp design. In addition to encouraging energy saving, this strategy supports Malaysia's dedication to sustainable development.

1.1 Problem Statement

In many homes and commercial spaces, conventional lighting systems consume excessive energy by remaining at a constant brightness regardless of available natural sunlight. . In 2016, in line with the increase of economic growth in Peninsular Malaysia, the electricity is expected to increase approximately by 4% between 2015 and 2016, that is from 117,219 MWh to 121,956 MWh[3]. Meanwhile, the total Maximum Demand is achieved it highest value in October 2017 that is 17,790 MW, which is an increment of about 5% compared to in 2015[3].

Lighting is one of the largest users of electrical energy in a typical commercial building that accounts for 5–15% of the total electric energy consumption[4]. Lighting represents almost 20% of global electricity consumption. This consumption is similar to the amount of electricity generated by nuclear power[5].

2. Literature Review

2.1 Energy Efficiency (Smart Energy)

In the past, during periods of fuel limited supplies, energy efficiency and conservation have been used to lower energy usage. Although these phrases are sometimes used interchangeably in policy talks, they have rather different meanings[6]. The ratio of energy intake to energy output is known as energy efficiency. It entails making the most of every energy unit produced or used. The term 'efficiency' is widely used not only in engineering, building design or product development but also in management, organization, economics and policy-making of all kinds[8]. In the context of JKR, energy efficiency (EE) refers to the effective use of energy throughout a building's operational lifecycle without compromising or sacrificing occupant comfort. Initially, EE may be accomplished by prudently implementing a number of energy-saving strategies during the building's design phase. Building energy in JKR-designed constructions is mostly related to electricity. This is frequently interpreted incorrectly as suggesting that electrical engineers are solely responsible for EE. In actuality, EE in buildings is connected to anything that ultimately results in the end-use of energy[7].

2.1.1 Benefits of Energy Efficiency in Smart Energy Systems

Energy-efficient technologies manifests with evidence that energy needs can be reduced without lowering the utility derived from the service. For example, automatic energy management systems, including smart thermostats and ambient light sensors, reduce unnecessary energy usage without sacrificing utility; they also provide real-time data to allow users to monitor and manage their energy consumption behavior. These technologies enable continuous optimization, thus improving operational efficiency and reducing costs for households, businesses, and industries alike[8].

2.2 Sensor Technologies for Ambient Light Detection

The most basic light sensors, like photoresistors, use substances like gallium arsenide or cadmium sulfide to measure light intensity by observing changes in resistance. More sophisticated devices, including photodiodes and phototransistors, perform better by more quickly and sensitively converting light into electrical current or voltage. By including amplifiers and analog-to-digital converters (ADCs), these parts can be further improved, allowing for improved resolution and noise reduction under a variety of illumination circumstances[9].

Recent innovations have led to the development of hybrid devices like the EL7900 and ISL29001 families, which combine photodiodes with transimpedance amplifiers and ADCs within a single package. These solutions address common challenges such as power consumption, signal noise, and sensitivity[9]. For instance, the EL7900 reduces noise and extends sensitivity from 1 lux to 100 kilolux, making it suitable for low-light applications.

2.2.1 Categories of Light Sensors

a. Photoelectric Devices (Photoemissive Sensors):
Photoelectric devices use the photoelectric effect to produce electricity as a function of light. These sensors are highly sensitive and efficient enough to be used for the applications which demand precision light detection. When photons hit their surfaces, these sensors will release some electrons, inducing electrical current [10].

b. Photoresistors (Photoconductors):
Photoresistors find their applications in many simple low-cost applications, namely: automatic night lights, energy-saving lamps, and street lighting systems. These sensors are low-cost, easy to use, and consume less energy to power, which is why they are affordable devices for normal daily use [11].

3. Methodology

This section provides a detailed explanation of each step of the technique that was used. If the right processes or procedures are taken, the system can be built as planned. The implementation of workflow on this project is following the objectives stated. It is crucial to select the acceptable model for the methodology in development of this application to ensure that the product produce functioning and can be used for the user. For this project, it consist of few steps to achieve the objective.

3.1 Proposed Design

The simulation circuit in Proteus was constructed to reflect the actual hardware design, incorporating the Arduino Uno microcontroller, Light Dependent Resistor (LDR), AC dimmer module, push button, and a 16x2 LCD. The Arduino was programmed using the Arduino IDE, and the compiled code was uploaded as a hex file into the simulation environment. The LDR was connected to a variable resistor to simulate different light intensities, and its analog readings were processed by the Arduino to control the firing angle of the TRIAC within the AC dimmer module. The dimmer was designed with zero-cross detection, and an oscilloscope was connected across the lamp to visualize waveform adjustments based on the brightness levels. Figure 1 shows the complete Proteus simulation of the smart energy-saving lamp system using an Arduino Uno microcontroller.

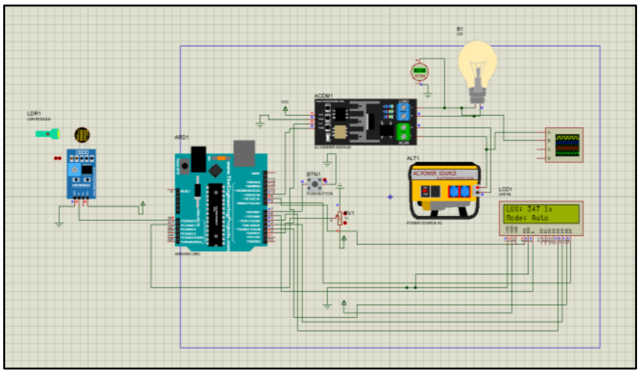

Fig. 1 *Sketching of project design in Proteus 8*

3.2 System Flowchart of Overall Project

The Arduino Uno microcontroller is used as the central control unit for this project. The software development process begins with designing a program to control the brightness of the lamp based on the analog values detected by the LDR sensor. The Arduino reads the sensor input through its analog pin and processes the data to determine the appropriate dimming level.

Programming is done using the Arduino IDE, which supports C/C++ language. The analog readings are mapped to timing values that determine the delay before triggering the AC dimmer module after each zero-crossing point of the AC signal. This delay controls the firing angle of the internal TRIAC within the dimmer module, thereby adjusting the brightness of the lamp. The code also ensures smooth transitions in brightness, preventing sudden changes that could cause discomfort. This software approach enables real-time responsiveness and efficient energy control based on ambient light conditions.

Programming is an essential aspect of making the system function correctly by controlling the outputs of the Arduino Uno, including the LCD display and the lamp. In this project, programming logic is used to read the ambient light data from the LDR sensor and control the AC dimmer module accordingly. The development of a flowchart is included to guide the software logic and ensure systematic implementation of the control process. The Arduino IDE, which utilizes the C/C++ programming language, was used for coding the system. Figure 2 illustrates the flowchart for the Arduino-based control logic.

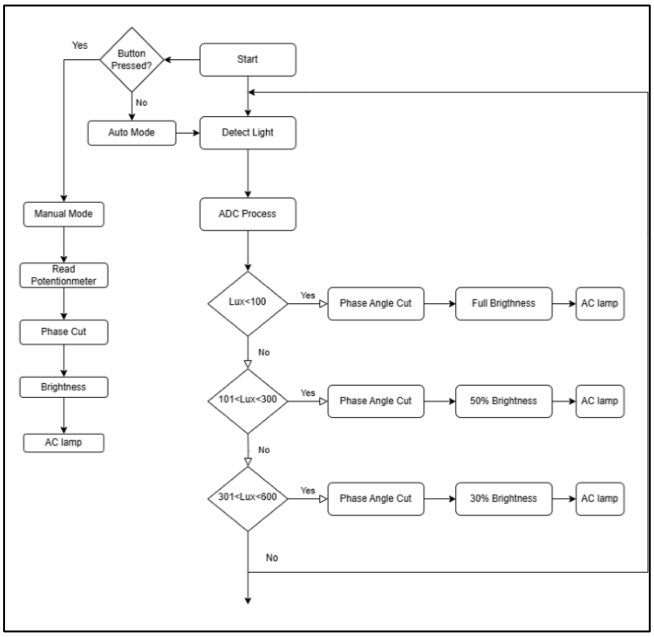

Fig. 2 *Flowchart of the project*

3.3 Design Connection and Testing in Auto Mode

When in automatic mode, the system uses the LDR to determine the ambient light levels. The analog signal is passed to the Arduino from the LDR. The Arduino determines the brightness level of the lamp by controlling the firing angle of the TRIAC in the AC dimmer module. Once the ambient light level drops in an environment, the system increases the brightness of the lamp in order to maintain the same illuminance level. As the ambient light increases, the system will proportionately decrease the I and potentially deactivate the lamp to help reduce energy usage. This automatic mode provides real-time environmental light, while also providing instantaneous adjustments of artificial light, depending on the amount of natural daylight around the area where the lamp works

3.4 Phase-Cut Dimming Technique

A phase-cut dimming method was used in this project to dim the 220-240V AC dimmable LED lamp. The system uses leading-edge phase-cut dimming, implemented via TRIAC control. In this method, the AC waveform is chopped at the leading edge after the zero-cross point. Phase-cut dimming relies on delaying the TRIAC firing, and thus delaying power to the lamp, after each zero-crossing, the amount of delay impacts how much power is delivered to the lamp; the longer the delay the less bright the lamp; so the shorter the delay the brighter the lamp. The Arduino Uno gathered this data by reading the ambient light levels from the LDR sensor and computing the correct delay. A zero-cross detection circuit was included in the hardware to ensure to keep the firing signal referenced to the AC waveform and to get around any issues with electrical noise or flicker. To safely turn on the TRIAC, its own MOC3021 opto-isolator is included in order to ensure safety galvanic isolation between the low-voltage Arduino control circuit and the 220V AC line. Overcurrent, voltage spike suppression and unresponsive triggered suppression are also implemented in the circuit design; a fuse rated at 400V, and 1A is also connected to provide overcurrent protection, an Resistor Capacitor snubber network is also connected across the TRIAC to suppress any undesirable peaks in the circuit, and where heat management is a problem, heat sinks are implemented to stabilize the circuit temperature during usage. Figure 3 shows a schematic diagram of the AC dimmer Module.

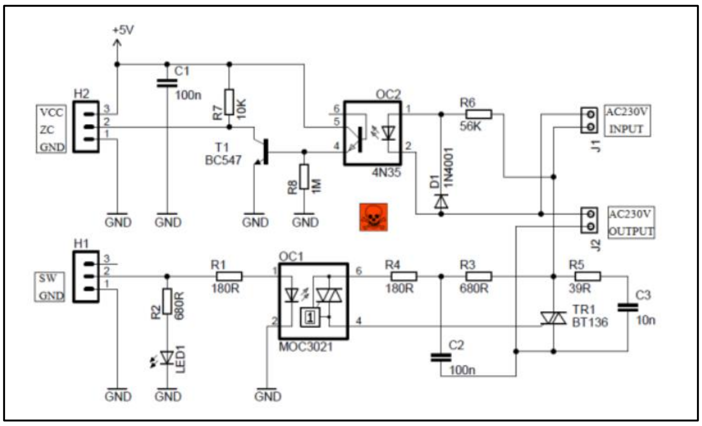

Fig. 3 *Schematic diagram of the AC dimmer module*

4. Result and Analysis

This section gives the experimental outcomes of the designed hybrid light dimmer system which is operated in both automatic (driven by LDR) and manual (driven by potentiometer) modes. The findings are centered on system reaction to ambient light, user control and the consequent reaction in the voltage output, current, power consumption and dimming performance. Mode-switching and LCD output are also appraised.

4.1 Table of Brightness Adjustment Logic

The Table 1 shows following logic was used to control brightness based on detected lux. The given table shows the way the system perceives the ambient light situation depending on the LDR readings (ADC values) and the way it correlates them with the brightness levels of the 14W LED lamp with the help of phase-angle control. Such mapping forms the basis of developing a system that is intelligent and efficient with respect to change in natural lighting.

Table 1 *Lamp Brightness following ambient light*

LDR ADC Value	Estimated Lux	Ambient Light Condition	TRIAC Delay (Dimming Value)	Lamp Brightness
900–1023	< 100 lx	Very Dark	5 (very early firing)	100% (Full)
700–899	100–300 lx	Dim Light	64	~50%
500–699	300–600 lx	Moderate Light	90	~30%

4.2 Measurements in Auto Mode

In order to test how well the system works in various lighting situations, the Smart Energy Saving Lamp was tested in Auto Mode whereby the LDR sensor is used to detect the ambient light levels. The system automatically (using phase-angle control) dims the 2x14W LED lamp through the AC dimmer module and regulates the brightness. Table 2 show the measurements under auto mode operation. The LDR provides an analog voltage mapped to ADC values (0–1023). To obtain lux, a calibration process was conducted by comparing LDR output with a lux meter.

Table 2 *Measurements under auto mode operation*

Ambient Light Condition	Estimated Lux	Voltage (V)	Current (A)	Power (W)
Very dark (night)	55 lx	225	0.116	28.2
Dim light (evening)	250 lx	155	0.098	16.2
Moderate light (daytime)	450 lx	120	0.078	10.1

Table 2 shows the system performance regarding varying ambient light levels in auto mode. As the ambient light is produced to be very dark (55 lx) and then varying to moderate daylight (450 lx), the voltage which is provided to the system changes to be 225 V which is then to 120 V. In turn, the current will also reduce to 0.078 A as opposed to 0.116 A. This leads to a power reduction of 28.2 watt to 10.1 watt. These findings prove that the system is effective in cutting power consumption in sunnier cases automatically controlling the intensity, which helps to achieve energy-saving goals and operate in an efficient manner.

Further tests to ascertain efficiency and uniformity of the Auto Mode dimming operation was conducted by operating the Smart Energy Saving Lamp system through five days consecutive operation, at three time intervals per day, in Morning, Afternoon and Night. This test was meant to note the behavior of the system in regard to the varying natural light, and how the system would adjust the brightness of the lamp.

Table 3 *5-day LDR-Based lamp control data (Auto Mode)*

Day	Time	Estimated Lux	Voltage Avg (V)	Current Avg(A)	Power Avg(W)	Energy (kWh)
Day 1	Morning	420 lx	155	0.070	10.85	0.043
	Afternoon	620 lx	120	0.060	7.20	0.029
	Night	55 lx	220	0.122	26.84	0.107
Day 2	Morning	430 lx	150	0.071	10.65	0.043
	Afternoon	640 lx	118	0.058	6.84	0.027
	Night	50 lx	222	0.120	26.64	0.107
Day 3	Morning	410 lx	158	0.073	11.53	0.046
	Afternoon	590 lx	125	0.063	7.875	0.032
	Night	60 lx	220	0.111	24.42	0.098
Day 4	Morning	450 lx	150	0.072	10.80	0.043
	Afternoon	660 lx	110	0.056	6.16	0.025
	Night	48 lx	220	0.118	25.96	0.104
Day 5	Morning	400 lx	160	0.068	10.88	0.044
	Afternoon	570 lx	130	0.061	7.93	0.032
	Night	58 lx	220	0.110	24.20	0.097

4.3 Normal Condition (14W LED Lamp Without Control System)

In order to provide a comparison level of investigating the effectiveness of the smart energy-saving lamp system, a regular 14W LED lamp was tested under normal operation without any automated or manual dimming access. This configuration is a traditional use case in which the lamp is operated at maximum brightness independent of ambient light or user desire. Table 4 shows the normal condition energy usage.

Table 4 *Normal condition energy usage (2x14W Lamp)*

Day	Voltage Avg (V)	Current Avg (A)	Power Avg (W)	Total Hours	Energy (kWh)
Day 1	220	0.128	28.16	12	0.337
Day 2	220	0.127	27.94	12	0.335
Day 3	219	0.128	28.03	12	0.336
Day 4	220	0.127	27.96	12	0.335
Day 5	220	0.129	28.38	12	0.341

4.4 Figures of Prototype

When the light is very low or in the night, the resistance of the LDR is high and thus a high value is obtained in the ADC. The Arduino will take that as a request to turn on all the light. a small value of TRIAC delay like 5 is employed, resulting in the TRIAC conducting very soon after each zero crossing, delivering approximately full-wave AC to the lamp. Consequently, the lamp lights at full power. Figure 4 show the full brightness lamp condition.

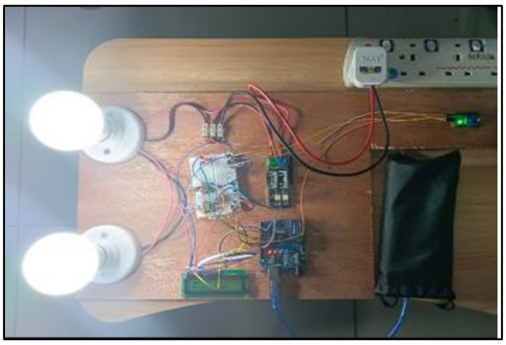

Fig. 4 *Full brightness lamp condition*

The LDR perceives moderate darkness in the early morning or evening hours, or in the shaded indoor locations. That system uses a medium delay (dimming value of approximately 64), and only a portion of the AC waveform is applied to the lamp. This would be 50% brightness which would consume less power and yet give sufficient light. Figure 5 shows the 50% brightness lamp condition.

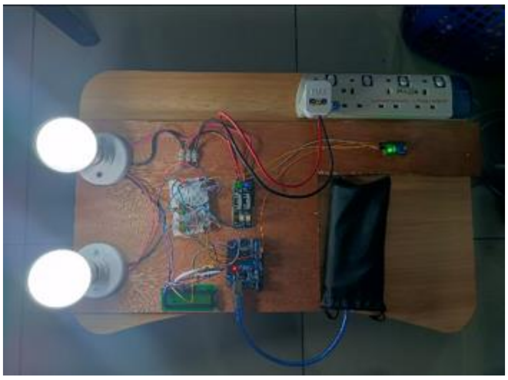

Fig. 5 *50% brightness lamp condition*

The system additionally decreases brightness in well-lit situations. An increased dimming delay in 90 presents reduced AC energy to the lamp. This dims the lamp power to 30% which in many cases is adequate and saves even more energy. Figure 6 shows the 30% brightness lamp condition.

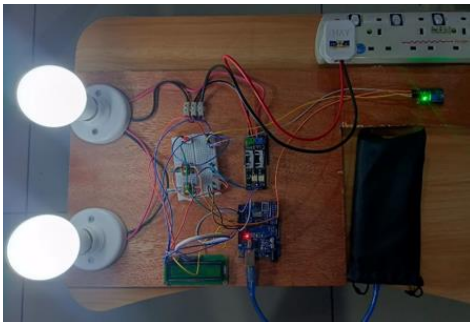

Fig. 6 *30% brightness lamp condition*

4.5 Comparison Between Normal Condition and Smart Energy Saving Lamp System

The Smart Lamp system shows an adaptable voltage and current profile depending on ambient lighting, in contrast to the normal lamp that operates at fixed brightness and power. Table 5 shows the comparison of electrical parameter normal condition and Smart energy Saving Lamp. All lux measurements include a ±5% tolerance, based on the LDR calibration curve. Power measurements were taken using a digital power meter with ±1% accuracy. Environmental factors such as temperature and reflection from surfaces may also introduce minor variations.

Table 5 *Comparison of electrical performance*

Parameter	Normal 14W LED Lamp	Smart Energy Saving Lamp
Operating Voltage (V)	Constant (220V)	Variable (110V – 220V)
Operating Current (A)	Constant (0.128 A)	0.056 A – 0.111A
Power Consumption (W)	Constant (28.0 W)	6.16 W – 25 W
Control Method	Manual switch	Auto (LDR) & Manual (Pot)
Brightness Adjustment	Fixed brightness	Variable brightness (phase-cut)

Although the system developed is analog and simple in terms of light detection and phase-cut dimming, the more advanced systems such as DALI and ZigBee based smart lighting offer addressability, remote control and programming. Such systems however demand increased cost and complexity. The offered lamp is cost-efficient, standalone solution that can be used in small scale, and can be later expanded in the direction of a wireless module adding capability. A notable issue with the leading-edge phase-cut dimming system is associated with the power quality influence. The AC waveform-chopping adds harmonic distortion and can cut the power factor (PF). In spite of the fact that in this project there was no measurement of Total Harmonic Distortion (THD) by means of measuring devices such as a power quality analyzer, a waveform snapshot captured on an oscilloscope was examined. Its future takes into consideration profiling or harmonic analysis tools and including filtering to reduce electrical noise.

4.6 Voltage Comparison

Voltage comparison graph indicates that the normal 2x14W lamp has a stable operating voltage of about 220V across the five days. This is normal since the lamp is simply wired to the AC supply without any dimmer in place. Refer to Figure 7 for the comparison.Conversely, the Smart Energy Saving Lamp system exhibits great voltage change, according to the amount of ambient light present. Under sunny day conditions the system will drop the voltage to around 110V 150V by chopping the AC waveform through phase angle control. At night time though the voltage is increased again to full 220V in order to permit the maximum brightness. This Smart dimming, results in this dynamic voltage adaptation, which in direct turn leads to energy savings.

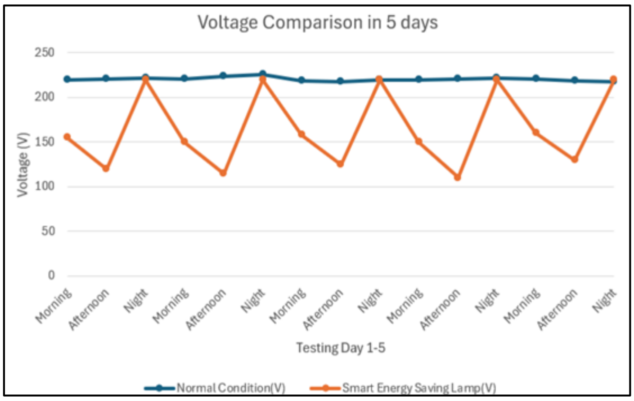

Fig. 7 *Voltage comparison*

4.7 Energy Consumption Comparison

Trends in energy consumption support the above results. The regular lamp uses 0.335 kWh every day, so during the 5 days test period, it will use 1.675 kWh. Comparatively, the Smart Lamp exhibits a dynamic energy pattern, consuming little energy during the day and much at night to give a cumulative consumption of 0.877 kWh within the 5 days period. Refer Figure 8 for comparison. This corresponds to a saving in energy of about 50 percent, indicating how the smart system has the potential to cut down the electric bills and contribute to sustainable use of energy without compromising on the control the users have or the quality of the lighting.

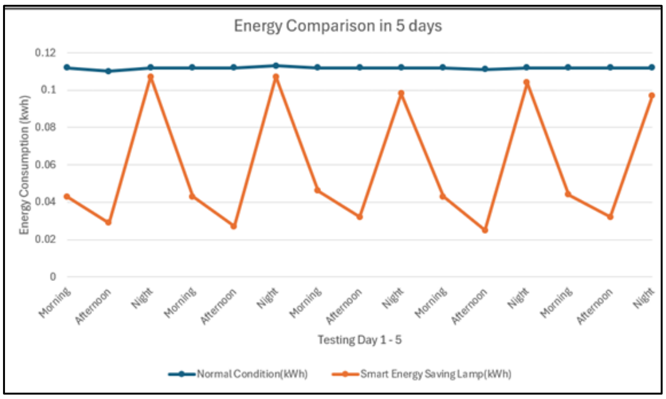

Fig. 8 *Energy comparison*

5. Conclusion

This project was mainly aimed at designing and realizing a Smart Energy Saving Lamp that can automatically regulates its brightness according to the amount of ambient light. The system successfully combined Light Dependent Resistor (LDR), Arduino Uno microcontroller, and TRIAC-based AC dimmer module to control a 14W LED lamp with phase-cut dimming method. Two control systems were realized, Auto Mode (controlled by LDR) and Manual Mode (controlled by a potentiometer). The Auto Mode was found to be suggestive and precise in real-time adjustment of the brightness according to the lux values in the surroundings whereas the Manual Mode offered users with adjustability. The system had additional usability features provided by LCD feedback and toggle switch control. By thorough testing and analysis it was proved that the smart system consumed a lot less power in comparison to a conventional 14W LED lamp which is being kept at constant maximum brightness. During 5 days of testing, Smart Energy Saving Lamp used about 45-50% less energy, which decisively confirmed its purposeful use in energy-efficient management. The waveform analysis also indicated that the implementation of the phase angle dimming was successful, and there were no pangs when passing through different levels of brightness.

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Conflict of Interest

Author declares that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to the paper as follows: study conception and design: Muhammad Abdul Azim Sukri, Nor Akmal Mohd Jamail; data collection: Muhammad Abdul Azim Sukri; analysis and interpretation of results: Muhammad Abdul Azim Sukri, Nor Akmal Mohd Jamail; draft manuscript preparation: Muhammad Abdul Azim Sukri, Nor Akmal Mohd Jamail, Qamarul Ezani Kamarudin;. All authors reviewed the results and approved the final version of the manuscript.

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