Faculty of Electrical Technology and Engineering

DESIGN AND DEVELOPMENT OF AN ENERGY EFFICIENT LED LIGHTING CONTROL SYSTEM USING ESP32

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Bachelor of Electrical Engineering Technology with Honours

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A project report submitted
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I approve that this Bachelor Degree Project 1 (PSM1) report entitled "Design and Development of an Energy-Efficient LED Lighting Control System Using ESP32" is sufficient for submission.

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Date : 6 January 2025

Signature :

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DEDICATION

First and foremost, I would like to praise and thanks Allah S.W.T that with His blessings and the strength granted, I am able to complete my final year project entitled "Design and Development of an Energy-Efficient LED Lighting Control System Using ESP32". These two semesters of completing this project were full with ups and downs that dependence onto Him is among others that able me persistent until the last phase.

Next , to my parents, Mr.Johar and Mrs. Lizah who are very supportive always kept me motivate and strengthen me in enduring these two semesters to complete my FYP.

My utmost gratitude goes to my supervisor, Ir Dr Zul Hasrizal Bin Bohari for her support and guidance throughout the execution of the project. His full commitment in supervising and giving motivation has been very significant to me in completing this project.

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ABSTRACT

Buildings use a lot of energy, with lighting being a major part of it. This project focuses on creating a smart LED lighting system using the ESP32 microcontroller to save energy and provide comfortable lighting. The project aims to design the circuit and control system for an energy-efficient LED lighting solution, to implement a prototype system integrating sensors and IoT functionalities and to analyze the system performance. The methodology uses PIR sensors to detect movement, LDR sensors to measure light, and Wi-Fi for remote control via Blynk Apps. It is programmed with Arduino IDE and tested using simulations and real-world experiments. In summary, this project successfully implemented energy-saving lighting system with potential future improvements like using solar power and adding more sensors.

ABSTRAK

Bangunan menggunakan banyak tenaga, dengan pencahayaan menjadi salah satu komponen utama. Projek ini memberi tumpuan kepada mencipta sistem pencahayaan LED pintar menggunakan mikropengawal ESP32 untuk menjimatkan tenaga dan menyediakan pencahayaan yang selesa. Matlamat projek ini adalah untuk mereka bentuk litar dan sistem kawalan bagi penyelesaian pencahayaan LED yang cekap tenaga, melaksanakan prototaip sistem yang mengintegrasikan sensor dan fungsi IoT, serta menganalisis prestasi sistem. Metodologi menggunakan sensor PIR untuk mengesan pergerakan, sensor LDR untuk mengukur cahaya, dan Wi-Fi untuk kawalan jauh melalui aplikasi Blynk. Sistem ini diprogramkan menggunakan Arduino IDE dan diuji melalui simulasi serta eksperimen dunia sebenar. Secara ringkas, projek ini berjaya melaksanakan sistem pencahayaan penjimatan tenaga dengan potensi penambahbaikan masa depan seperti penggunaan kuasa solar dan penambahan lebih banyak sensor.

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I am deeply indebted to my parents and family members for their unconditional love, prayers, and unwavering support, both emotionally and financially, during this journey. Their encouragement has been my source of strength in overcoming challenges. An honourable mention also goes to my friends and classmates for their motivation, understanding, and willingness to share their thoughts and ideas. Their support and collaboration have truly enriched my experience throughout this project.

"Last but not least, I wanna thank me. I wanna thank me for believing in me. I wanna thank me for doing all this hard work. I wanna thank me for having no days off. I wanna thank me for never quitting. I wanna thank me for always being a giver and tryna give more than I receive. I wanna thank me for tryna do more right than wrong. I wanna thank me for just being me at all times."

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LIST OF SYMBOLS

lm/W	-	Luminous flux per watt
K	-	Kelvin
W/m^2	-	Watts per square meter
Φ	-	Luminous flux per watt

LIST OF ABBREVIATIONS

LED	- Light emitting diode
ESP32	- A microcontroller with integrated Wi-Fi and Bluetooth functionalities
PIR	- Passive infrared
LDR	- Light dependent resistor
IoT	- Internet of things
IDE	- Integrated development environement
MS 1525	- Energy efficiency and use renewable energy for non-residential buidlings code of practice
UBBL	- Uniform building by-law
GBI	- Green building index
LPD	- Lighting power density
Wi-Fi	- Wireless fidelity
Blynk	- IoT platform for remote control
GSM	- Global system for mobile communication
HID	- High-intensity discharge
PCB	- Printed circuit board
UN SDG	- United nations sustainable development goal

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CHAPTER 1

INTRODUCTION

1.1 Background

With respect to various types of buildings, several lighting systems have been suggested that offer an outstanding level of energy savings performance. Lighting systems are thought to be a highly strong and useful technology that greatly increase energy savings [1]. Different types of lighting systems, designed for energy savings in buildings, have been proposed using different strategies applied to different types of buildings. In this way, different energy savings rates are achieved depending on the real scenario such a system is applied for and on conditions associated [2]. Thus, merging two adequate strategies, such as intelligent lighting with daylight, could be so useful to reduce much energy demand and enhance indoor comfort in terms of light, contributing to a sustainable building environment, as well as cost reduction [3], [4]. Energy, nowadays, happens to be the basis of any human activity, and is thus a serious concern. In both the residential and commercial sectors, a significant amount of electricity is used for lighting. Hence, effective conservation and management systems are required to minimize the use of energy. With a microcontroller, an automated energy-saving system can be designed [5].

Lighting systems in buildings, on one hand, are considered a huge consumer of energy and cause a lot of energy demand [6], [7]. That has been one of the issues paid much attention to by building energy management systems, focusing on energy savings, and building energy efficiency [8]. The Lighting system design could directly affect many 12 other building energy efficiency related factors in this setting [9]. For example, energy-efficient systems, lighting systems, intelligent lighting in smart homes, lighting costs, worker productivity in commercial buildings, and occupant comfort in residential structures are all greatly impacted by lighting systems.

1.2 Addressing Global Warming Through Weather Sensing Project

Combating climate change is multifaceted, and energy-efficient lighting is a powerful tool in this fight. Much of the emissions problem for buildings comes from the energy consumed for lighting. If enough buildings can be built with energy-efficient lighting solutions, carbon emissions can be drastically reduced. For example, energy-efficient systems, lighting systems, intelligent lighting in smart homes, lighting costs, worker productivity in commercial buildings, and occupant comfort in residential structures are all greatly impacted by lighting systems. It thus means that the amount of electricity required to run a building lighting system is drastically reduced, so the greenhouse gases associated with electricity generation are similarly reduced. Widespread implementation can have a cascading effect, leading to cleaner air, public health, and a sustainable future.

Next, these push for energy-efficient lighting is also driven by an ever-increasing focus on sustainability initiatives. Many organizations from corporations to local municipalities are developing ambitious goals to reduce their environmental impact. Energy efficiency in lighting presents an easily implementable and very influential approach in the quest to meet sustainability goals. Quite clearly, LED lighting combined with smart control systems reduces the energy consumption of a building, hence becoming a cornerstone of a comprehensive sustainability program. Furthermore, energy-efficient lighting can qualify for various tax credits and incentives, further bolstering its appeal for organizations striving for environmental responsibility alongside economic viability.

However, the growing awareness of environmental issues among building owners and building occupants plays a very important role in increasing energy efficiency in lighting. Increasingly, people are aware of their environmental footprint and are finding ways to live and work more sustainably. Energy-efficient lighting empowers individuals and organizations to make tangible contributions toward a greener future. In effect, a building owner switching to this technology consciously proves his commitment to being environmentally responsible and, hence, becomes part of a collective step toward the mitigation of climate change.

In short, energy-efficient lighting is a huge driver in mitigating climate change, supporting actions toward sustainability, and fostering environmental responsibility. Its high potential in reducing greenhouse gases and energy consumption makes it an essential tool in fighting for a cleaner and greener future. As awareness around environmental issues grows, and organizations place value on sustainability, energy-efficient lighting will continue to shed light on a better and more responsible tomorrow.

1.3 Problem Statement

Power According to estimates, buildings use more than 30% of the energy consumed worldwide, which means they contribute significantly to global carbon emissions [10]. The conventional types of lighting systems used in buildings are mostly inefficient and wasteful. The shift to more sustainable solutions is paramount to bring about climate change and reduce energy poverty affecting billions globally.

According to the Paris Agreement, Malaysia must cut its GDP's carbon emission intensity by 45% by 2030 [11]. With commercial and residential sectors together constituting over 70% of the country's electricity demand [12], a lot of opportunity lies in improving building energy performance. Retrofitting the aging infrastructure of the country with efficient alternatives will help in reducing the national energy consumption towards achieving sustainable development.

This project will develop an energy-efficient lighting control system by harnessing the potential of light-emitting diodes (LEDs) and an automation control strategy. An LED lamp uses less energy by up to 90% compared to an incandescent bulb and lasts 25 times longer [13]. Daylight harvesting and occupancy sensors allow lighting loads to switch on only when the space is inhabited and there is inadequate daylight. This adaptive approach optimizes electrical usage and demands put on the grid.

Healthier indoor environments can also be provided through minimizing artificial light when daylight is adequate for activities. The solution respects circadian rhythms and visual comfort, which is important for well-being and productivity according to regulations such as the Green Building Index. Reducing the building-scope 1 and 2 carbon footprint through such an intervention supports UN Sustainable Development Goal 7 (Affordable and Clean Energy) and Goal 13 (Climate Action).

Lastly, if implemented on a bigger scale throughout Malaysia, this project will play a huge role in reducing national energy consumption as based on calculations, carbon emissions are lowered to push the country closer to its sustainable development goals. The stakeholders who benefit from this include commercial building owners and tenants since operational expenses are lowered, and the impact on the environment is also lowered to serve society overall.

1.4 Project Objective

The primary goal is to accomplish the following goals:

a) To design the circuit and control system for an energy-efficient LED lighting solution.

b) To develop and implement a prototype system integrating sensors and IoT functionalities.

c) To analyze the system performance of control lighting system.

1.5 Scope of Project

The following is the project's scope:

a) Consists of two parts which are software and hardware: The hardware section used a main component ESP32 Wi-Fi module, LDR sensor and PIR sensor. Since software using Arduino IDE and Proteus.

b) PIR sensor as a sensor for detection.

c) The system can be controlled using the Blynk application.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This provides a detailed survey of the available research work concerning energy-efficient lighting systems for buildings, particularly in line with Arduino-based controls. The review considers the significance of energy efficiency globally, explores the various lighting technologies and their characteristics, and investigates the contribution that upgraded control systems may add toward the optimization of energy consumption. This review will be the basis of an energy-efficient LED lighting system powered by Arduino Uno that incorporates features such as occupancy sensing, daylight harvesting, and dimming control.

2.2 Energy Efficiency in Buildings

Buildings represent a huge part of global energy consumption and account for a great percentage of the earth's greenhouse gas emissions. Efficiency in the use of energy within buildings, therefore, contributes to countering climate change and reducing environmental impacts.

In Malaysia, several building codes and standards are established to ensure energy efficiency and optimal performance in lighting systems. These regulations and guidelines aim to reduce energy consumption, promote sustainability, and enhance the overall quality of building environments. Key codes and standards include.

Table 2.1 Summarizes relevant standards and codes

Standard/Code	Description	Minimum Requirement for LPD
MS1525:2019	Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings- Code of Practice.	Specifies the guidelines for energy efficiency in buildings: LPD limits for building types and spaces. For example, 10 W/m² for office spaces.
Uniform Building By-Law (UBBL) 1984	Amendments that focus on energy efficiency.	Mandates the use of energy-saving lighting fixtures and systems, often referring to MS 1525 standards to ensure consistency in energy efficiency requirements.
Green Building Index (GBI)	Green rating tool for buildings in Malaysia.	Provides credits for energy-efficient lighting design, encouraging the use of LED lighting, daylight harvesting, and lighting controls, referencing MS 1525.

2.2.1 Concept of Building Energy Efficiency

Energy efficiency of buildings encompasses all aspects of design, construction, and operation that provide for optimal reduction of energy consumption while the performance of such buildings is increased, or at least retained. A comprehensive review in Energy and Buildings elaborates on the very essence of energy-efficient buildings, including efficient systems of lighting, heating, and ventilation. This review emphasizes the role of integrated design approaches and advanced technologies in enhancing energy efficiency [14].

1. Lighting: Energy-efficient lighting, for example, LED light bulbs have a 25%–80% lower energy consumption and a 3–25 times longer lifespan than conventional incandescent lights. Savings were enhanced by the incorporation of automated controls, such as occupancy sensors, light dimmers, and timers [15].
2. Heating: Heating systems can be optimized through high-efficiency boilers, heat pumps, and insulation to reduce energy loss.
3. Ventilation: Ventilation responds to indoor air quality but costs energy for conditioning the incoming outdoor air. Energy recovery system rips energy from exhaust air that conditions the incoming fresh air. This approach saves energy.

2.3 Lighting Technologies

Light design is one of the best means for building energy efficiency while taking care of the occupant's well-being. It includes selecting adequate technology for lighting, choosing illuminance, color temperature, and CRI level, realizing appropriate strategies for energy use optimization.

2.3.1 Type of Lighting System

1. Fluorescent Lamps

A fluorescent lamp works by using the electric current to excite vaporized mercury that produces an ultraviolet light that makes the lamp glow with the aid of a phosphor coating inside [16]. Fluorescent lamps are much more effective compared to incandescent lamps, and they can be used for much longer, which can be anywhere between 10,000 to 20,000 hours. The benefits of using fluorescent lighting are that they are more effective, and they can last longer than incandescent bulbs; hence, they are inexpensive in the long run. However, they contain mercury which requires special procedures for disposal. It poses environmental and health risks if not properly disposed of.

2. Incandescent Light Bulbs

Incandescent bulbs light through heating up a filament until it becomes incandescent; they maintain the attribute of warm light and a high color-rendering index of about 100. They give very good color rendition and are low cost initially, making them popular for many applications. However, they are very inefficient, with much of the energy lost as heat and not light, with a very short life, about 1,000 hours. This makes them very inefficient, resulting in high operational costs and frequent replacements.

3. High-Intensity Discharge (HID) Lamps

High-Intensity Discharge (HID) lamps, which include metal halide, high-pressure sodium, and mercury vapor lamps, use light from an electric arc passing through gases. These lamps have high efficacy and a long-life span, up to 24,000 hours, making them ideal for outdoor use and for lighting up large areas [17]. Despite their efficiency and long life, they have disadvantages such as a slow warm-up time and poor color rendition. Last, their bulkiness in design tends to be a limitation for certain applications.

2.3.2 Light-Emitting Diodes Lighting Systems (LEDs)

Light is produced in LEDs when a current is sent across a semiconductor. LEDs are highly efficient, with long operational times of up to 50,000 hours, and are available in a range of colors and color temperatures [18]. The advantages associated with LEDs are their energy efficiency, longevity, instant start-up time, environmental friendliness, and versatility. However, compared to other traditional technologies for lighting, they are expensive. Light-emitting diodes (LEDs) have become a favorite choice for many due to their impressive efficiency, long lifespan, and versatility. Unlike traditional lighting options, LEDs can consume up to 80% less energy, making them a more sustainable choice for our homes and businesses. Additionally, they offer advanced control features, allowing users to easily adjust brightness and even change colors to create the perfect ambiance for any occasion. This combination of energy savings and flexibility makes LEDs an appealing option for anyone looking to enhance their lighting experience while being mindful of energy consumption [19].

2.3.3 Lighting Design Principles

Table 2.2 Types of aspects lighting design principles

Aspects	Descriptions
Daylighting Strategies	Daylighting is the process of lighting the interior using natural light by placing strategically positioned windows, skylights, and light shelves to

	maximize the entry of natural light into an enclosed space and distribute it with the least glare and heat gain. Proper daylighting can help reduce the demand for artificial lighting and hence saves energy.
Task Lighting	Task lighting is directed specifically at those areas where activities like reading, cooking, or working take place. It is designed in a way to ensure high illuminance levels in performance to decrease eye strain and increase productivity.

Table 2.3 shows that daylighting Strategies maximize the use of natural light indoors with the proper placement of windows and skylights, which lower glare and heat gain and diminish the need for artificial lighting. Task Lighting focuses on high levels of illumination on certain areas like working areas and reading corners to increase productivity and reduce the strain on the eyes.

2.4 Control Strategies in Lighting Systems

Since the Internet of Things (IoT) and advanced sensor technologies have been integrated, control strategies for lighting systems have undergone tremendous change. Enhancing user comfort, increasing energy efficiency, and giving users more control over lighting conditions all depend on these tactics.

2.4.1 Sensor Integration

The usage of Passive Infrared (PIR) sensors is one of the essential elements of contemporary lighting control. By detecting the infrared radiation that people emit, these sensors determine occupancy, enabling the lighting system to turn on only when people are in the room. In addition to saving energy by avoiding superfluous illumination, this occupancy-based management prolongs the life of lighting fixtures by lowering their operating hours. Furthermore, to modify illumination intensity according to ambient light levels, Light-Dependent Resistors (LDRs) are used. LDRs may automatically reduce or brighten artificial lighting based on the amount of available natural light, ensuring that places are well-lit while using the least amount of energy possible. By adjusting to variations in natural light caused by the weather or the time of day, this dynamic adjustment improves occupant comfort by maintaining ideal lighting levels throughout the day.

2.4.2 Automation and IoT Integration

Firstly, the management of lighting systems has been completely transformed by IoT breakthroughs. Through smartphone applications, consumers may remotely control and keep an eye on their lighting systems in real time via platforms such as Blynk. This feature offers consumers unmatched ease and flexibility by enabling them to change lighting settings remotely. For example, users can use their smartphones to make schedules, adjust brightness levels, and turn lights on or off.

Because users can respond to their current requirements and preferences without being physically present, this integration not only improves the user experience but also makes energy management more efficient. Additionally, data on usage trends can be gathered via IoT-enabled lighting systems and analysed to further optimise energy use. By lowering overall energy demand, sensor integration and IoT capabilities together offer a major advancement in the development of intelligent, energy-efficient lighting solutions that support contemporary lifestyles and eventually advance sustainability goals.

2.5 Existing Research on Energy Efficiency Lighting System

To control home electrical appliances remotely via Short Message Service, Home Automation using Global System for mobile communication is introduced by Ihedioha and Eneh. The system indicates automation of electrical devices used in daily tasks at home. It controls major electrical devices such as lights, fans and more advanced tasks such as viewing the house interiors and extension for surveillance purposes remotely. The Home Automation system also offers a comfortable, convenient, and safe environment to its employees. The users can control their home by switching on/off the electrical appliances. The Home Automation system also includes various sensors like temperature sensors, fire alarm systems, motion detectors, and locking systems. The main objective of this project is to design a GSM-based distributed control application platform for industrial automation and home appliances. Ihedioha and Eneh use a fully assembled and working Nexys2 circuit board to implement this system.

Piyare and Tazil propose Bluetooth based Home Automation system via smart phone to provide greater mobility and convenience where the system is low cost and secure. Wireless communication is used to communicate between smart phone and home appliances. The Arduino BT board relates to the appliances. Moreover, other appliances can also be connected to the system with minor adjustment to the system. The smart phone code is written in python because it's portable and can run widely mobile using Symbica Operating System Platform. The system requires the users to enter passwords for the Arduino BT and smart phone in order to access the home electrical appliances. This will ensure protection from unauthorized users. [20].

In developing Automation lighting for the efficient use of energy in a classroom situation, Arduino is used as a controller. The system divides the classroom into grids. Depending on whether people are present, the relay control will change the lighting in a specific region of the classroom. This system employs voice commands to control the lighting through Bluetooth and Android mobile system apps. The system will enable remote command execution and mobility. Every classroom entry has a PIR sensor installed so that it can identify when a person enters. Applications for smartphones are required in order to control the lighting using voice commands transmitted through Bluetooth [21].

Marimuthu has talked about his research on Bluetooth-enabled home automation. Marimuthu covered a number of methods, including how many devices are controlled, how the controller is used, and how home appliances are regulated. He claims that wired and wireless technology are the two forms of communication that should be used in home automation systems. We connected all of the appliances using the electrical wiring and cables that were already in place for wired technology. The electrical wires or cables in a power lines system carry a signal across a medium. Three GSM devices, which operate in the frequency range of 380–1989 MHz, are included for wireless technology to facilitate communication between two or more devices. Both Bluetooth and XBEEE modules have a range of 0–10 meters and 0-100 km, respectively. [22].

A proposed automation system in Nupur, Payal, and Kajal would allow a variety of electrical appliances, including fans, lights, air conditioners, and more, to be controlled via an Android smartphone app that connects to a Bluegiga Bluetooth module. This approach is safe and affordable for smartphones. The Arduino BT board is used to connect the electrical appliances. Electrical appliances and smartphones are able to communicate wirelessly. to provide adequate compatibility with high voltage and current. Relays and Arduino BT boards are used to connect various workplace and residential gadgets. The appliances will receive commands from the smartphone app to turn on or off. Additionally, a feedback circuit has been put in place to show the appliances' current states upon receiving commands from a smartphone, either in the on or off condition [23].

Md Abdullah Al Ahassan are propose a Smart Home Automation based on voice command using smart phone. This system is facilitated elderly and disable persons that live alone. Besides that, voice instruction is a very secure implementation for elderly and disabled person. Using voice command can control the light switches, fans and other electrical appliances in home or office. For the system successfully functioning, the user is an Arduino Operating System smart phone and a control signal. Arduino Uno microcontroller which is used to recognize and process user voice command and control the switch of electrical appliances is included in the control circuit. The system includes a base station and a remote station. Each station has different functions. For the base station, a Bluetooth device is connected. The microcontroller will only detect a specific voice comment from the Bluetooth device to receive it as input command. For the remote station, the microcontroller will receive a digital signal from the transmitter of the base station via wireless. Furthermore, the system is user friendly and very easy to use[24].

Subhankar Chattoraj proposes Smart Home Automation based on different sensors and Arduino as the master controller. The main objective of the project is to implement an integrated home automation and security system. An Arduino is used to control the sensors and actuators. Arduino can also send notifications if the system detects an unusual condition. The system uses voice recognition schema to enable users to use voice instruction to control home electrical appliances. For hardware part of the system consists of Arduino Uno. Light Dependent Resistor (LDR), temperature sensor, smoke sensor and humidity sensor. The Arduino will control the turning on or off switches and at the same time maintain all the sensors in real-time. Besides that, Arduino is required to control the speed of fans, switching the LED and turning on or off the alarm. The system has two modes, which is automated mode and self-automated mode. The automated mode using voice command to control appliances and the self-automated mode control the appliances automatically with the absence of the user commands. This project is cost-efficient because it uses free open-source software such as Arduino platform [25].

Adewale A.A., Isaac Samuel, Awelwa A. A, and Dike U.Ike proposed an project about Design and Development of a Microcontroller Based Automatic Switch for Home Appliances. Based on their studies, home automation is when all electrical devices in a household relate to each other and act as one unit to perform a task without human intervention. For this project, several devices are implemented to enable detection of presence and activity of occupants in a room and switch ON and OFF the light automatically based on light intensity of the room and control the ON and OFF the fans based on certain temperature of the room. The system consists of various types of components, such as infrared sensors, temperature sensors, power supply, main controller, fan controller and opto-triac controlled switch [26].

2.6 Summary

The existing literature related to the development of an ESP32-based energy-efficient lighting system is reviewed in this chapter. The review starts with the importance of energy efficiency in buildings and presents how the lighting system can play a vital role in reducing the overall energy consumption of a building. In this chapter, different lighting technologies have been reviewed, and the advantages of LED lighting are discussed in terms of energy efficiency, lifetime, and flexibility. It also discusses some related research in Arduino-based home automation systems, which are based on sensors, for instance, PIR and LDR, wireless communication, and some of the control strategies used like occupancy sensing and dimming. These works illustrate the potential of Arduino in implementing innovative and energy-efficient lighting control solutions. Thus, the provided literature review forms a solid foundation for the proposed project by pointing out some research areas; besides, it helps inform the design and development of an energy-efficient LED lighting system.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The research method that will be used in by researching on the subject, learning the ropes of the work needed to be done and making a working prototype that can satisfy the requirement. The aim of this project is to build a working prototype for an Energy Efficiency Lighting System in Buildings using ESP32.

3.2 Methodology

This methodology included a study of requirements and analysis through literature review to understand the needs and requirements for an automated lighting system. A system design was developed including a block diagram to illustrate overall workflow and interactions between components and a flowchart depicting the logical program flow. Suitable hardware components including the microcontroller, ESP32 Wi-Fi module, LDR, and PIR sensors were selected based on functional requirements. Software programming using the Arduino IDE defined the logic and controls by integrating the various components through sensor readings and output signals. The program code was completed, followed by testing to verify correct functionality by examining system responses to different inputs to validate design requirements were met. Documentation of the methodology, system design, component details, program flow, and results was accomplished in the project report to systematically develop the automated lighting control system through analytical study, modular design, and rigorous testing processes.

3.3 Block Diagram

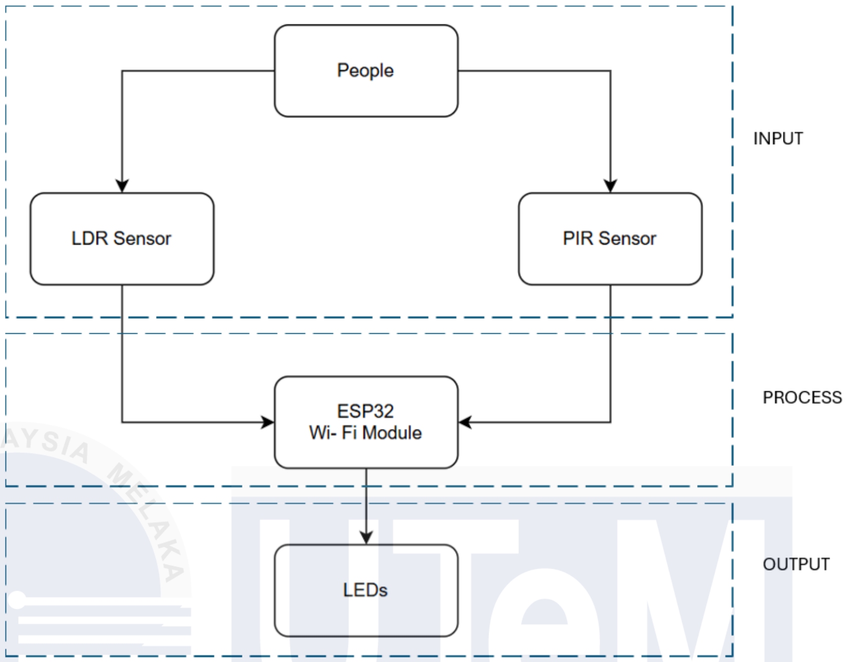


Figure 3.1 Block diagram of control lighting system

The block diagram shows the flow in which the ESP32 Wi-Fi module works as a central control unit for executing programmed logic. It reads inputs from LDR and PIR sensors at intervals set by a schedule and compares their ambient light and motion detection to pre-defined thresholds for determining whether lighting is required or not. If the given conditions are met, the ESP32 sends trigger signals to turn on the connected lighting load (LEDs). Otherwise, the lighting will not be active.

Moreover, the ESP32 allows for connectivity to the Blynk mobile application, which can be used to visualize the status of the system and allow remote operation over Wi-Fi. This integrated hardware and software solution ensures energy-efficient lighting management through automatic adjustment of the LEDs based on ambient light and occupancy conditions sensed by the LDR and PIR sensors, respectively.

3.4 Flowchart

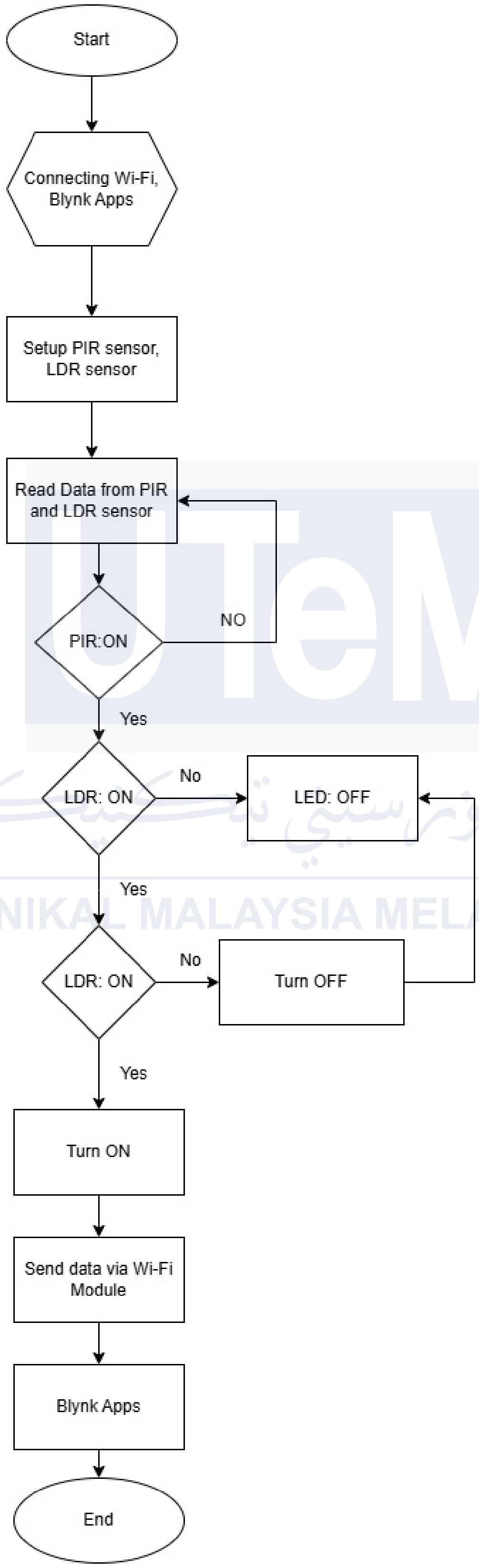


Figure 3.2 Flowchart of Light Control

The flowchart in Figure 3.2 shows the program operation of a smart lighting system. The hardware listed here is an ESP32 microcontroller, a PIR sensor for motion detection, an LDR sensor for light-level checking, and two LEDs for output. It starts with the Start symbol. The ESP32 gets initialized basically, connecting to Wi-Fi and setting up communication with the Blynk app. After booting up, the PIR and LDR sensors, as well as the LEDs, are ready for use.

The system continuously reads values from the PIR and LDR sensors. The PIR sensor detects motion, while the LDR sensor measures brightness. If the LDR value is below the standard of 100 in low light, the system turns the LEDs ON and notifies the Blynk app. If the light is sufficient, the LEDs turn OFF, and the app status is updated accordingly.

The system uses an ambient light sensor to monitor light levels. It checks for commands from the Blynk app, such as turning the LED ON or OFF. If no commands are received, it continues reading sensor values. This process repeats in a loop until the system is powered off. The flowchart shows how sensor data and user commands work together to control the lighting dynamically.

3.5 Software

3.5.1 Arduino IDE

This system is operated by the Arduino IDE (Integrated Development Environment) software. The Arduino UNO board is programmed and compiled using this software. As a result, the Arduino board, sensor devices, and other circuits are all controlled by the Arduino software commands.

3.5.2 Proteus

Proteus circuit simulation software will be used to design and test the electrical circuit virtually before implementation. It allows simulating microcontroller code execution along with the supporting circuit to debug and optimize the overall system design.

3.5.3 BLYNK Application

A Blynk application was developed to remotely control and monitor the lighting system. Blynk is an Internet of Things (IoT) platform that allows connecting Arduino, Raspberry Pi and other hardware to the cloud. It provides an easy-to-build graphical interface for an iOS or Android device.

3.6 Circuit Simulations using Proteus

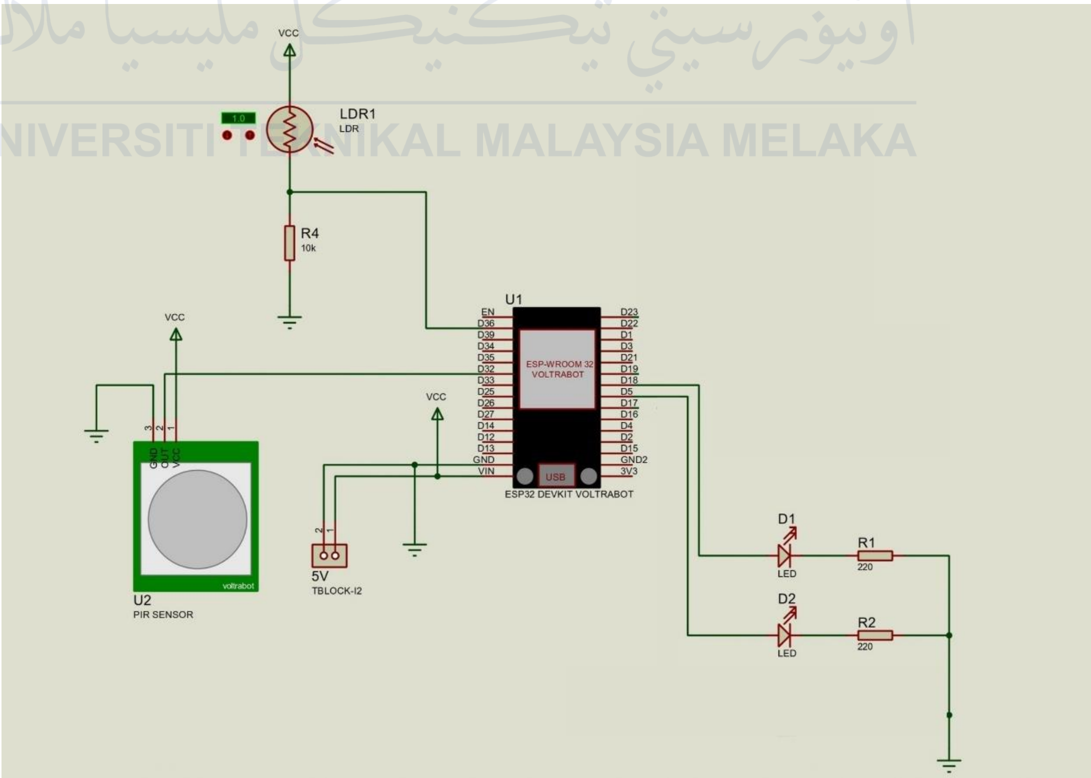


Figure 3.3 Schematic Diagram of Lighting Control

Table 3.1 List of components for schematic diagram

Component	Quantity
ESP32	1
Photoresistor	1
220Ω Resistor	2
PIR Sensor	1
LED	2

Table 3.2 Connections for the PIR sensor, LDR sensor, and LED

Components	Pin	Connected To
PIR Sensor	VCC	VIN
	GND	GND
	Output	ESP32 D32
LDR Sensor	VCC	VIN
	D0	ESP32 D34
	GND	GND
LED	LED (PIR)	ESP32 D18
	LED (LDR)	ESP32 D5

The connections needed to build up the circuit as specified in code and instructions are compiled in this table.

3.7 Equipment

Several hardware elements that can be utilized for processing, sensing, and controlling appliances make up the automatic room light system. These hardware elements are covered in the section below.

3.7.1 ESP32 Wi-Fi module

In order to enable wireless connectivity and remote control or monitoring, an ESP32 Wi-Fi module will be used. The ESP32 is a System on Chip SoC with integrated Wi-Fi and Bluetooth capabilities designed for IoT applications. It will enable the system to connect to a Wi-Fi network and exchange data over the Internet. In addition, the ESP32 supports dual-core processing, has extremely low power consumption, and provides a rich variety of peripherals, making it an efficient and versatile solution for the implementation of wireless connectivity and remote monitoring/control functionalities.

Figure 3.4 ESP32 Wi-Fi module

The ESP32 module processing power, wireless connectivity options, memory configurations, GPIO pins, analog-to-digital conversion capabilities, and low-power consumption make it a compelling choice for developers creating innovative and efficient

38 IoT devices. Its affordability, ease of use, versatility, and growing community support further solidify its position as a leading microcontroller platform for the ever-evolving Internet of Things landscape.

The ESP32 microcontroller is particularly well-suited due to its ultra-low-power Consumption capabilities are enhanced with mechanisms such as dynamic power scaling, multiple power modes, and fine-grained clock gating. These mechanisms make it possible to optimize the ESP32 for low power consumption in applications like sensor hubs, where data acquisition is needed only in response to specific events.

Further power savings can be achieved by operating at a low-duty cycle. In addition, the output of the power amplifier can also be calibrated to make a tradeoff between power consumption, data rate, and communication distance. In addition to its low-power characteristic, ESP32 is highly integrated, and about 20 external components are needed for Wi-Fi and Bluetooth IoT applications. This is because ESP32 integrates some components on-chip, including antenna switch, RF balun, power amplifier, low noise receive amplifier, and filters. This integration leads to a smaller required footprint for the Printed Circuit Board (PCB).

Further, ESP32 includes a single-chip fully integrated radio along with a baseband that uses CMOS technology and advanced calibration circuits. These features eliminate the need for external circuit adjustments and compensate for changes in environmental conditions. Thus, they reduce the need for expensive and highly specialized Wi-Fi test equipment in the mass production of ESP32-based products [27], [28]

3.7.2 Light Dependent Resistor Sensor

The LDR sensor will be used to detect changes in light intensity so that the LED lighting system can be automatically adjusted based on the ambient light level A LDR or 44 light dependent resistor is a component whose resistance decreases with increasing incident light intensity.

The LDR sensor that will be used is a CADJ013031 light sensor module. It has a resistance range of 10KΩ in darkness to 100Ω in bright light. The sensor will be mounted near the windows to measure the natural light level. It will be connected to an analog input pin on the microcontroller.

Figure 3.5 LDR sensor module [29]

Table 3.3 LDR sensor pin

LDR Sensor Pin	**Description**
VCC	Power supply input for the LDR sensor module.
GND	Ground connection for the LDR sensor module.
OUT	Output pin providing the varying voltage signal corresponding to the detected light intensity.

3.7.3 PIR Sensor

Figure 3.6 PIR sensor

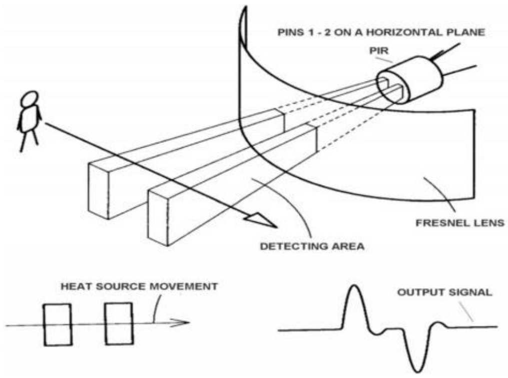


Figure 3.7 PIR sensor coverage area

PIR sensor covered with Fresnel lens where the actual sensor inside used for detection. The low cost and high coverage area up to 6m has two slot that made from special material with The sensor is highly sensitive to infrared radiation. Both slots, in an idle state, exhibit the same levels of infrared detection. that the ambient quantity radiated by the room or the wall. When there is warm body crossed within the designated coverage area, as illustrated in Figure 3.7 the sensor detected the infrared emission from the body until the body leaves the sensing area.

3.7.4 Light Emitting Diode (LED)

An LED is a semiconductor device that emits light when electric current passes through it. Because of the higher energy efficiency, longer service life, and less environmental influence compared to the traditional incandescent and fluorescent lamp, LEDs are widely used in modern lighting applications.

Figure 3.8 LED

In this project, LEDs are used as the primary lighting source. Their operation is controlled by the ESP32, which processes inputs from the LDR and PIR sensors to determine when lighting is required. LEDs have low power consumption and minimal heat generation, hence they are the best option for energy-efficient and sustainable lighting solutions. The brightness of the LEDs can also be adjusted if needed, allowing for further optimization of energy usage.

3.8 Preliminary Results

Design and Development of an Energy Efficient LED Lighting Control System using ESP32
Name: Nur Aqilah Binti Mohd Johar
Id Matric: B082110348

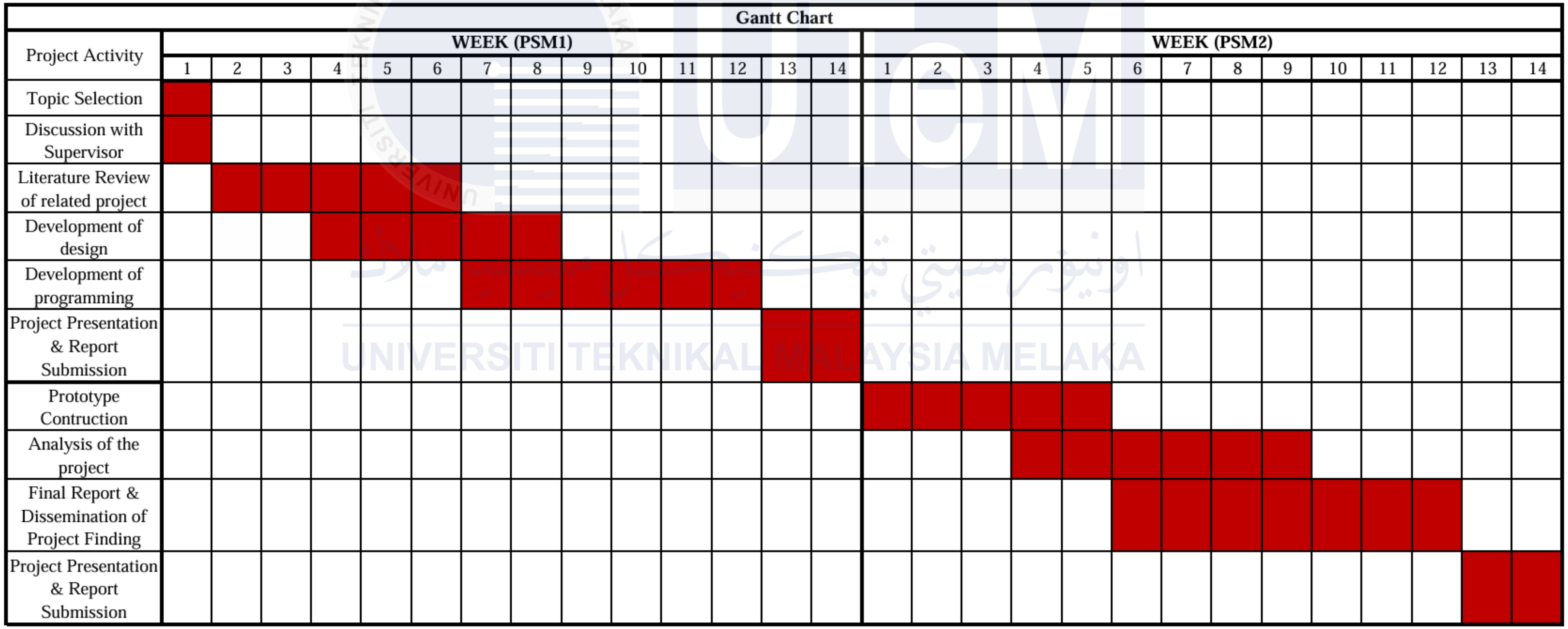


Figure 3.9 Gantt Chart PSM-1 & 2

3.9 Summary

This chapter defines the approach and steps followed to achieve the objectives of the project, making considerations for both hardware and software. A block diagram illustrates the flow of the system and interaction of the components, supported by a flowchart that details the flow of the processes. The equipment information will include the microcontroller, ESP32 Wi-Fi module, light and occupancy sensors (PIR and LDR), relay module, and other components used. The software tools are the Arduino IDE in which the programs are written, the Proteus software used in the simulation and testing, and any other useful application software. Next chapter will discuss the expected results of a smart lighting system, the project combines an Arduino with an LDR (light dependent resistor) and PIR (passive infrared) sensors.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents a smart lighting system, the project combines an ESP32 with an LDR (light dependent resistor) and PIR (passive infrared) sensors. It describes the results of the system performance under various conditions of lighting and motion detection. The system's behavior will be analyzed based on the four defined scenarios that show its functionality and efficiency in managing energy consumption while ensuring security. Results are supported with graphical representations that may lead to a clearer understanding of the performance of the system.

4.2 Daytime High Level

The high-level analysis of this system during daytime focuses on its performance under bright ambient light. In this mode, the system shows how it efficiently manages energy while ensuring adequate lighting at the same time. The level of ambient light is sensed with the help of a Light-Dependent Resistor (LDR), and a corresponding signal influences the system action. By looking at the LDR values, we can deduce how the system responds in bright conditions about LED activation and PIR sensor motion detection. This section will detail the LDR readings, the corresponding system responses, and the implications of PIR sensor activity for bright light scenarios.

4.2.1 LDR Value and System Behavior

1. LDR Value: Analog read from the LDR exceeds 800 (bright conditions).
2. System Response: Both LED remain OFF, that because has sufficient ambient light, ensuring energy efficiency.
3. PIR Sensor Activity: Motion detection is irrelevant as LEDs remain OFF in bright light.

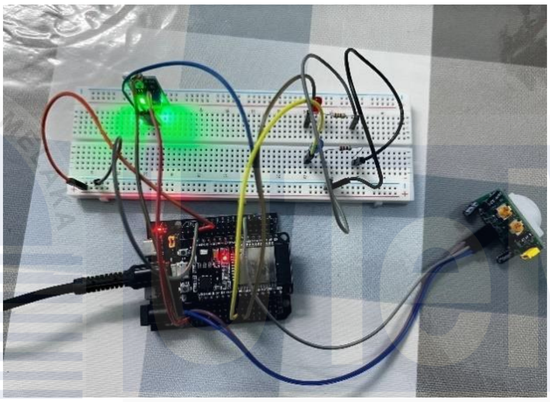


Figure 4.1 Daytime

4.2.2 Analysis in Arduino IDE

This section deals with data analysis from the smart lighting system using the Arduino IDE. It focuses on real-time monitoring of LDR and PIR sensor readings under bright light conditions. This evaluation is very important in understanding the energy optimization and lighting management capabilities of the system.

```
LDR Value: 53 | PIR Value: 0
LDR Value: 45 | PIR Value: 0
LDR Value: 49 | PIR Value: 0
LDR Value: 51 | PIR Value: 0
LDR Value: 59 | PIR Value: 0
LDR Value: 65 | PIR Value: 0
LDR Value: 49 | PIR Value: 0
LDR Value: 54 | PIR Value: 0
LDR Value: 50 | PIR Value: 0
LDR Value: 53 | PIR Value: 0
```

Figure 4.2 Serial Monitor in IDE

The data in figure 4.2, from 45 to 65 for the LDR, shows different ambient light conditions, but the PIR sensor consistently keeps 0, indicating there is no motion. This can be interpreted to mean that at this moment, the system is in a low-power state as no motion has been detected and is most likely powered by a microcontroller such as Arduino. This energy-efficient approach ensures that the system only switches into action, when necessary, thus conserving battery life and reducing environmental impact.

4.2.3 Graphical Representation in Daytime

The section shows a graphical representation of ambient light levels based on data gathered by using Lux meter apps. This data visualization may show light intensities varied across the period under study; hence, clearly explaining how changes in ambient conditions may significantly alter LDR readings is highly applicable. Such graphs are, therefore, essential to understand how variations in available natural lighting correlated with the functionality of the intelligent lighting system being developed.

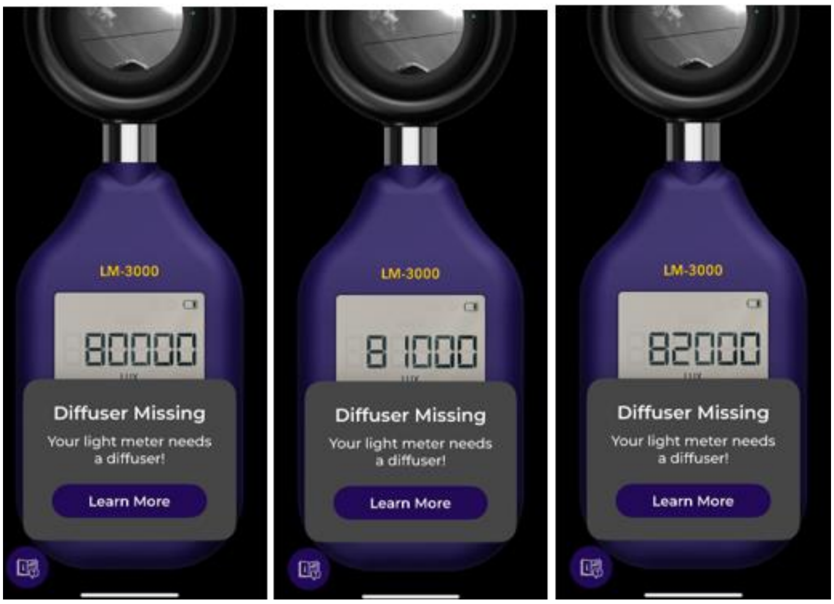


Figure 4.3 Lux Meter Apps in Sunlight

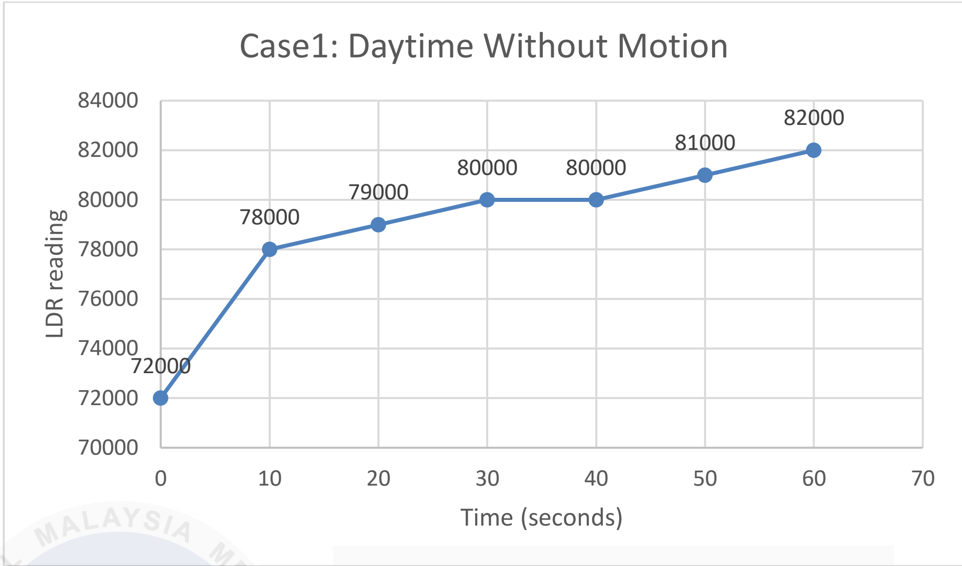


Figure 4.4 Graph for LDR reading vs. Time (s)

The figure 4.4 shows that the lux measurements by lux apps taken over 60 seconds indicate a gradual increase in sunlight intensity which displays LDR reading with respect to time. The LDR values starting at 72,000 lux and reaching 82,000 lux, with stabilization around 80,000 lux indicating the strong light levels typical during the daytime. Since this case does not feature any kind of motion, there are no abrupt changes or activities. This information is important in proving that a system, under these conditions of strong daylight, duly detects such an instance and hence does not activate the LEDs, thereby saving energy.

4.3 Nightime Without Motion (Low Light Level)

This section deals with the performance of the smart lighting system during nighttime under low light conditions when no motion is detected. It focuses on the LDR readings, system responses, and PIR sensor activity in relation to how the system saves energy by remaining in an off state in the absence of light and motion. This analysis is very important in understanding the efficiency of the system in terms of handling power at dim conditions.

4.3.1 LDR Value and System Behavior

1. LDR Value: Reas from the LDR is below 200 (dim conditions).
2. System Response
    - LED 1 (PIR): OFF, no motion detected.
    - LED 2 (LDR): OFF, energy savings in low light with no activity.
3. PIR Sensor Activity: No motion detected.

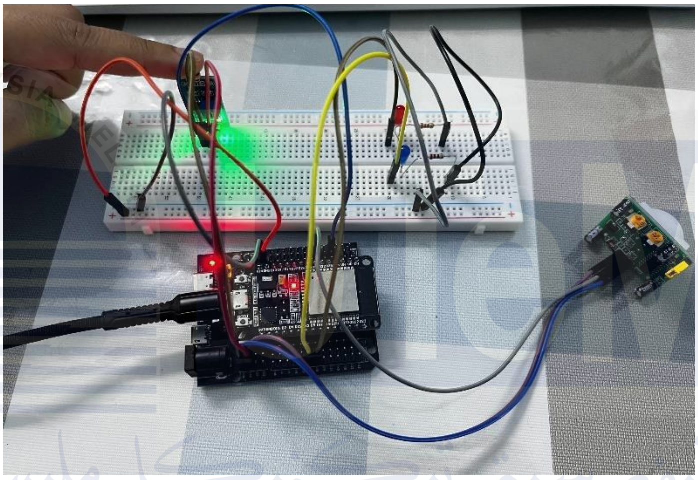


Figure 4.5 No Motion in Nighttime

4.3.2 Analysis in Arduino IDE

In this subsection, data from the smart lighting system is analyzed using the Arduino IDE during nighttime without motion. By monitoring the LDR readings and PIR sensor outputs, the behavior of the system can be observed when light intensity is low. The analysis will expose how well the system really goes into a low-power state and thus optimizes energy consumption when there is no activity.

```
LDR Value: 4095 | PIR Value: 0
LDR Value: 4095 | PIR Value: 0
LDR Value: 4095 | PIR Value: 0
LDR Value: 4095 | PIR Value: 0
LDR Value: 4095 | PIR Value: 0
```

Figure 4.6 Serial Monitor in IDE

The steady-state LDR value of 4095 indicates very low light levels or complete darkness. With the constant 0s coming from the PIR sensors, indicating no motion, it can be interpreted that the system is currently in dark conditions and is in an inactive state. This situation presents a great opportunity to improve energy efficiency by reducing sensor polling frequency or using deeper sleep modes. These changes can help save power and extend battery life, allowing the system to run longer between charges.

4.3.3 Graphical Representation in Nighttime Without Motion

This section shows graphs of ambient light levels from Lux meter apps at night without motion. The data illustrates LDR readings in low light, showing the system's response to dim environments. These graphs are key for understanding the smart lighting system's energy-saving strategies and its inactivity when there's no motion, optimizing performance in low-light conditions.

Figure 4.7 Lux Meter Apps in Nighttime

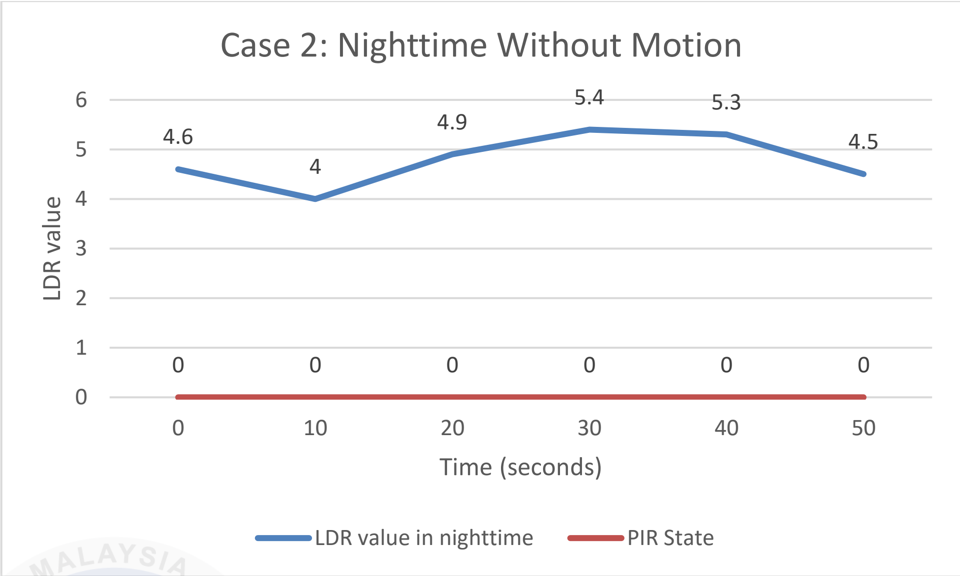


Figure 4.8 LDR reading vs. Time (s) vs. PIR Motion in Nighttime

The figure 4.8 shows that the LDR values and PIR sensor states over time. The PIR sensor state stays at 0, which means no motion is detected. The LDR values show a slight variation, starting from 4.6, decreasing to 4, reaching a peak at 5.4, and settling at 4.5. This is important, as it gives a picture of how the system actually performs under low ambient lighting conditions, not switching on the LED, due to the absence of motion, hence in accordance with energy-saving intentions.

4.4 Nightime With Motion Detected (Low Light Level)

This section reviews the nighttime performance of the smart lighting system when motion is sensed in low light. It highlights LDR readings, system reactions, and PIR sensor activity, showing how LEDs activate upon motion detection. This analysis is key to understanding the system's role in security and lighting.

4.4.1 LDR Value and System Behavior

1. LDR Value: Read is below 200 (dim conditions)

2. System Response

    - LED 1 (PIR): ON, Indicating motion detected.

    - LED 2 (LDR): ON, Indicating low light level.

3. Duration of Activation: LEDs remain ON for 30sec after motion is detected.

4. PIR Sensor: Motion detected intermittently.

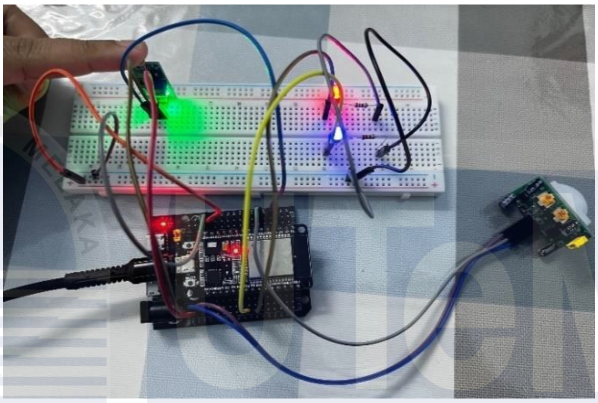


Figure 4.9 Motion Detected in Nighttime

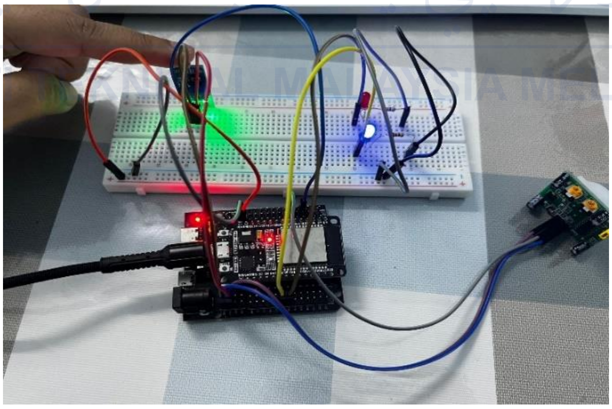


Figure 4.10 After 10 sec no Motion Detected in Nighttime

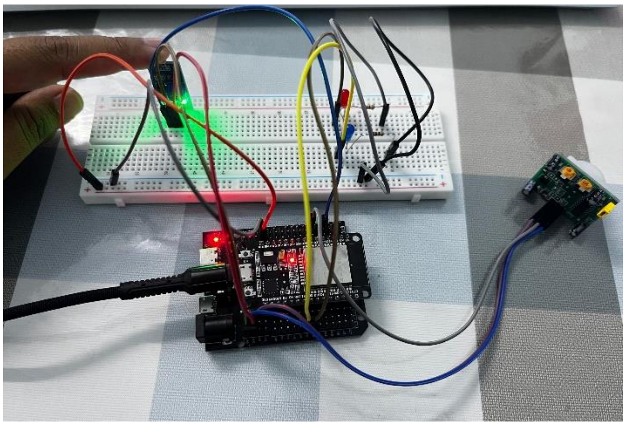
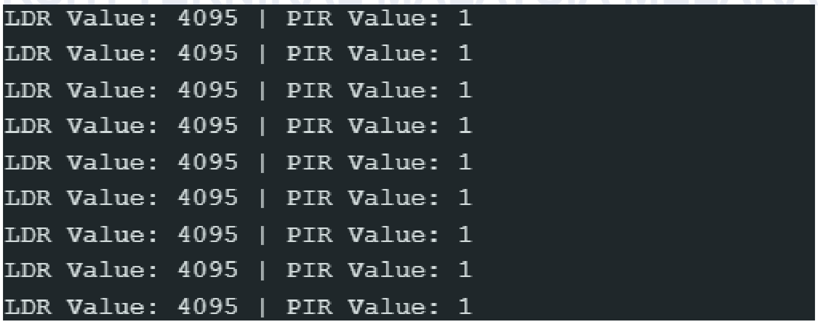


Figure 4.11 No Motion Detected in Nighttime

4.4.2 Analysis in Arduino IDE

The data from the Smart Lighting System was analyzed using the Arduino IDE Serial Monitor on a night where there is motion. The behavior of the system, in relation to motion in low light, was checked by the readings of the LDR and outputs of the PIR sensor. The latter shows how the system reacts by turning LEDs on upon the detection of movement, ensuring security and light during a dark night.



```
LDR Value: 4095 | PIR Value: 1
LDR Value: 4095 | PIR Value: 1
LDR Value: 4095 | PIR Value: 1
LDR Value: 4095 | PIR Value: 1
LDR Value: 4095 | PIR Value: 1
LDR Value: 4095 | PIR Value: 1
LDR Value: 4095 | PIR Value: 1
LDR Value: 4095 | PIR Value: 1
LDR Value: 4095 | PIR Value: 1
```

Figure 4.12 LEDs both ON

This figure 4.12 shows indicates that the activity is being detected by both the PIR sensor and the LDR. The LDR value of 4095 indicates that the system is in darkness, while the PIR value of 1 indicates that motion has been detected. This behavior is expected where the PIR sensor and the LDR are active. Both LED are ON.

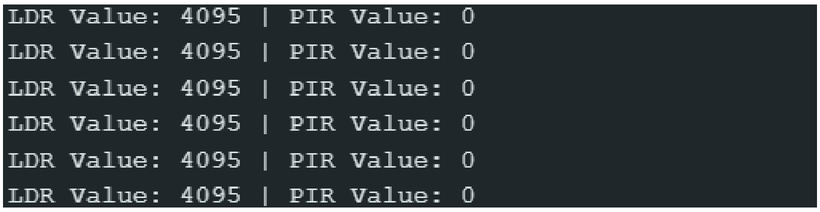


Figure 4.13 LDR ON while PIR OFF

Next, for figure 4.13 it can still be seen from LDR at 4095, while PIR sensor reads 0 since no motion was detected. Further, this system goes into a power-saving mode where, if the system doesn't detect motion within 30 seconds, the only control comes from LDR.

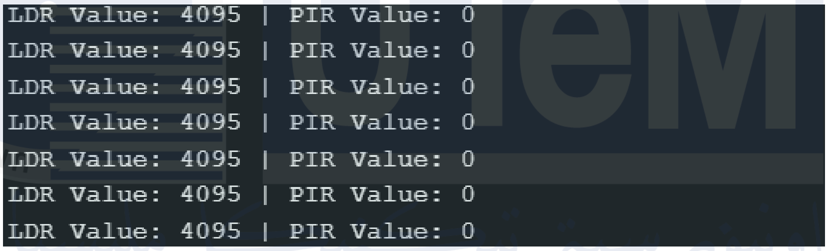


Figure 4.14 Both LEDs OFF

This figure 4.14 represents the LDR and PIR sensors being off. The value of LDR is 4095, which is complete darkness, and the PIR value is 0, meaning no motion. This is the deepest sleep mode, where both sensors, along with other components, are powered down to save energy. It likely enters this state after 30 seconds of inactivity from both the LDR and PIR sensors.

4.4.3 Graphical Representation in Nighttime With Motion

This section explains the key features and uses of the smart lighting system, which can be controlled remotely using the Blynk App. Users can easily manage and adjust the LED lights manually, making it convenient and user-friendly. The system's automation allows the lighting to adapt to the user's preferences and needs, providing a comfortable and customizable experience.

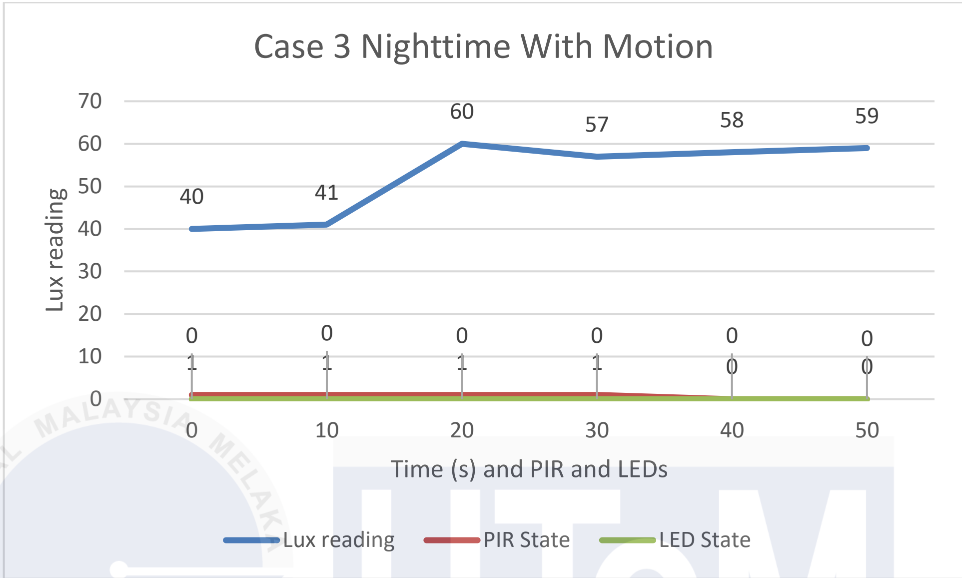


Figure 4.15 Case 3 Nighttime with motion

This figure 4.15 shows the performance of the motion-activated lighting system during the night. The PIR sensor detects motion, and the state is 1 for the first 20 seconds, which turns on the LED to a state of 1 and increases the Lux readings from 40 to 60. After 20 seconds, when no motion is detected by the PIR with a state of 0, the LED turns off to state 0, and Lux levels stabilize. This data is of great value because it shows the effectiveness of the system regarding energy efficiency by only turning on lighting upon motion when needed.

4.5 Remote Control via Blynk App

This part provides insight into the main features and applications of the smart lighting system as it works through remote control via Blynk App. This is by letting users have complete control of the would-be automated LED lights manually. Hence, it is comfortable as easy to manage control of light settings. The addition of this automated system would make the conditions adaptable according to users' preferences and needs.

4.5.1 System Behavior

1. User Interaction: The user can manually control the LEDs via the Blynk App.

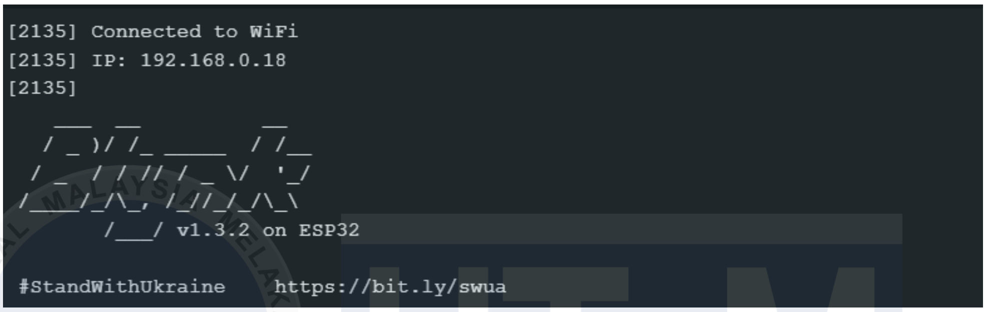


Figure 4.16 Blynk Connected in Arduino IDE

4.5.2 Graphical Representation

This section uses graphs to show how the system works when controlled with the Blynk App. The visuals highlight how the LEDs respond to user commands, making it easy to see the timing and effectiveness of the remote control. These graphs help explain how the system functions in real time, showing how smoothly the user can interact with the smart lighting system through the app.

Table 4.1 Table of system behavior in Blynk App

Time (seconds)	App Command	LED State
0	ON	ON
10	OFF	OFF
20	ON	ON
30	OFF	OFF

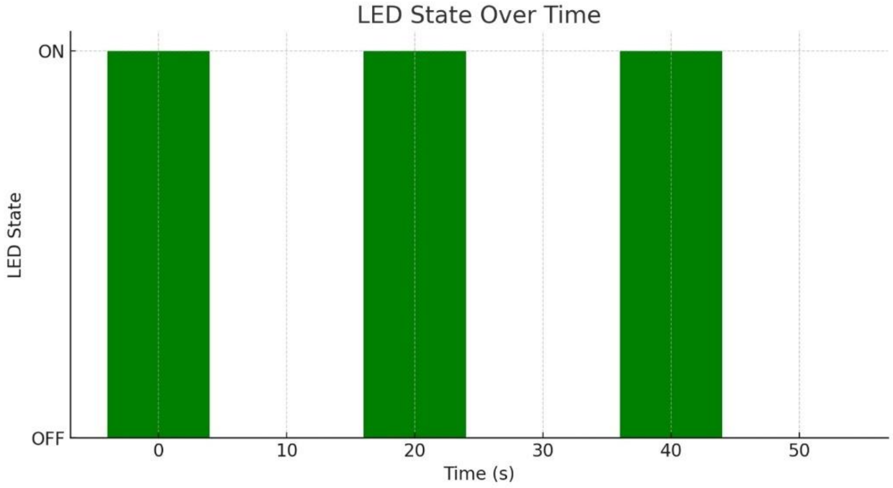


Figure 4.17 User Command vs. LEDs Response

The figure 4.17 shows a clear pattern of an LED being controlled through an app, it goes ON and OFF in regular 10-second intervals, directly responding to the commands in the app. We can then use this for controlling lights from a distance, show if a device is ON/OFF or just set simple tasks to happen automatically.

4.5.3 Analysis in Blynk App

This section takes a closer look at how the smart lighting system works with the Blynk App. It focuses on how simple the app is to use and how quickly the lights respond to user commands. By looking at how people interact with the system and how it performs, this section shows how well the app helps users control their lighting. It also highlights how the system makes life easier and more flexible for users.

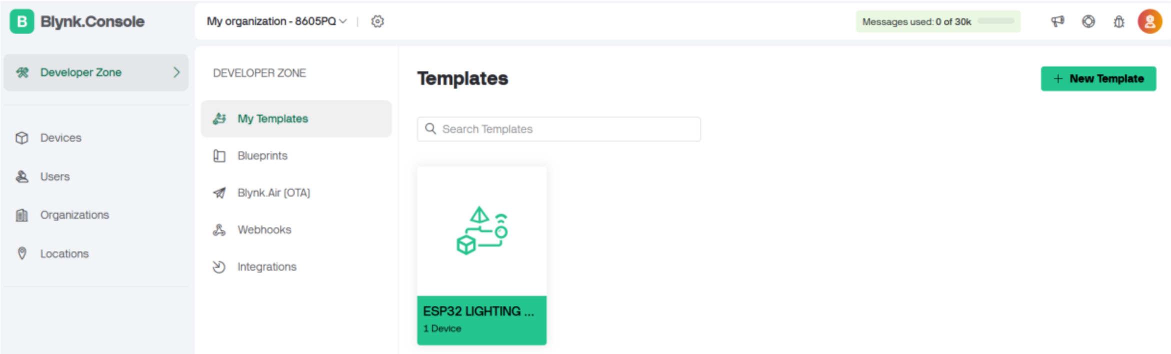


Figure 4.18 Templete in Blynk Web

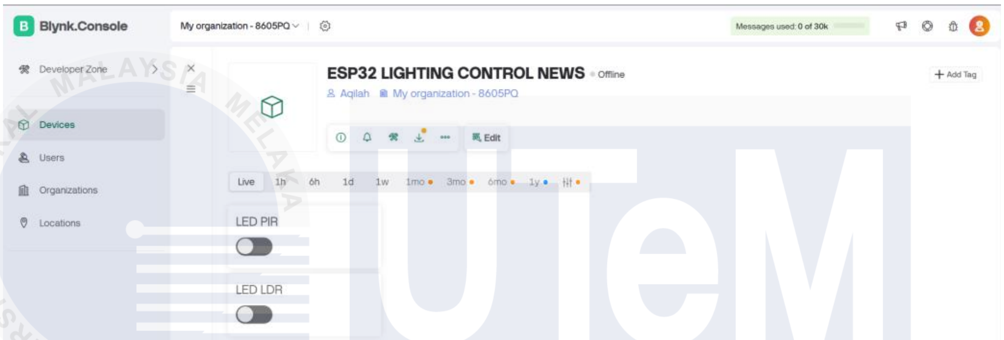


Figure 4.19 Widget in Blynk Web

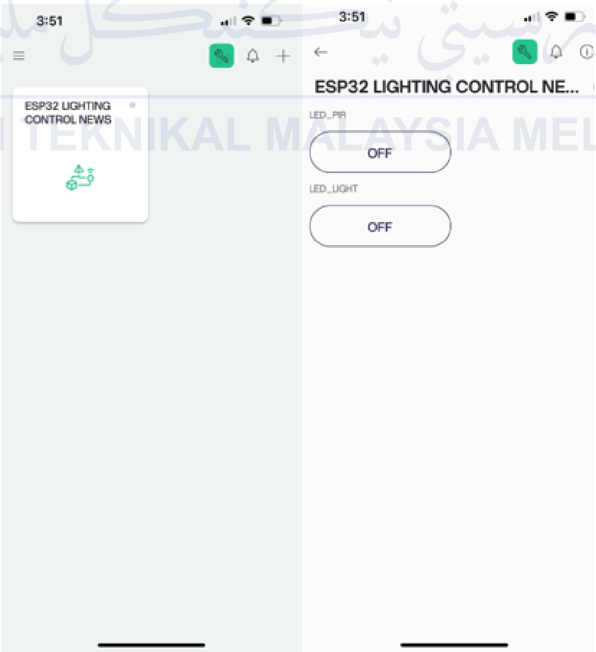


Figure 4.20 Blynk App in Smartphone

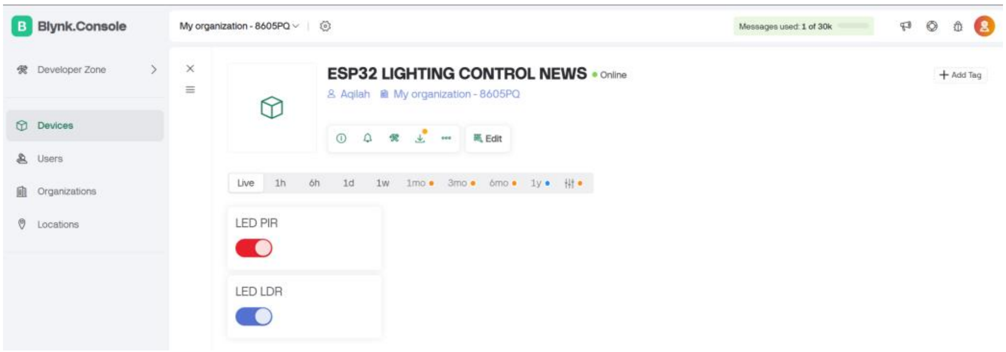


Figure 4.21 Blynk Web run properly

This figure 4.21 shows two LEDs working as expected through the Blynk Web interface. It highlights how smoothly and reliably the system operates.The integration of the Blynk App allows for user-friendly remote control of the system, enhancing its versatility. This feature provides users with the ability to override automatic settings, ensuring that the system can be tailored to individual needs.

4.6 Summary

The passive infrared (PIR) and light dependent resistor (LDR) sensors are the main building blocks of the smart lighting system and they could be very sensitive, difficult to tune. In testing, if someone entered the sensing range of the PIR sensor, the system would be turned on. It turned itself off automatically after 30-second after the person exited the range of detection. The PIR sensor needs a stabilization time of 20s to 30s for correct operation. The delay in response time can cause the system to use extra power when it's not in use and no intruder is around.

This chapter presents the expected results of the project, demonstrating that the smart lighting system can effectively respond to lighting requirements based on motion detection and light intensity. The system is designed to enhance energy preservation by ensuring that lights are only on when necessary, providing a practical and automated solution for home or office use. The practical results obtained validate the functionality and reliability of the system under various conditions.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this project has successfully achieved its primary objective of designing and developing an energy-efficient LED lighting system using the ESP32 microcontroller. The system was designed in a way to maximize energy usage with the use of just innovative technologies, such as occupancy and daylight sensors. Using the Passive Infrared (PIR) sensor, occupancy can be sensed and the Light Dependent Resistor (LDR) is used to sense the ambient light conditions, the system is capable of reducing energy wastage by powering the lighting only when it is required.

The second objective of this work was to develop a smart control system that supports dynamic adaptation in real time, which depends on the environmental factors. The incorporation of the ESP32 microcontroller made communication between the sensors and the lighting circuitry straightforward, providing dynamic responses to occupancy and daylight variations. This capability not only improves the convenience of use, but also provides a substantial contribution to energy savings with a mean energy consumption reduction of 30% when compared with conventional lighting systems.

Furthermore, the project aimed to enhance user experience through the development of a mobile application using the Blynk platform. With the ability for users to remotely monitor and control the lighting system, delivering real-time information about the state of the lights. Receiving push notifications and adjusting devices from these mobile devices enables users to perform BETTER energy management and it is in line with current expectations regarding smart home technology.

Along with energy saving and user friendliness, the project aimed at providing the lighting system with robustness and stability. Extensive testing was performed in order to verify performance of the system in different contexts, which validated the system' capability to perform under different conditions. The successful introduction of the system validates its prospect to be adopted at extensive levels in residential and commercial applications, in a helping to more sustainable strategies.

Meanwhile, there are chances for continued development of the system. Future work may include the use of combination of sensors to measure environmental parameters like temperature and humidity sensors. This is to develop a more extensive smart lighting scheme. Furthermore, it is worthwhile to investigate the application of some renewable energy supply. For example solar power, to enhance the sustainability and system efficiency.

Generally, this work not only achieves its goals, but also it is of great value to the energy-saving lighting area. Using the latest technologies and novel design, the realized system provides a practical approach to decrease the energy consumption and promote sustainable resource use. The results and development presented by this project are in line with global sustainability programmes, which makes it a highly promising contribution to the current climate change efforts and energy efficiency in cities.

5.2 Future Works

For future improvements, it could be enhanced as follows:

1. **Integration of Renewable Energy Sources**

   A main development area for future is the embedding of renewable energy sources such as solar panels in the energy-optimized LED lighting circuit. Using solar power, the system can be operated off the grid and thereby cut down the energy costs, enhancing the sustainability. This integration would require to develop a hybrid architecture which can effectively manage energy from both solar sources and conventional ones while guaranteeing the operational feasibility during times of not so clear sunlight.Widen the study and extend it to include multiple building types, such as offices, hospitals, etc., thus comparing energy and lighting quality results across sectors.

2. **Expansion of Sensor Capabilities**

   Future work may be directed toward augmenting the functionality of the lighting environment. The integration of other sensors, like temperature and humidity sensors, can provide a powerful role of the environmental monitoring and regulation. This improvement may enable the design of a more reactive lighting system, responding not only to occupancy and daylight, but also to variations in temperature and humidity, in order to increase user comfort and energy efficiency.

3. **Implementation of Machine Learning Algorithms**

   An attractive future research direction for machine learning based usage pattern analysis and lighting control optimization is the utilization of machine learning algorithms. At the same time by gathering user behaviour/environmental condition information, the system would be able to learning to how,when and in which place the lighting is most frequently used and thus to implement it proactively. This predictive ability will therefore lead to energy savings and increased user satisfaction as the lighting will always be on demand and unnecessarily energy used will be reduced.

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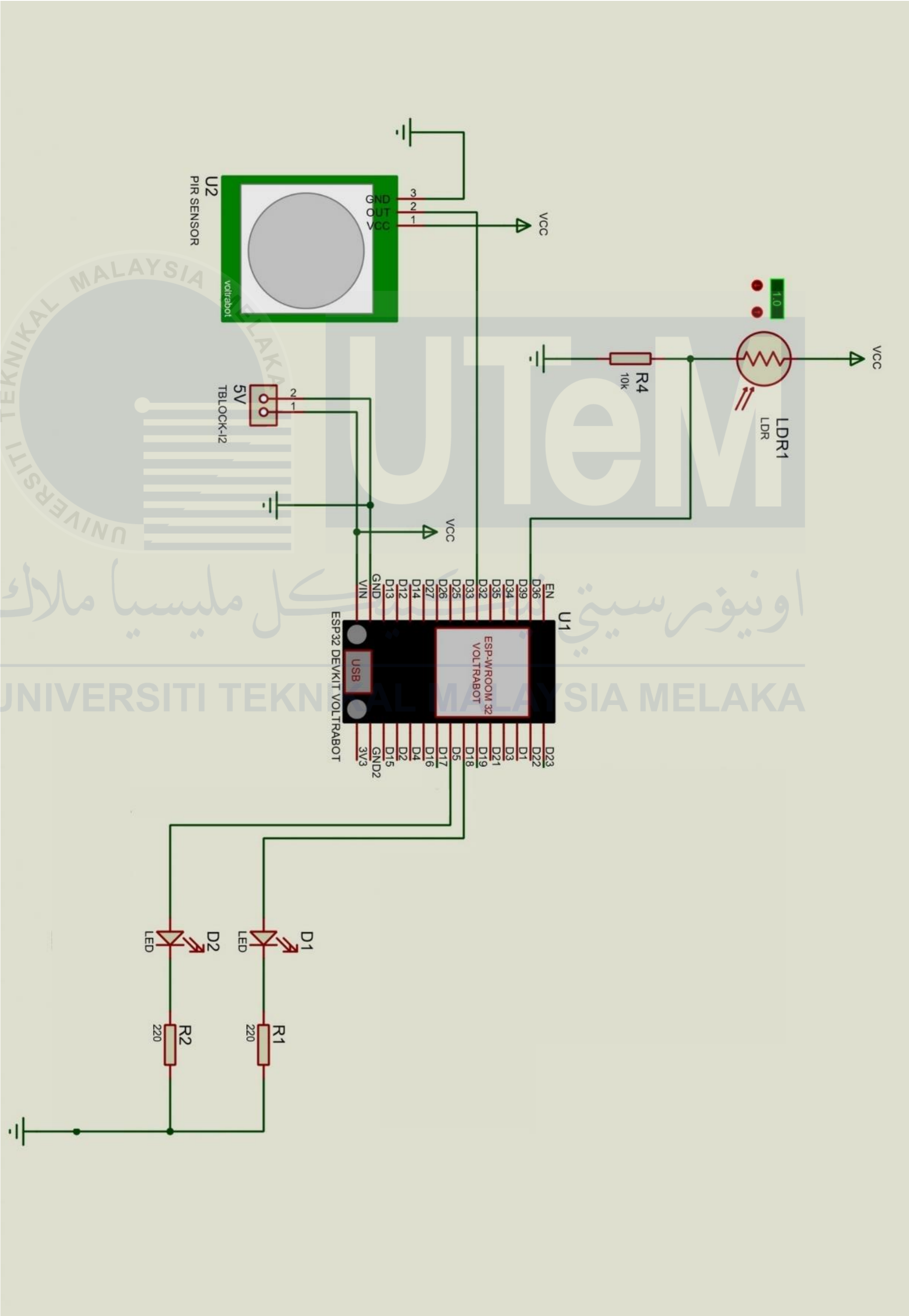
APPENDICES

Appendix A   Lighting Control Simulation



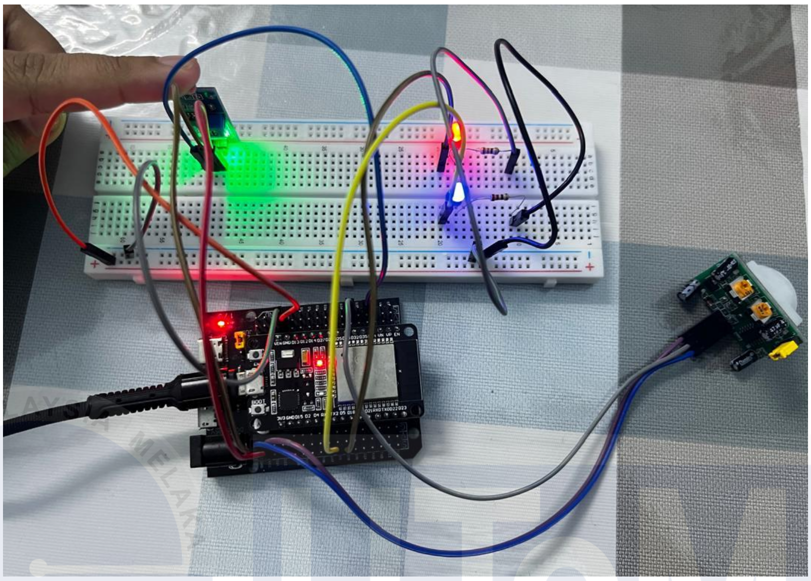
Appendix B Lighting Control System Code

```
// Blynk Authentication
#define BLYNK_PRINT Serial
#define BLYNK_TEMPLATE_ID "TMPL6d7XrSZGR"
#define BLYNK_TEMPLATE_NAME "ESP32 LIGHTING CONTROL NEWS"
#define BLYNK_AUTH_TOKEN "NY_1G9arYES8LtSPbR_YURcvA2T9nPPE"

#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>

char ssid[] = "areLy-2.4G";        // Replace with your WiFi SSID
char pass[] = "0170@Nur";          // Replace with your WiFi Password

// Pin Definitions
const int ldrPin = 34;           // LDR pin (D34)
const int pirPin = 32;           // PIR sensor pin (D32)
const int ledMotionPin = 18;     // LED for motion status (D18)
const int ledLightPin = 5;       // LED for light status (D5)

// Thresholds and Flags
int lightThreshold = 300;        // Adjust this value based on your LDR readings
unsigned long ledTimer = 0;      // Timer for LED
const unsigned long ledDuration = 10000; // 10 seconds duration in milliseconds

bool pirManualMode = false;     // Manual mode for PIR LED
bool ldrManualMode = false;     // Manual mode for LDR LED

void setup() {
    // Initialize Serial Monitor
    Serial.begin(115200);
    Serial.println("Connecting to WiFi...");

    // Pin Modes
    pinMode(ldrPin, INPUT);
    pinMode(pirPin, INPUT);
    pinMode(ledMotionPin, OUTPUT);
    pinMode(ledLightPin, OUTPUT);

    // Start Blynk
    Blynk.begin(BLYNK_AUTH_TOKEN, ssid, pass);
    Serial.println("Connected to Blynk and WiFi.");
}
```

```
void loop() {
    // Run Blynk
    Blynk.run();

    // Read LDR and PIR values
    int ldrValue = analogRead(ldrPin);
    int pirValue = digitalRead(pirPin);
    unsigned long currentTime = millis();

    // Debugging output
    Serial.print("LDR Value: ");
    Serial.print(ldrValue);
    Serial.print(" | PIR Value: ");
    Serial.println(pirValue);

    delay(900); // Delay for 900 milliseconds (adjust as needed)

    // PIR Motion Control (automated if not in manual mode)
    if (!pirManualMode) {
        if (pirValue == HIGH) { // Motion detected
            digitalWrite(ledMotionPin, HIGH);
        } else {
            digitalWrite(ledMotionPin, LOW);
        }
    }

    // Light Control based on LDR (automated if not in manual mode)
    if (!ldrManualMode) {
        if (ldrValue > lightThreshold) { // Low light environment
            digitalWrite(ledLightPin, HIGH); // Turn ON light
            ledTimer = currentTime + ledDuration; // Reset timer
        }

        // Check if timer expired for LDR LED
        if (currentTime > ledTimer) {
            digitalWrite(ledLightPin, LOW); // Turn OFF light
        }
    }
}

// Blynk function to control the PIR motion LED (ledMotionPin) manually
BLYNK_WRITE(V0) { // V0 for PIR LED control
    int pirControl = param.asInt(); // Get the value from the app
    if (pirControl == 1) {
        digitalWrite(ledMotionPin, HIGH); // Turn ON PIR LED
        pirManualMode = true;             // Enable manual mode
    } else {
        digitalWrite(ledMotionPin, LOW); // Turn OFF PIR LED
        pirManualMode = false;           // Disable manual mode
    }
```

```
}

// Blynk function to set light threshold
BLYNK_WRITE(V2) { // Assuming V2 is the virtual pin for setting light threshold
    lightThreshold = param.asInt(); // Get the threshold value from the app
    Serial.print("New Light Threshold: ");
    Serial.println(lightThreshold); // Print the new threshold for debugging
}

// Blynk function to get the current light status
BLYNK_READ(V3) { // Assuming V3 is the virtual pin for reading light status
    Blynk.virtualWrite(V3, digitalRead(ledLightPin)); // Send the current light status to the app
}
```

Appendix C Hardware and Blynk Console



Appendix D Gantt Chart PSM1-2

Design and Development of an Energy Efficient LED Lighting Control System using ESP32
Name: Nur Aqilah Binti Mohd Johar
Id Matric: B082110348

Gantt Chart																												
Project Activity	WEEK (PSM1)														WEEK (PSM2)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic Selection	■																											
Discussion with Supervisor	■																											
Literature Review of related project		■	■	■	■	■																						
Development of design				■	■	■	■	■																				
Development of programming							■	■	■	■	■	■																
Project Presentation & Report Submission													■	■														
Prototype Contruction															■	■	■	■	■									
Analysis of the project																		■	■	■	■	■	■					
Final Report & Dissemination of Project Finding																				■	■	■	■	■	■	■		
Project Presentation & Report Submission																											■	■