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EcoPower Guardian in Mas Gading

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Abstract

There are 105 Community colleges in Malaysia. It plays a vital role in providing technical and vocational training to students and offering lifelong learning opportunities to the community. However, these colleges face increasing operational costs, particularly in electricity expenses. For instance, Mas Gading Community College shows its electricity bill increase by RM 1633 from January to March 2024, highlighting the urgent need for more efficient energy management solutions. Despite various awareness campaigns aimed at reducing electricity consumption, these efforts have been ineffective due to human errors and inconsistent application of energy-saving measures. Therefore, to address this challenge, the EcoPower Guardian project proposes an innovative automatic light control system that controls using Internet of Things (IoT) technology. This system uses a timer-based mechanism, controlled by the ESP32 IoT board, to schedule lighting according to predefined timings. Additionally, it includes a manual override button for flexibility. The IoT integration allows for remote control and monitoring through the Arduino IoT Cloud, ensuring that lights are only used when necessary. As a result, the implementation of EcoPower Guardian lights saw a substantial 45% cut in power usage, resulting in annual electricity bill savings of RM368.28 and contributes to reduction in carbon emission as much as 0.93tCO2e annually. In conclusion, implementing the EcoPower Guardian in Mas Gading Community Colleges is a significant step towards addressing the critical issue of rising energy costs. The project promises substantial financial savings, technological innovation, and a strengthened commitment to sustainability. By integrating advanced IoT technology for energy management, community colleges can achieve consistent energy savings, improve financial stability, and promote environmental responsibility.

1. Introduction

In Malaysia, there are 105 community colleges play a pivotal role in providing technical and vocational education and training (TVET) and lifelong learning opportunities [1][2]. However, these institutions face a pressing challenge in escalating operational costs, particularly in electricity expenses. For instance, Mas Gading Community College has seen a notable RM 1633 increase in its electricity bill from January to March 2024, underscoring the urgent need for efficient energy management solutions. Despite concerted efforts through awareness campaigns, reducing electricity consumption has remained a persistent issue due to human errors and inconsistent application of energy-saving measures. To address this challenge effectively, EcoPower Guardian project proposes an innovative Internet of Things (IoT) solution, capitalizing on the fact that over 10 billion IoT devices are now connected worldwide [3]. This project introduces an automatic light control system designed to optimize energy usage through precise scheduling, remote monitoring, manual control, and bypass control. Balancing performance with cost-effectiveness, ESP32 is an excellent option for IoT Devices [4] and hence, emerged as the ideal core for this project. Aimed at startups, this project was installed at Mas Gading Community College to automatically control Level 2 corridor lighting and exhaust fan based on pre-defined schedules that consider working hours and historical light usage. The system offers dual control methods for the lights other than the pre-defined schedule. A control panel with four buttons and indicator lights allows for manual operation, while the Arduino IoT cloud app provides two buttons for convenient remote control and power usage monitoring. Additionally, four bypass buttons ensure continued control even in case of system failure. The system ensures lights are activated only when necessary, thus minimizing wastage. Moreover, the integration of this project not only promotes sustainability by lowering concerning carbon emissions [5] but also serves as an educational tool, fostering awareness about energy conservation among students and staff.

1.1 Problem Statement

Mas Gading Community College faces a significant challenge with the rising electricity bills over the past six months. This uncontrolled electricity consumption is driving up the operating costs. Therefore, to effectively address this rising electricity cost, the college requires innovative solutions that manage electricity use more efficiently, ideally without the burden of continuous manual intervention.

1.2 Objectives

The objectives of this project are as follows:

i. To develop an innovative automatic light control system utilizing IoT technology, scheduling lighting based on predefined timings and allowing for remote monitoring and control through the Arduino IoT Cloud to reduce electricity consumption and operational costs during office hours.
ii. To evaluate the effectiveness of the implemented system in reducing energy consumption and carbon emission.

2. Methodology

2.1 Project Development Method

This project developed according to the Waterfall model which is a sequential development approach where progress flows through clearly defined phases: analysis, design, implementation, testing, and maintenance [6]. Each phase must be completed and approved before moving on to the next [7]. Unlike a recursive process with endless repetition, the Waterfall model emphasizes a linear progression. However, revisions can occur within a phase to ensure deliverables meet quality standards before proceeding. The project flow was as shown below:

2.1.1 Analysis Phase

Before starting the project, it's important to clearly understand the goals and concerns. The main aim is to make sure the project meets its objectives and solves any potential problems. This analysis guides the determination of materials and software needed. Specifications like control lines, energy consumption, and microcontroller type are considered, ensuring reliability, scalability, testability, availability, maintainability, performance, and quality standards.

2.1.2 Design Phase

Following thorough project planning, the development phase begins. This phase involves two crucial steps:

i. Program Flowchart Design

A flowchart is created to map the program's logic, considering control from various sources like timing algorithms, manual button inputs, inputs through Arduino IoT cloud, and a bypass button.

ii. Hardware Connection Block Diagram

A block diagram is then developed to illustrate the hardware connections within the EcoPower Guardian system.

2.1.3 Implementation Phase

Since the design phase has provided a roadmap, the implementation phase brings the conception of EcoPower Guardian system to reality. This phase involves programming and hardware development.

i. Programming Development

The program logic defined in the flowchart is translated into code using the Arduino IDE, which involves writing functions to handle various tasks. Code is written to implement the scheduled power management based on the pre-defined timing algorithm associated with the RTC module and to toggle the lights and exhaust fan in response to manual button presses. Additionally, the IoT cloud input involves communication between the EcoPower Guardian and the Arduino IoT Cloud to receive and interpret commands for remote control and power monitoring, with the code uploaded to the ESP32 via the Arduino IoT Cloud.

ii. Hardware Development

Component selection involves choosing specific hardware components based on the block diagram and design specifications, including the ESP32 IoT board, current sensors, RTC module, relay module, and power supply. Circuit construction entails physically connecting the hardware components according to the block diagram, using Dupont wires for electronic parts and proper wiring for electrical parts as per the designed connections. Furthermore, a bypass button is included to ensure the system's functionality in case of a failure, allowing for a temporary override of the system's automated control.

2.1.4 Testing Phase

i. Software Testing

As each section of code is written, thorough software testing is conducted by simulating various scenarios such as button presses, timing triggers, and current sensing to identify and fix any bugs. Individual functions of the code are tested in isolation to verify they operate as expected with the sensors or buttons added to the system. Once these functions are validated, the code is combined and tested to ensure the relay module interacts smoothly with the RTC and buttons, guaranteeing smooth data flow and overall program behavior.

ii. System Testing

With the complete program loaded onto ESP32, comprehensive testing that mimics real-world use cases was conducted. This involves testing various control inputs such as timing triggers, button presses, cloud commands and monitoring power management behavior to ensure the entire system functions as intended.

ii. Hardware Testing

Once the circuit is built, it undergoes rigorous testing. This involves powering it up with a safe voltage source to verify functionality, ensuring proper communication between components, and confirming power management behavior. Only after successful completion of the verification and validation process, the EcoPower Guardian system be deployed in a real-world application. This final step marks the successful completion of the development process, bringing the system to life and ready for practical use.

2.1.5 Maintenance Phase

To ensure the system remains effective over time, a well-defined maintenance phase is implemented. This phase includes several key activities. Regular system checks involve periodic inspections to verify functionality, such as monitoring power consumption, testing button presses, and evaluating communication protocols to identify potential issues early. Besides that, updates and bug fixes are performed to improve system functionality upon request or to address any bugs discovered during operation. Moreover, component replacement is necessary since electronic components, especially buttons, have limited lifespans and need to be replaced over time. This maintenance phase involves identifying failing components and replacing them to maintain system reliability. By implementing a comprehensive maintenance plan, the EcoPower Guardian system's lifespan can be extended, ensuring it continues to deliver optimal performance in the long run.

2.2 Software and System Flow Design

As for the software part, Arduino IDE is used for offline programming and Arduino IoT Cloud are used for online programming purposes. Then, the remote control and monitoring was done by IoT Remote apps in Android system. Arduino IDE is a free, open-source software platform for writing code for Arduino boards and other compatible microcontrollers like the ESP32. It provides a text editor for writing code, a compiler to translate the code into machine-readable instructions, and a debugger to help identify and fix errors [8]. Arduino IoT Cloud is an online platform that allows IoT devices to be connected to the cloud, manage them remotely, and visualize sensor data [9]. The Arduino IoT Remote App is a mobile application that allows interaction between devices registered in the Arduino IoT Cloud with smartphone or tablet. Here is where dashboards created in Arduino IoT Cloud display data in real-time and control relays remotely to turn on/off lights and exhaust fan connected to the relays.

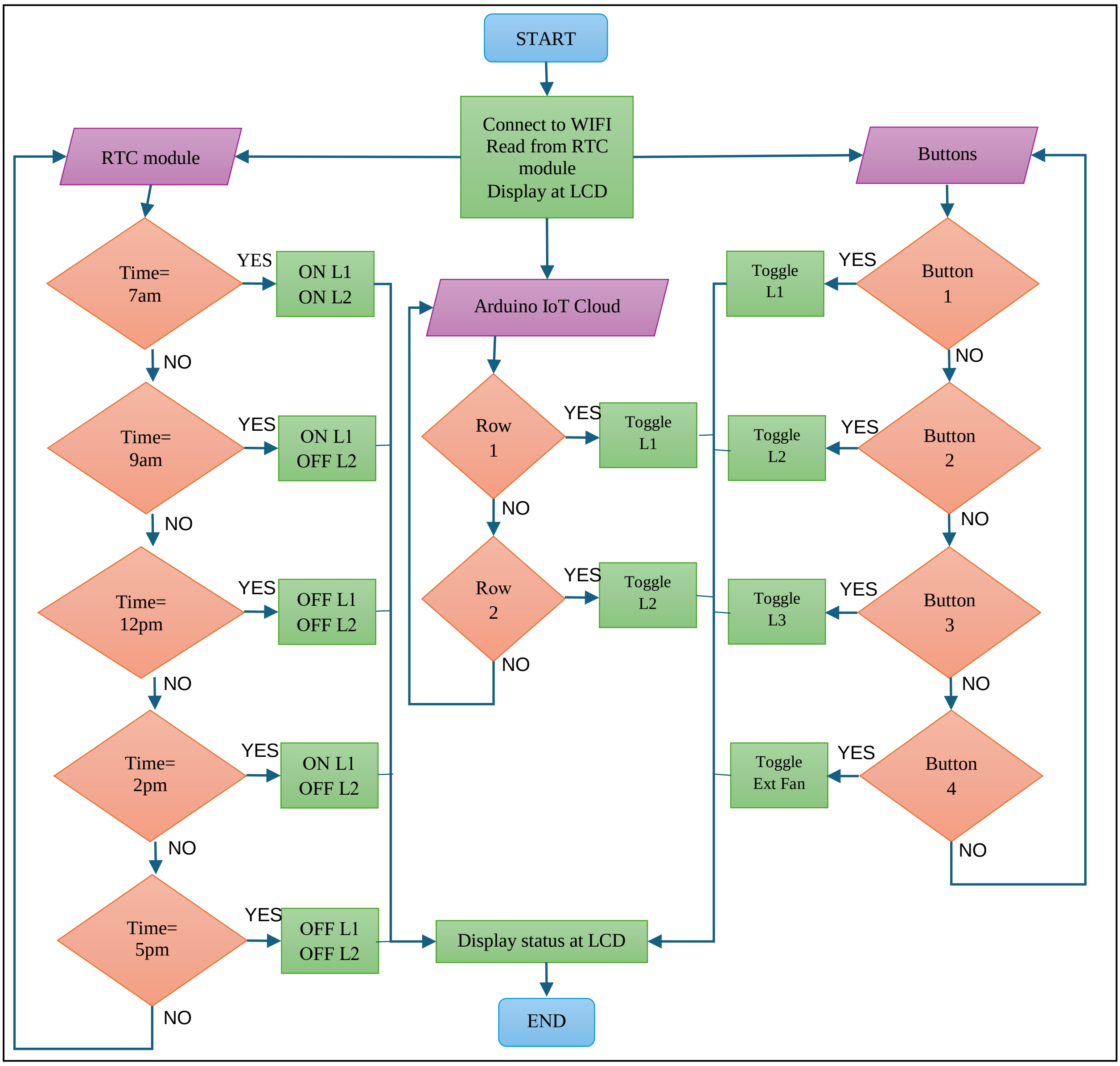

Fig.1 *System Flowchart*

2.3 Hardware Design and Development

Below is detailed breakdown of the EcoPower Guardian system with the provided components:

i. 5V Power Supply Unit
ii. ESP32 microcontroller with integrated Wi-Fi and Bluetooth
iii. DS3231 Precision RTC module
iv. ZMCT103C 5A single phase AC current sensor module
v. 2004 Liquid LCD
vi. channel relay module

The hardware of EcoPower Guardian is connected as shown in Figure 2. The ESP32 receives signals from RTC module and interprets the signals into real time clock for scheduling purposes. The total power usage from the control lines is sense by the AC current sensor is determined. Then, the power usage is displayed at the liquid LCD screen attached to the control panel dan IoT remote apps. The lights connected to the relay module were controlled by the timing algorithm wrote in coding and button on the control panel. This can be remotely controlled by using IoT remote apps through the internet.

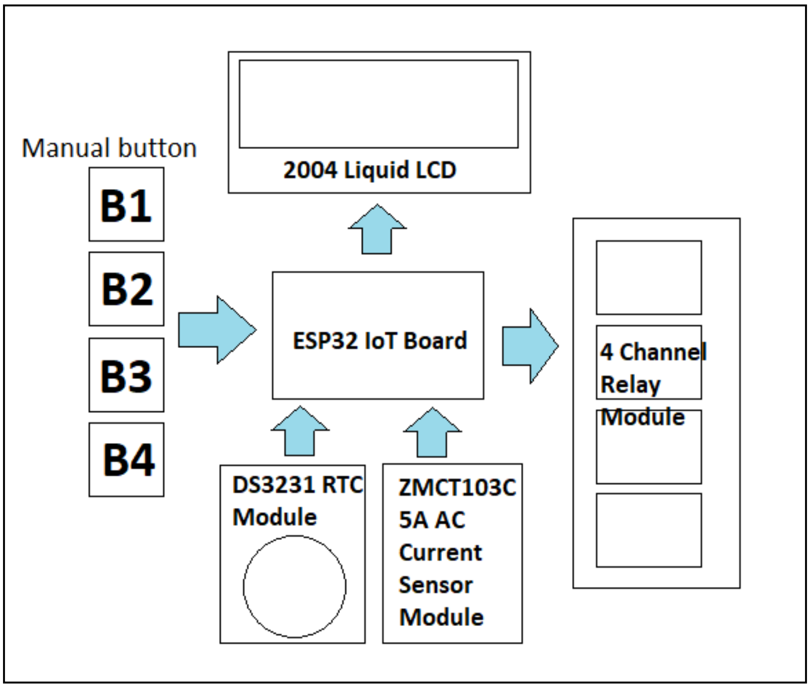

Fig.2 *Hardware Block Diagram*

The control panel houses electronic and electrical components wired according to a block diagram. The electronic components were wired through dupont wire while the electrical part which connected to the main AC supply was wired using 2.5mm^2 cable considering the load connected. The internal wiring of the control panel is as shown in Figure 3.

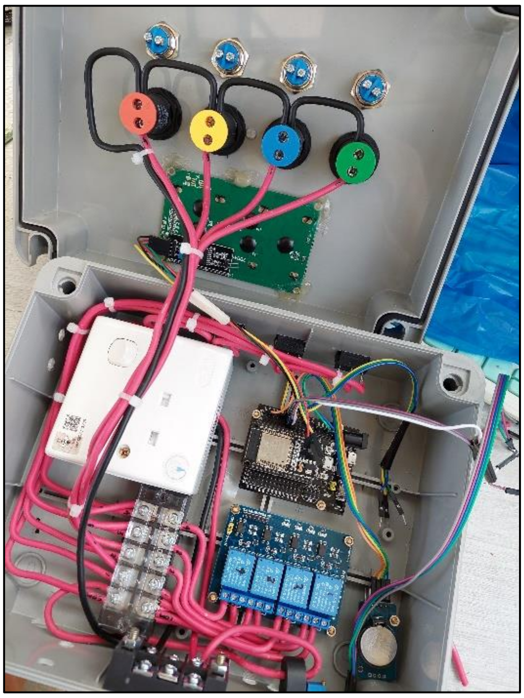

Fig.3 *Internal Wiring of Control Panel*

3. Result and Discussion

Mas Gading Community College has successfully installed EcoPower Guardian, a system designed to control various lighting and ventilation elements. The system manages 10 sets of corridor lights divided into two lines, staircase lighting, and an exhaust fan. Once the testing phase is complete, and ongoing monitoring is performed to ensures the system's stability and functionality.

When the button was pressed, the red indicator and yellow indicator were lit up and the LCD shows the status of the light as shown in Figure 4. At this time, the Level 2 corridor lights were turned ON as shown in Figure 5 (a). At this time, the light ON/OFF status and total power usage is displayed on the dashboard of IoT Remote as shown in Figure 5 (b). From the IoT Remote, there are 2 buttons to toggle 5 lights on row 1 and 5 lights on row 2 and this can control at any places through internet.

Fig.4 *Control Panel with Four Buttons*

(a) **(b)**

Fig.5 (*a) Level 2 Corridor Lights Turned ON, (b) IoT Remote Dashboard*

When using the pre-defined schedule for timing algorithm for Level 2 corridor lights control as shown in Table 1, the total operating hour is reduced from 10 hours to 5.5 hours compared to fully turned ON light during normal working hours before implementation of EcoPower Guardian which saved 45% of normal energy consumption for corridor lights.

Table 1 *Timing Schedule for 24 Hours*

Time	Period	Row 1	Row 2	Load
7.00am – 9.00am	2 hours	ON	ON	Full (1000W)
9.00am – 1.00pm	4 hours	ON	OFF	Partial (500W)
1.00pm – 2.00pm	1 hour	OFF	OFF	No load (0W)
2.00pm – 5.00pm	3 hours	ON	OFF	Partial (500W)
5.00pm – 7.00am	14 hours	OFF	OFF	No load (0W)

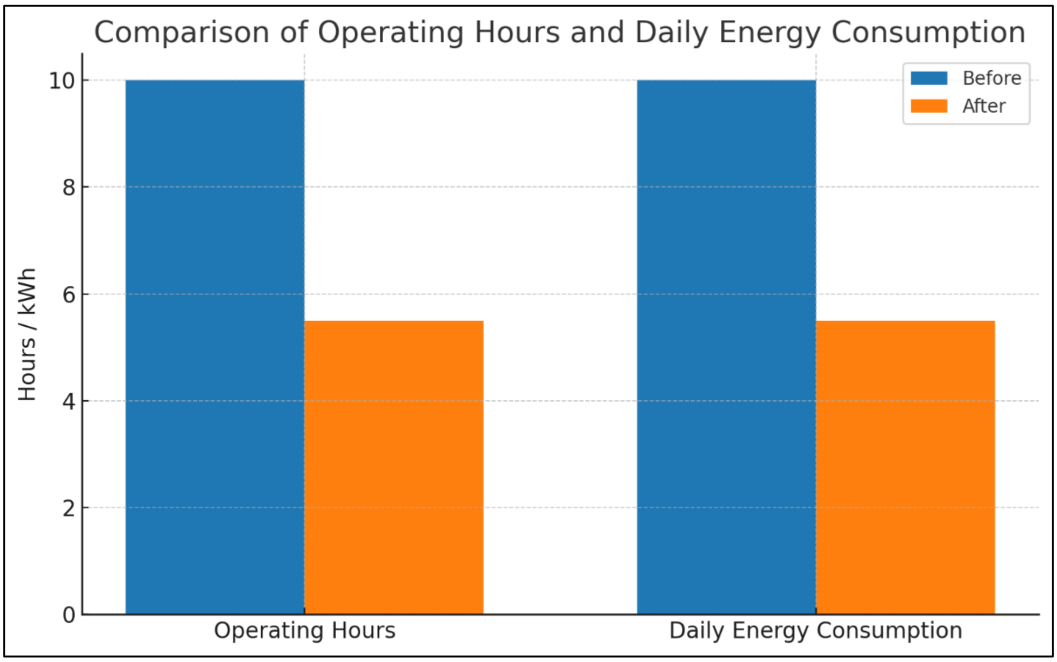

Fig.6 *Comparison of Operating Hours and Daily Energy Consumption*

The bar chart at Figure 6 illustrates the impact of implementing the EcoPower Guardian, showing a reduction in both operating hours and daily energy consumption. Operating hours decreased from 10 hours per day to 5.5 hours per day, while daily energy consumption was halved, dropping from 10 kWh per day to 5.5 kWh per day.

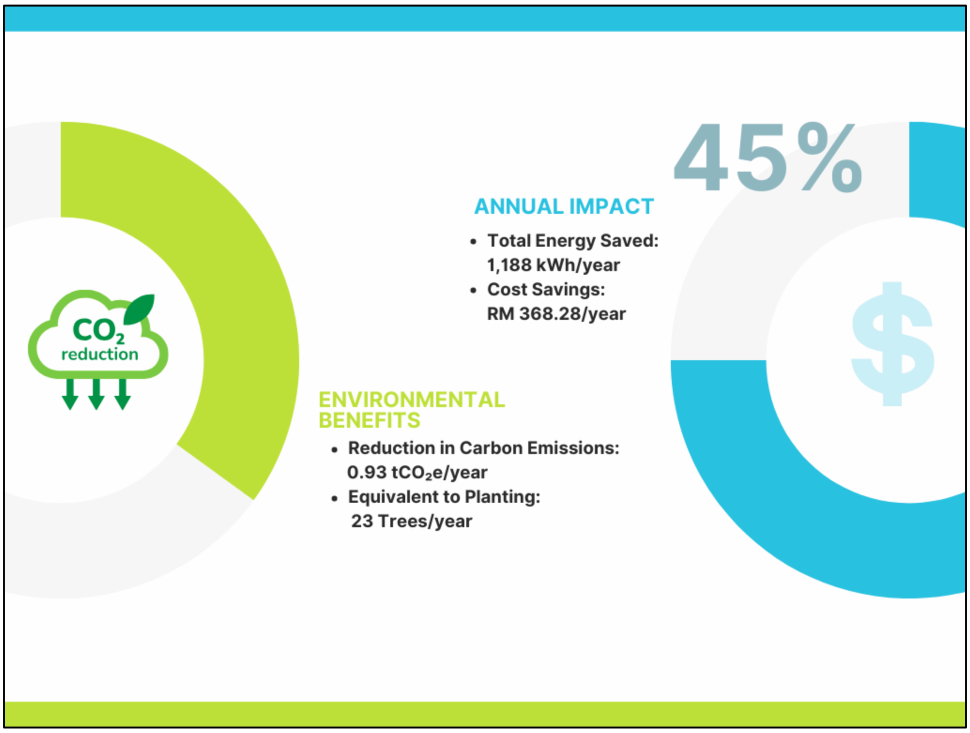

Fig.7 *The Impact of The New Schedule on Reducing Both Time And Energy Usage*

The implementation of the EcoPower Guardian has resulted in significant energy savings of 4.5 kWh per day, representing a 45% reduction in daily energy consumption. Assuming an average of 22 working days per month, the total energy consumption saved per year amounting to 1,188 kWh annually. These energy savings lead to a cost saving of RM 368.28 per year, based on a rate of RM 0.31 per kWh [10].

In terms of environmental benefits, the electricity factor for carbon emissions, as per the Malaysian Energy Commission 2019 Grid EF, is 0.78 kgCO2e per kWh [11]. Therefore, the reduction in carbon emissions due to the energy saved is 1,188 kWh x 0.78 kgCO2e/kWh, equating to a reduction of 0.93 tCO2e per year. This reduction in carbon emissions is equivalent to the environmental impact of planting 23 mature trees annually, as each mature tree can absorb approximately 0.4 tCO2e per year.

4. Conclusion

This project met expectations where an automatic light control system with scheduling lighting, remote monitoring and control was successfully developed with appropriate code and components connection. The hardware and software part integrated seamlessly after few adjust throughout the testing phase. This system is designed to receive input from multiple sources from input buttons at the control panel and through cloud. Moreover, backup plan is included in the design where bypass button is available to continue operate even in the event of primary input failure. This enhances system reliability and user safety. The effectiveness of the system is determined where 1,188kWh is saved annually and this contributes to reduction in carbon emission as much as 0.93tCO_2e. The reduction in energy consumption is equivalent to saving 23 trees, contributing to a smarter and greener future. Although this number does not seem to have significant changes compared to the previews total usage, it's important to remember this is just the beginning as currently, the system is only implemented in a limited area, occupying no more than 10% of the building. Hence, there is potential for even greater energy savings and emissions reductions as the system expands.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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