Design and Implementation of Internet of Things-Based Lighting and HVAC Control System

Rancang Bangun Sistem Pengendalian Pencahayaan dan HVAC Berbasis *Internet of Things* (IoT)

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ABSTRACT — In this modern era, numerous buildings require effective and intelligent energy management solutions. An automatic control system for lighting and HVAC based on the Internet of Things (IoT) has been developed with the aim of improving energy efficiency in learning spaces. The system is designed to ensure the lighting intensity meets the standards set by the Ministry of Energy and Mineral Resources (ESDM) (≈250 lux), with an ideal room temperature of 22°C–26°C. The device consists of five Wemos D1 Mini units connected to DHT22 sensors to detect temperature and humidity, and BH1750 sensors to measure light intensity. All components are centrally controlled using an ESP32 microcontroller. Data is transmitted via MQTT protocol, which can be monitored in real-time through Blynk application. The implementation method includes literature study, prototype design and assembly, programming, hardware and electrical assembly, performance testing, evaluation, and final project reporting. This system allows five lamps and one air conditioner to operate automatically according to predefined parameters. The test results show that the light intensity reached 264.8 lux in the morning and 263.9 lux in the afternoon with four lamps on, which meets the classroom lighting standard. Meanwhile, the HVAC test produced an average room temperature of 30.6°C, which did not significantly affect energy efficiency. However, the system was still able to reduce power consumption by approximately 39% compared to manual operation. The implementation of IoT in this system is expected to support the realization of smart buildings that are more efficient and environmentally friendly.

KEYWORDS — BH1750, Blynk, DHT22, ESP32, Internet of Things, MQTT

INTISARI — Di era modern saat ini, bangunan seperti kelas, perkantoran, maupun fasilitas publik semakin memerlukan solusi dalam pengelolaan energi yang efektif dan pintar. sebuah sistem kontrol otomatis pada pencahayaan dan HVAC berbasis *Internet of Things* (IoT) dengan tujuan untuk meningkatkan efisiensi energi di ruang belajar. Desain sistem disusun agar intensitas pencahayaan memenuhi standar Kementerian ESDM, yakni sekitar 250 lux, dengan suhu ruang ideal pada kisaran 22°C–26°C. Perangkat terdiri dari lima Wemos D1 Mini yang terhubung dengan sensor DHT22 untuk mendeteksi suhu dan kelembapan, serta sensor BH1750 untuk membaca intensitas cahaya. Semua komponen dikendalikan terpusat menggunakan ESP32. Data dikirim melalui protokol MQTT dan dapat dipantau secara *real-time* melalui aplikasi Blynk. Metode pelaksanaan meliputi studi literatur, perancangan dan perakitan prototipe, pembuatan program, perakitan *hardware* dan *electrical,* pengujian kinerja alat, serta evaluasi hingga tahap pelaporan proyek akhir Sistem ini memungkinkan lima lampu dan satu pendingin dioperasikan otomatis berdasarkan parameter yang telah diatur. Hasil pengujian menunjukkan intensitas cahaya mencapai 264,8 lux pada pagi hari dan 263,9 lux di siang hari dengan empat lampu menyala, sesuai dengan standar ruang belajar. Sementara itu, pengujian pada sistem HVAC menghasilkan suhu rata-rata ruangan sebesar 30,6°C, yang tidak memberikan dampak signifikan terhadap efisiensi energi. Namun demikian, sistem ini tetap mampu menekan konsumsi listrik hingga ±39% lebih hemat dibandingkan pengoperasian secara manual. Pemanfaatan IoT diharapkan dapat mendukung terwujudnya bangunan pintar yang efisien dan ramah lingkungan.

KATA KUNCI — BH1750, Blynk, DHT22, ESP32, Internet of Things, MQTT

I. INTRODUCTION

Energy efficiency is one of the main issues in building management such as office, school, and public facility. According to Indonesian Ministry of Energy and Mineral Resourced (Kementerian Energi dan Sumber Daya Mineral, ESDM), the energy consumption in Indonesia has increased with the growth rate around 6.5–7% per year [1]. Building sector contributes more than 30% from the entire energy consumption across the world, with lighting, and Heating, Ventilation, and Air Conditioning (HVAC) as the main contributor from this increase based on data from International Energy Agency (IEA). One of the primary factors is the inefficiency in energy usage, particularly in lighting and HVAC systems which resulted in significant energy waste.

One of building components which consumes the most energy is lighting. According to Indonesian National Standard (Standar Nasional Indonesia, SNI) 03-6197-2000, the recommended lighting for study room is 250–500 lux [2]. The best lighting for studying is 300–500 lux to make sure visual comfort. While the ideal room temperature to study is 22°C–26°C with relative humidity between

40%–60%. However, in the reality, there are some buildings which keep using improper lighting and temperature that led to the spike of electricity consumption.

With the technological advancement, Internet of Things (IoT) offers creative solution to manage energy in a building. Through real time data, IoT allows devices to connect and operate automatically. Environmental sensors can also be utilized to act as input for the lighting and HVAC intelligent control system. Previous studies regarding IoT based energy management systems that have been executed by several institutions in Indonesia can reduce electricity consumption up to 30%. This mainly applies to automated lighting and air ventilation system. This is in accordance with the President’s Decree No. 22 2017 about National General Energy Plan (Rencana Umum Energi Nasional, RUEN) which arranges the target to increase national energy efficiency of 17% in 2025.

To achieve the energy efficiency in a building, this research is going to design and develop an IoT-based lighting and HVAC control system in order to manage energy usage with IoT system. The primary component of the system is ESP32, integrated with DHT22 sensor to monitor temperature and humidity, also BH1750 sensor to measure the light intensity. The data from these sensors will be used automatically to control lighting and HVAC system, so the devices only operates when it is required to. As an example, the system will turn on the lighting to fulfill the necessity if the lighting is less than 250 lux. Moreover, HVAC will be controlled based on the standard of ideal temperature on the study room.

It is expected that the more energy can be saved and environmentally friendly with the implementation of this system. The proposed system is not only reducing operational cost and electricity consumption, but also to support the smart building idea which is more responsive to the environmental changes. With the application of IoT, the system can be installed at numerous buildings: school, office, and public facility which shall contribute to greater impact in a sustainable energy conservation effort.

II. LITERATURE REVIEW

Co-simulation method to evaluate the energy saving impact from occupancy based in residence research is done in [3] using EnergyPlus integrated with occupancy simulator and HVAC control via UCEF platform to simulate 6 strategies thermostat control in 5 different climate zones in US. Simulation resulted thermostat-based occupancy can save energy 11-34%, while the adaptive control which adapt the setpoint according to the outdoor temperature can save up to 54% without compromising the residents comfiness with the return on capital less than a year in most of the locations.

Air Conditioner control system information study in [4] pinpointed the monitoring and control of HVAC system based on Wi-Fi technology using CC3200 Texas Instruments microcontroller as Wi-Fi which can increase energy efficiency significantly, node module with touchscreen LCD with all zones, and Raspberry Pi as the central Wi-Fi network, communicating with all devices through MQTT protocol with SSL/TLS encryption. The experiment resulted 75–94% while there is only 1 active zone, and 44% when all zones using AC, compared with single-zone conventional system.

An IoT open-source platform is developed to make management and sensor/actuator integration automatically becomes easier with web interface based on Angular JS, NoSQL database/time-series, and Complex Even Processing (CEP) with event-condition-action rule. The demonstration successfully implemented automatic HVAC system in smart office prototype using Bosch XDK and Raspberry Pi which can adjust real-time room temperature. [5]

Other previous research also showed that the IoT energy management system can reduce electricity consumption up especially for automatic lighting and HVAC [4], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21]. This research affirms the significance of IoT technology to attain national energy efficiency as regulated on President’s Decree No. 22 2017. Even so, the study is limited to a single system and hasn’t integrated simultaneous automatic control between lighting and HVAC in a platform, which make them less optimum for efficiency and user comfort in general.

III. RESEARCH METHOD

This research involves the development of IoT-based system through several steps as shown in Figure 1: literature review, hardware and software design, prototype assembly, empirical system performance testing, analysis, conclusion, and finally the report. At the first phase, literature review is done to understand the fundamentals and relevant technologies–BH1750 sensor, DHT22 sensor, ESP32 development board, and Blynk as control platform. Then, a hardware schematic of the system integration between ESP32 as the main control. The software is developed using an Arduino IDE based programming with MQTT communication protocol to sends real-time data to Blynk app. After the hardware assembly and programme installation, a trial run and system performance test in a 4 × 3 m theory classroom with a SHARP PJ-A26MY-B as its cooling system, eight units of 18-W LEDs in conventional system (former condition of class conventional lighting–without the proposed system), and five units of 30-W LEDs as lightings for IoT system to ensure the system is capable of reading data sensor accurately, and automatically adjust the lighting and HVAC based on the defined standard. The trial run was performed during morning and day time with various parameter, then it is analysed to judge the effectivity of energy efficiency and system response. The collected data is then processed statistically to gain full representation about system performance in context of energy efficiency and user comfort.

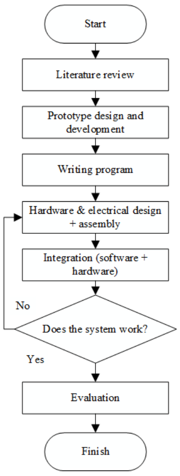

Figure 1. Systematic Overview of the Research Process

Figure 2 is the design of the prototype for a lamp pole consists of: (1) lamp, (2) PVC pipe, (3) panel box, and (4) elbow. System configuration using 5 lamp poles, one pole installed each corner of 4, and a pole at the middle of the theory classroom at Politeknik Manufaktur Bangka Belitung Negeri (Polmanbabel). Each pole has a 30-Watt LED lamp and inside the panel box there are relay and ESP32 as the system main control. This design optimised for lighting distribution and centralised control.

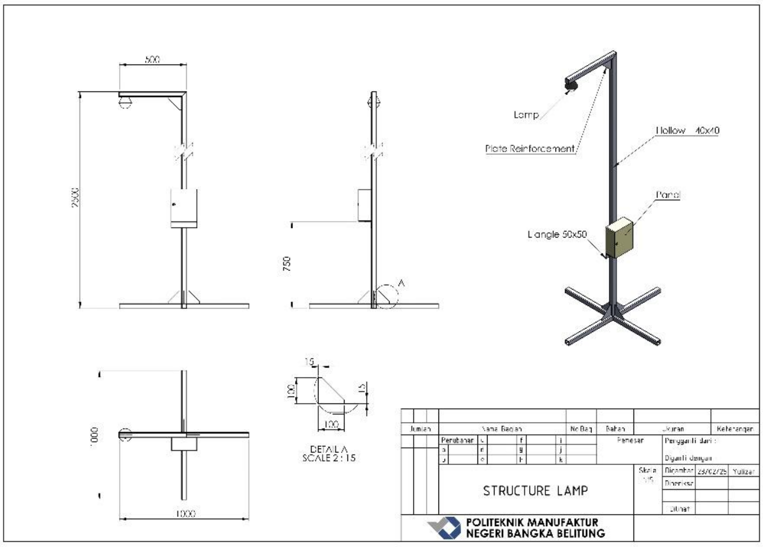

Figure 2. Prototype Design

Hardware design is shown on Figure 3 (a) and (b). The main hardware (Figure 3 (a)) includes ESP32 and a set of relays which control the lightings and HVAC, while the other poles have Wemos D1 Mini with DHT22 sensor to measure temperature and a BH1750 sensor to measure light intensity (Figure 3 (b)).

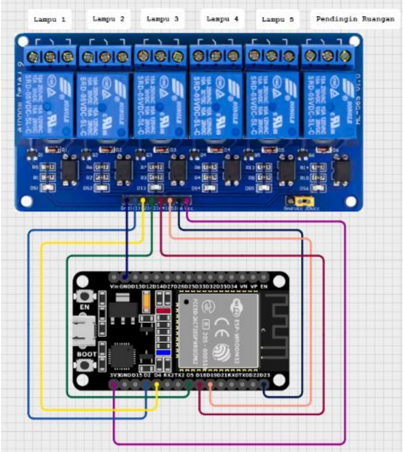

Figure 3 (a). Main Control Schematic

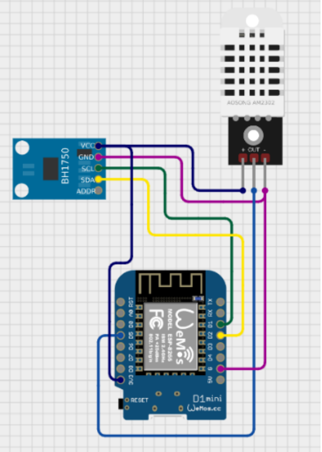

Figure 3 (b). Hardware on 4 poles

Finally, the User Interface of Blynk app which shows the measured light intensity from BH1750 sensor and temperature from DHT22 sensor along with the status of lighting (on/off) is shown on Figure 4.

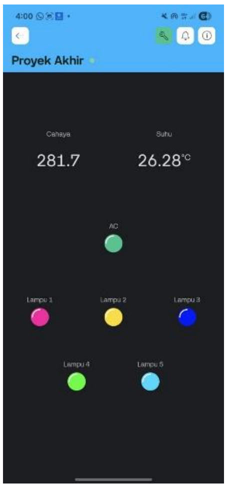

Figure 4. Blynk User Interface

IV. DISCUSSION

The findings proved that the IoT based automation system to control lighting and HVAC at study room in Polmanbabel campus is a significant innovation in the effort to extend energy efficiency and the user comfortability. Four sets of a Wemos D1 mini, BH1750 sensor to measure light intensity and DHT22 to measure temperature at the room are integrated to the main control system, which is ESP32 development board. The system is capable of performing real-time measurement, then automatically configures the lightings and HVAC based on each parameter: lighting at least 250 lux and room temperature between 22°C–26°C. The final product and installation of the proposed research is shown respectively in Figure 5 (a, b, c) and Figure 5 (d).

Figure 5 (a). Main Pole

Figure 5 (b). Hardware on 4 Poles

Figure 5 (c). All 5 Poles

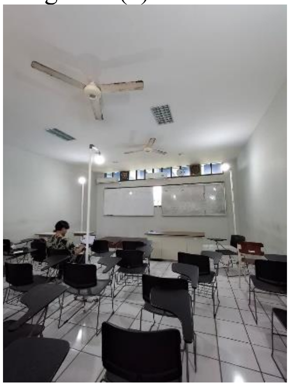

Figure 5 (d). Implementation

A. LIGHTING SYSTEM PERFORMANCE

Based on the implementation, it can be observed that the light intensity inside the study room (theory room at Polmanbabel) is affected by the number of 30W LED lamp being turned on during the class. In the testing which performed during 10.00 AM-11.00 AM as shown in Table I, the initial condition when all lamps off is lower than the minimum SNI 03-6197-2000 standard, which was only 19.22 lux, far below the minimum standard which must be between 250-300 lux. The light intensity increased gradually along with the increment of the lamps being turned on, where a lamp produces 118.12 lux, 2 lamps: 178.54 lux, 233.86 lux, 4 lamps: 264.80 lux. When 4 lamps turned on, the light intensity already fulfils the minimum requirements of the standard, so it can be concluded that 4 lamps are sufficient to provide standard illumination inside the room. Finally, 5 lamps usage provided the highest light intensity (350.24) which is beyond the maximum range of the standard.

TABLE I
PERFORMANCE RESULT DURING 10.00 AM-11.00 AM

No	Lighting Condition	Average Light Intensity (Lux)
1	All lamps off	19.22
2	1 Lamp	118.12
3	2 Lamps	178.54
4	3 Lamps	233.86
5	4 Lamps	264.8
6	5 Lamps	350.24

On the other hand, similar pattern is also visible for the testing during 01.00 PM-03.00 PM as displayed on Table II, even if there is some difference between the initial condition where the natural light intensity during afternoon class is higher (57.54 lux) when all lamps are turned off. This shows that sunlight contributes during the day. With gradual light addition, the light intensity increased. It can be observed from the data that 4 lamps are sufficient to satisfy the standard and 5 lamps turned on surpassed the standard range.

TABLE II
PERFORMANCE RESULT DURING 01.00 PM-03.00 PM

No	Lighting Condition	Average Light Intensity (Lux)
1	All lamps off	57.54
2	1 Lamp	118.12
3	2 Lamps	174.40
4	3 Lamps	216.88
5	4 Lamps	263.90
6	5 Lamps	348.80

Data visualisation on Figure 6 (a) and 6 (b) shows the lighting dynamics during testing. Figure 6 (a) shows 10.00 AM-11.00 AM shows first light intensity was below 50 lux, then steadily increased to more than 350 lux at the end of time. While Figure 6 (b) was a data visualisation during 01.00 PM-03.00 PM. The comparison between 2 different times indicates that during day, the standard is easier to achieve with minimum lamps rather than morning.

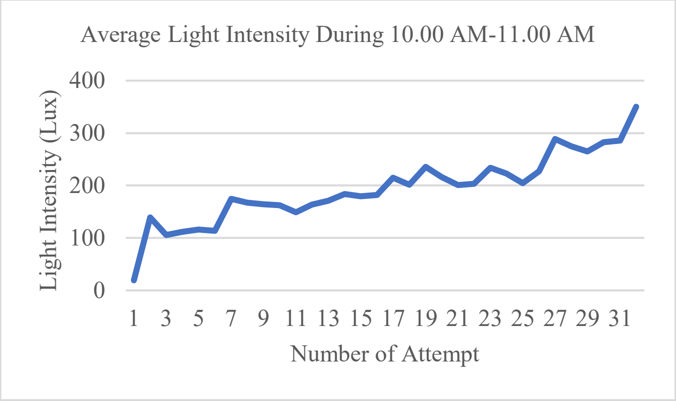

Figure 6 (a). Average Light Intensity During Morning Class

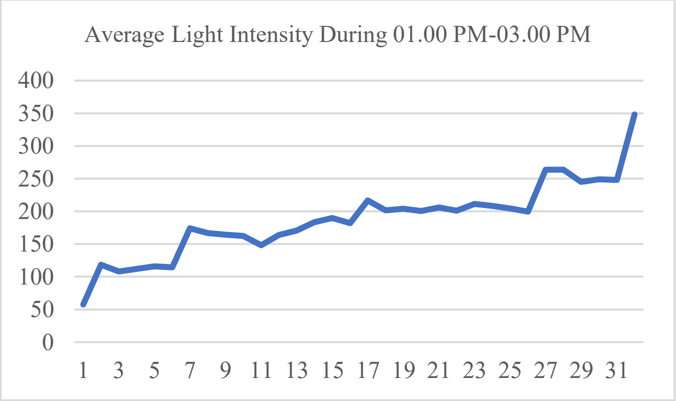

Figure 6 (a). Average Light Intensity During Afternoon Class

B. HVAC PERFORMANCE

HVAC performance testing is carried out to take room temperature data in Celsius during 04.00 PM-05.00 PM (GMT +7). This time selection is based on the room temperature which reached its peak during afternoon due to the accumulated heat from sun radiation all day. This period is the best worst-case scenario to evaluate automatic HVAC system to cool down the temperature effectively. Data in Table III was taken every 10 minutes to routinely monitor the temperature and judging the system's response against temperature change. Monitoring was done in a 4 × 3 m room using DHT22 sensor connected with IoT system, so that the cooling fan can work automatically according to the real-time temperature reading.

TABLE III
AVERAGE ROOM TEMPERATURE DURING 04.00 PM-05.00 PM

No	Time (PM)	Average Temperature (°C)
1	04.00	32.0
2	04.10	30.8
3	04.20	30.0
4	04.30	29.9
5	04.40	30.0
6	04.50	29.7
7	05.00	29.7

C. ENERGY EFFICIENCY AND SAVING

Energy efficiency is a crucial factor in automatic IoT-based system. The power of electricity of a device can be calculated by using:

$$P = V \times I \qquad (1)$$

Information:
P = Power (Watt)
V = Voltage (Volt)
I = Current (Ampere)

While the electric energy consumption formula is:

$$E = P \times t \qquad (2)$$

E = Energy consumption (Wh or kWh)
P = Power (Watt)
t = Time (hour)

The developed automatic system includes:

TABLE IV
POWER CONSUMPTION OF THE USED COMPONENTS

Components	Quantity	Power Consumption per Unit (Watt)	Subtotal of Power Consumption (Watt)
ESP32	1	0.80	0.80
Wemos D1 Mini	5	0.35	1.75
DHT22 Sensor	5	0.0125	0.0625
BH1750 Sensor	5	0.0006	0.003
Relay (3 active channels)	1	1.05	1.05
Total Power Consumption			**3.6655**

With the assumption that the system works 8 hours per day, then the daily power consumption per day is:

$$E = P \times t = 3.6655 \times 8\ hours = 29.324\ Wh = 0.0293\ kWh \qquad (3)$$

Which means the system only consume: $0.0293\ kWh \times 30\ days = 0.8796\ kWh$.

Next, the electricity usage of lamps is calculated into 2 scenarios: automatic system (the proposed system) and conventional system. Based on the calculation, the proposed system can save up to 54% energy per month in lighting usage.

TABLE V
POWER CONSUMPTION COMPARISON BETWEEN PROPOSED SYSTEM VS CONVENTIONAL

Parameter	Condition 1 (Automatic Proposed System)	Condition 2 (Conventional)
Number of Lamps	5	8
Power per Lamp (Watt)	30	18
Average Daily Usage (Hour)	4	8
Daily Energy Consumption (kWh)	$5\ lamps \times 30\ W \times 4\ h = 600\ Wh$	$8\ lamps \times 18\ W \times 8\ h = 1.152\ Wh$
Monthly Energy	$0{,}6\ kWh \times 30\ days + 0.8796 = 18.8796\ kWh$	$1{,}152\ kWh \times 30\ days = 34.56\ kWh$

Finally, the HVAC energy saving calculation is shown on Table VI. The proposed system can save up to 39% energy per month in HVAC usage according to the calculation.

Parameter	Condition 1 (Automatic System)	Condition 2 (Conventional / No System)
Power Consumption (W)	65	65
Total Operation Period per Day (hour)	8	8
Effective ON Time per Day (hour)	6	8
Daily Energy Consumption (kWh)	0.39	0.52
Monthly Energy Consumption (kWh)	11.7	15.6

D. SYSTEM ADVANTAGES AND LIMITATION

The main advantage of this system is its ability to perform automatic adjustment without the needs of human intervention, so in helps to enhance user comfortability and energy efficiency at the same time. By utilising MQTT protocol to send data and Blynk as its interface, this system provides easy access of remote monitoring and control which supports the smart and sustainable building concept. The integration of 2 aspects: lighting and HVAC in the proposed system can fulfil the SNI standard.

However, there are several limitations which needs to be noted, such as the average temperature which was still relatively high and HVAC was still not optimal, shows that there needs to be more parameter setting and advanced control system to gain more efficiency.

V. CONCLUSION

The test results and analysis have proven that the Internet of Things-based lighting and HVAC control system, which has been developed, works effectively and responds according to the given parameters. The remote monitoring feature via Blynk has shown optimal performance in monitoring real-time room conditions. Test results showed an average light intensity of 265 lux with four 30-Watt lamps and the average room temperature of 30.6°C using a fan (Sharp PJ A26MY-B). System implementation is capable of saving energy consumption up to 54% for lighting and up to 39% for HVAC (compared to conventional conditions) during a one-month trial. This indicates the potential of IoT technology to enhance energy efficiency in building automation systems.

Further development can be enhanced through: an automatic alarm and circuit breaker as a security system to detect harmful conditions, remote notification for early warning system trouble, and the usage of high-quality sensors to improve the accuracy of environmental parameters. These developments are hoped to enhance performance, security, and system reliability.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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