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Energy Efficiency Analysis of LED, CFL, and Incandescent Bulbs with Smart Energy Management (SEM) Technology

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ABSTRACT

This study focuses on the comparative energy efficiency analysis of LED, CFL, and incandescent bulbs to assess the potential savings offered by LED technology. With growing global concerns about energy consumption and carbon reduction, it is essential to evaluate lighting options based on energy efficiency. Incandescent bulbs, though widely used, are inefficient as they emit more energy as heat than light. Compact Fluorescent Lamps (CFLs) are more energy-efficient but have a shorter lifespan compared to LEDs, making them less environmentally friendly. In this research, the real-time power consumption of each bulb type is measured using ACS712 and ZMPT101B sensors, connected to an Arduino Uno R3 microcontroller. The ACS712 sensor is used to monitor electrical current, while the ZMPT101B sensor detects voltage, enabling accurate energy consumption calculations. All bulbs are tested under identical conditions, providing clear, comparative data on their energy efficiencies. The analysis demonstrates that LED bulbs not only offer lower energy consumption but also result in long-term environmental and economic benefits. These findings suggest significant savings in electricity costs, supporting the shift towards energy-efficient LED lighting.

Keyword : Energy Consumption Analysis, Energy Efficiency Comparison, Smart Energy Management (SEM) Technology.

INTRODUCTION

With the increasing awareness of the need for energy conservation and the environmental impact of energy consumption, the lighting sector has become a major focus in efforts to improve energy efficiency. Conventional lighting using incandescent bulbs has been one of the largest contributors to energy consumption in households and the commercial sector. Although incandescent bulbs are affordable and provide adequate illumination, they are highly inefficient because most of the energy consumed is converted into heat rather than light [1]. As an alternative, Compact Fluorescent Lamps (CFL) and Light Emitting Diodes (LED) were introduced to replace incandescent bulbs, claiming lower energy consumption and longer lifespans [2][3]. However, despite the growing popularity of LED technology, many consumers still question whether the higher initial cost of purchasing LED bulbs is truly worth the long-term energy savings [4].

The main issue in selecting lighting sources is the low energy efficiency of incandescent bulbs, which are still widely used in many households. Incandescent bulbs consume more energy to produce light, and most of that energy is wasted in the form of heat. Meanwhile, CFLs offer better efficiency but have the downside of shorter lifespans and the use of hazardous materials such as mercury, which can pollute the environment if not disposed of properly [5]. On the other hand, while LED bulbs offer significant advantages in terms of efficiency and durability, their higher purchase cost often becomes a barrier for many consumers to switch from incandescent or CFL bulbs [6]. Therefore, although LED lighting technology promises significant energy savings, more solid evidence comparing the energy consumption of LED, CFL, and incandescent

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bulbs is needed to motivate consumers to make the switch to LEDs [7].

To address these issues, this study aims to provide clear quantitative evidence regarding the energy consumption comparison between LED, CFL, and incandescent bulbs using accurate measurement tools. In this study, the ACS712 sensor will be used to measure the current consumed by each type of bulb, while the ZMPT101B sensor will be used to measure the voltage received by these bulbs. The collected data will be analyzed to calculate the power consumption of each bulb type over the same time period. This data processing will be carried out using an Arduino Uno R3 microcontroller, enabling real-time and precise power measurements [8][9]. Through this experiment, it is expected to be proven that LED bulbs are indeed far more energy-efficient compared to incandescent and CFL bulbs. The results of this research will not only provide accurate technical information about the energy consumption of lighting but also serve as a reference for the public to choose more energy-efficient LED bulbs as a sustainable and cost-effective lighting solution in the long run [10][11].

METHOD

Smart Energy Management (SEM) represents a cutting-edge approach to addressing the challenges of energy consumption and sustainability. It integrates advanced technologies such as sensors, Internet of Things (IoT) devices, and data-driven systems to create a comprehensive framework for monitoring, analyzing, and controlling energy usage in real-time. By leveraging these intelligent solutions, SEM enables precise tracking of energy consumption patterns and provides actionable insights to optimize efficiency. The core objective of SEM is to enhance energy utilization while minimizing waste and reducing operational costs. It achieves this by employing real-time data analytics to identify inefficiencies, predict energy demands, and implement automated controls that adjust consumption to actual needs. Moreover, SEM plays a vital role in supporting sustainability initiatives by promoting the adoption of energy-saving practices and reducing carbon footprints.

Through its ability to connect multiple devices and systems, SEM ensures seamless integration across various sectors, including residential, commercial, and industrial applications. It empowers users to make informed decisions about their energy usage, fosters greater transparency, and drives the transition towards smarter, more sustainable energy management practices. As a result, SEM not only contributes to cost savings but also aligns with global efforts to mitigate environmental impact and build a more energy-efficient future[12].

RESULTS AND DISCUSSION

This research aims to design and develop a prototype tool that can monitor and analyze the power consumption of various types of light bulbs, namely LED, incandescent, and CFL (Compact Fluorescent Lamp). The system developed focuses on monitoring power consumption, measuring the voltage and current flowing through the lamps, and calculating the cost efficiency of energy usage for each type of lamp.

The Arduino Uno R3 microcontroller acts as the central processing unit for the input data from the sensors. The data obtained from the sensors is then displayed in real-time on the LCD 20x4 connected to the system, making it easier for users to monitor and analyze information related to energy consumption directly.

This system utilizes two main sensors:

1. ACS712 Current Sensor: This sensor is used to measure the electric current flowing through the lamp. The ACS712 sensor has a specification of up to 30A, allowing it to accurately measure current across a wide range.
2. ZMPT101B Voltage Sensor: This sensor is used to measure the electrical voltage supplied to the lamp. The ZMPT101B enables precise voltage measurement, which is crucial for calculating the power consumption of each lamp.

With the combination of these two sensors, the system can calculate the power used by each lamp using the power formula ***P=V×I***, where ***P*** is the power in watts, ***V*** is the voltage in volts, and ***I*** is the current in amperes, ***R*** is resistance with units of Ohm (Ω).

$$P = V\,x\,I \;\; atau \;\; P = \frac{V^2}{R} \qquad \text{.................... (1)}$$

$$P = \frac{W}{t} \qquad \text{.. (2)}$$

Additionally, the system can calculate the cost of using each lamp by considering the applicable electricity rate, allowing users to compare the electricity costs of each type of lamp.

This tool is designed to provide accurate data on the energy efficiency of each lamp, enabling users to select the most energy-efficient and cost-effective lighting solution. The results of this research are expected to provide insights into energy efficiency in lighting systems and contribute to energy cost savings in households or industries.

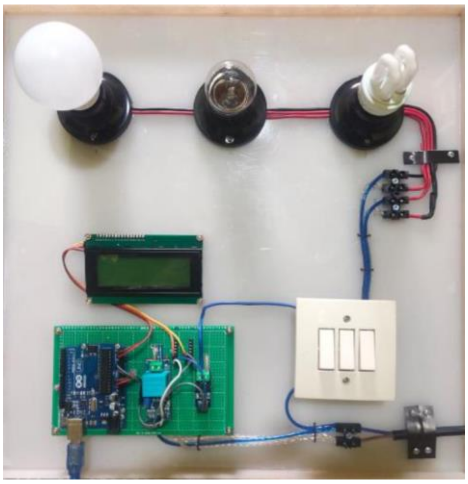

Figure 1 Tools for measuring light

Figure 2 Display for the results of the light measurement test

Based on the test results that have been carried out, it can be concluded that incandescent lamps consume more electricity, which is around 6-12 Watts with a 5 Watt lamp specification, so that electricity usage becomes more wasteful. Because the light produced by incandescent lamps is from the heating process, the stability of the electric current determines whether the lamp is on or not. In the test results, CFL lamps use power consumption ranging from 5-6 Watts and it can be said that the lamps are expensive, and are no longer widely sold because these lamps also produce heat and are not very bright. The best lamp to save electricity costs is an LED lamp with a power consumption of 4-6 Watts. Because it uses LED (Light Emitting Diode) technology and makes the lamp very energy efficient and brighter. LED lamps can save up to 90% energy compared to incandescent lamps. 95% of the energy from LED lamps is used to produce light, and the remaining 5% produces heat. Based on the test, it can also be seen that there are differences in the calculation results between the tool system and mathematical calculations. Because the monitoring results carried out by the sensor also have an error tolerance, namely for the ACS712 current sensor between 0% and 1.5% and for the ZMPT101B voltage sensor between 0% and 0.5%. The monitoring results from the sensor are also displayed in decimal form, so that rounding of numbers by the system on the microcontroller may occur.

Table 1 Test Results of Various Lamp Brands

No	Lamp Brands	Average Price (Rp.)	A	V	W	Cost (Rp.) Electricity 2200 VA
1	LED Philips	29.000	0,24	220,23	5,23	Rp. 7.67
2	LED In-Lite	18.000	0,24	220,23	5.23	Rp. 7.67
3	LED Pion	6.000	0,21	220,23	4,65	Rp. 6.83
4	LED Morgen	15.000	0,26	220,23	5,80	Rp. 8.51
5	LED Volvo	10.000	0,34	220,23	7,53	Rp. 11.05
6	CFL Philips	40.000	0,24	220,23	5.23	Rp. 7.67
7	CFL Broco	34.000	0,24	220,23	5.23	Rp. 7,67
8	CFL INS	29.000	0,26	220,23	5,80	Rp. 8.38
9	CFL VIGA	30.000	0,29	220,23	6.38	Rp. 9.21
10	CFL OMI	25.000	0,26	220,23	5,80	Rp. 8.38
11	Bulb Chiyoda	13.000	0,29	220,23	6,38	Rp. 9.21
12	Bulb Procyon	7.000	0,42	220,23	9.26	Rp. 13.37
13	Bulb Lumment	12.000	0,53	220,23	11,56	Rp. 16.69
14	Bulb Pioline	5.000	0,58	220,23	12,71	Rp. 18.35
15	Bulb Hemat	7.000	0,58	220,23	12,71	Rp. 18.35

The results of the table above are measured one by one using the following formula:

Power calculation

$$P = V \times I$$

$$P = 220{,}23 \times 0{,}24$$

$$P = 5{,}28 \text{ Watt}$$

Calculation of lamp usage costs

$$P = \frac{\text{Watt} \times 1444}{1000}$$

$$P = \frac{5{,}28 \times 1444}{1000}$$

$$\text{Price} = \text{Rp. } 7.62 \text{ /kWh}$$

CONCLUSION

The research compares various types of lamps (LED, CFL, and Incandescent Bulb) from different brands based on average price, current (***A***), voltage (***V***), power (***W***), and estimated monthly electricity cost assuming a power usage of 2200 VA. This data enables a comparative analysis of the efficiency, costs, and electrical characteristics of each type of lamp.

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Analysis Based on Lamp Type:
LED (Light Emitting Diode): Generally, LED prices vary significantly, ranging from IDR 6,000 to IDR 29,000. The power consumption (W) is also relatively low, ranging from 4.65 W to 7.53 W. This suggests that LEDs tend to be more energy-efficient compared to other lamp types.
CFL (Compact Fluorescent Lamp): The price of CFLs tends to be more stable compared to LEDs, ranging from IDR 25,000 to IDR 40,000. Power consumption is relatively similar to some LEDs, at around 5.23 W to 6.38 W.
Incandescent Bulb: This type of lamp shows the highest power consumption, ranging from 6.38 W to 12.71 W, with a relatively low price range from IDR 5,000 to IDR 13,000. This confirms that incandescent bulbs are less energy-efficient compared to LEDs and CFLs.

Analysis Based on Price and Efficiency:
There is not always a linear correlation between price and efficiency. Some LEDs with higher prices do not necessarily have the lowest power consumption. For instance, the Philips LED (IDR 29,000) and In-Lite LED (IDR 18,000) have the same power consumption (5.23 W).
Incandescent bulbs, despite being the cheapest, have the highest operational (electricity) costs due to their high power consumption. This indicates that although the initial investment is low, the long-term costs are higher.

Analysis Based on Electricity Costs:
The monthly electricity cost varies significantly, ranging from IDR 6.83 for the Pion LED to IDR 18.35 for some incandescent bulbs. This difference emphasizes the importance of considering energy efficiency when selecting lamps to reduce operational costs.

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