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Original Article

The Potential Energy Saving in Lighting Systems on Campuses in Tropical Areas: A Combination of Natural and Artificial Light

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Abstract: Energy consumption continues to increase and is predicted to increase by up to 30 percent by 2040. Therefore, systematic efforts are needed to reduce energy use, including using natural lighting in lighting systems inside buildings. The object of this study is the library room in the Electrical Engineering Department building, Universitas Andalas, Indonesia, to calculate the potential for energy savings with a lighting automation strategy with dimming control. Measurement of natural light level at three work nodes has been determined for one week as reference data. The shortage of artificial light required and the electrical energy consumed is calculated by referring to the minimum standards for room lighting intensity. On the basis of each lamp's working hours and power, the potential for energy savings in the lighting system of the object can be determined. This study found that the potential for saving energy consumption for one week at three different nodes was 32.3, 64.2, and 82.8 percent. This study concludes that the maximum value reached 893 lux on Tuesday at 13:00 at node C, and the lowest was 3 lux on Saturday at 15:00 WIB at node A. Node C had an average light intensity of 402.298 lux, and node B had an average of 206.765 lux during the week. In contrast, node A has the lowest lux average, with 87,711 lux in one measurement week. Also, with the combination of natural and artificial light sources with dimming control strategies, the voltage values given to each lamp range from 0 to 180 VAC. Potential savings in energy consumption by combining natural and artificial light with dimming control strategies in the library room with three different nodes (A, B, C) are 32.3, 64.2, and 82.8 percent.

Keywords: Energy saving; Natural and Artificial Light; Light dimming control.

1. Introduction

World energy consumption has doubled in the last 40 years and is predicted to increase by around 30% by 2040 (Lewis et al., 2018). According to statistical calculations, there is a potential for 20–40% energy savings in buildings that can be achieved if steps can be taken to increase buildings' energy efficiency (Chirarattananon & Taveekun, 2004; Hong et al., 2015). One approach to reducing energy use, especially electrical energy in the building sector, is energy conservation on the usage side (Yan et al., 2017). Regarding electrical energy consumption, the characteristics of electrical energy use in tropical areas will differ from those in non-tropical areas (Belussi et al., 2019). A study of buildings for educational facilities in Malaysia, which has a tropical climate, found that utilizing natural light without artificial light during operational hours can reduce artificial lighting energy use by up to 100% on regular days (Mahyuddin et al., 2022). It was found that potential savings of 24.5% were obtained by regulating natural and artificial light sources in China. The use of natural light sources integrated with artificial light sources with dimming techniques is also mentioned that can achieve savings of around 65% -78% (Han et al., 2019; Hong et al., 2015; Pandharipande & Caicedo, 2011).

Combining natural and artificial lighting in buildings has also been found to save energy consumption by up to 20-25% in tropical areas (Pujani et al., 2020; Wijaya et al., 2019). Natural lighting is light emitted directly by the sun. Natural lighting in a building is determined by sky conditions and the use of reflected light from outside into the building. Natural lighting can be good during the day between 08.00 and 16.00 local time. It also has enough light entering the room, and the light distribution is even and does not cause disturbing contrast (Megginson, 2007). Meanwhile, artificial lighting is produced by sources other than natural light. Artificial lighting is necessary in rooms where it is difficult to get natural lighting or when it is insufficient. Research on indoor natural lighting systems has been conducted using various methods. Analysis has also been carried out regarding the study of the potential for natural light to be used in buildings in Malaysia using light pipe systems (Kadir et al., 2016). The research was carried out by looking at the response of the light pipe system to differences in sky conditions. This research shows that the sky's condition influences the amount of light entering the room.

In other research, natural lighting has been optimized in spaces, resulting in lighting system conditions based on standardization (Nurhaiza & Lisa, 2019). This research measured light intensity using a lux meter, and the data varied with time. In other research, the same study has also been carried out, but the analysis was carried out with different variables (Wika & Jamala, 2020). The research only looked at how big the influence of natural lighting entering the room was and did not discuss energy saving opportunities. In a previous study at the Universitas Andalas Campus, Padang, which is in a tropical area, an analysis of energy use during the April 2019 period was also carried out in faculty buildings for administration, lecture buildings, and libraries (Pujani et al., 2019). This study found opportunities for the efficiency level in using electrical energy during working hours with a 9-21% value range. The total electrical energy consumption in the Faculty of Engineering building at Universitas Andalas reached 10,710.22 kWh in a week.

In contrast, the electrical energy consumption of the Electrical Engineering Department building was worth 1239.33 kWh. Lamps are the most widely used electrical equipment after air conditioning, with 25% or 1782.29 kWh of energy consumption per week (Pujani et al., 2020). Strategies that can be implemented to save energy include energy management policies, changing people's habits regarding energy use, and using automation (Pujani et al., 2019). This strategy also applies to room lighting systems. Several approaches for automating lighting has been introduced, such as on/off control (Kaminska, 2020), time-scheduling (Qahtan et al., 2019), occupant detection (Papinutto et al., 2022), retrofitting (Al-Ghaili et al., 2020), constant illumination (Han et al., 2019) and dimming control (Kaminska & Ożadowicz, 2018). In previous research, dimming control contributed to more than 30% of energy savings compared to implementing on/off control (Kaminska, 2020). Therefore, in this research, a study was carried out on the potential for saving electrical energy consumption in one of the rooms in the Electrical Engineering Building with a lighting system automation strategy with dimming control.

2. Materials and Methods

In this study, the potential for energy savings will be calculated by measuring the natural lighting that the study room already has and calculating the need for artificial light sources needed to achieve the minimum lighting level for the room. In this study, we assume the minimum lighting level is 350 lux at each work node, which follows the standard average lighting level in reading rooms (SNI 03-2396-2001, 2001).

2.1. Object of the Study

The object of this research study was the library room located in the Electrical Engineering Department Building, Universitas Andalas campus, in the Limau Manih area, Pauh, Padang. This building is located at -0.9141140032777805,100.46501315472173. Meanwhile, the library room is on the 3rd floor in one corner. An aerial view of the room can be seen in Figure 1, and the object of study is marked with a yellow box that is shaded.

Figure 1. Aerial View of the Study Object Marked with a Yellow Striped Box

This room measure 13 x 4.5 x 3 in length, width, and height, each measured in meters. Currently, this room has six lights installed in 3 rows, with two lamps per row. The distance between rows is 3.6 meters. Currently, LED lights with 19-Watt power and 250 lux are installed at each light node. This room is also equipped with one glass door with an aluminum frame measuring 0.9 x 2 m for access in and out. This door is located southwest of the room. Figure 2 shows the top view of the room.

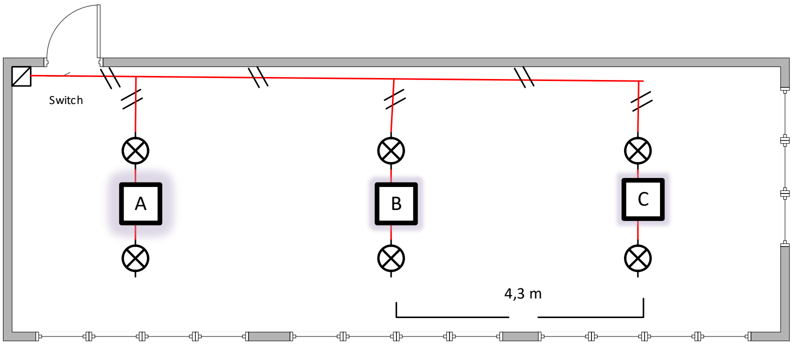

Figure 2. Top View of the Library Room with Installed Light

This room has two sides facing the outside of the building, namely the northeast and northwest sides. The other side is adjacent to another room. The northeast side is also equipped with three glass windows, 3.6 x 1.8 each, arranged symmetrically to each other. On the northwest side, a glass window of 2.7 x 1.8 meters. Figure 3 show the room's northeast and northwest sides with the existing windows.

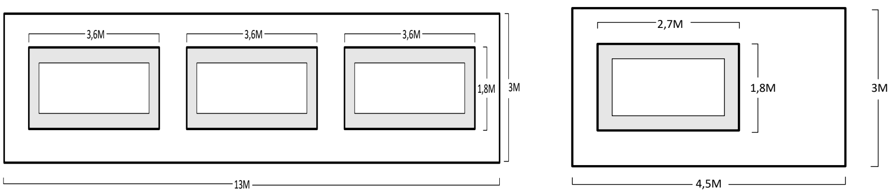

Figure 3. Northeast and Northwest Side include Glass Installed of Object

All windows are installed with permanently installed glass or can be opened for air circulation. Because the position of the room with the installed windows is closer to the east and north sides, the sunlight in the room tends to be higher in the morning to afternoon (06.00-12.00 WIB).

2.2. Measurement of Room Illuminance Level

This study used three work nodes on a working table with a height of 0.75 meters from the floor surface. The workbench is at the center node between 2 lamps in each row. They are located parallel and symmetrical in each row of lights. Each work node is labeled with nodes A, B, and C. The placement of work nodes can be seen in Figure 4.

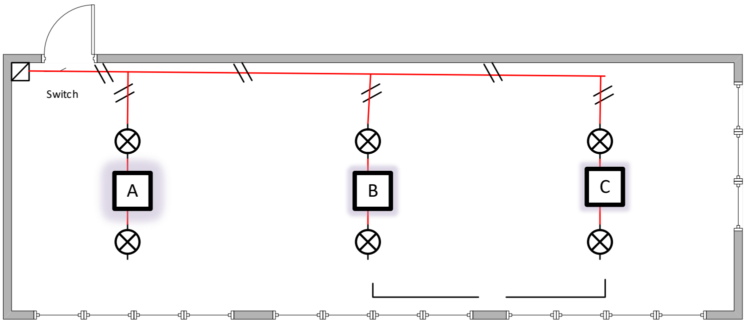

Figure 4. Distribution of Specified Measuring Mode

Work node measurements will be taken every 30 minutes from 08.00 AM to 4.00 PM at each work node using a measuring instrument consisting of light sensor components, Arduino's microcontroller, a real-time clock, and a micro-SD module. The BH1750 sensor records the light intensity, and the RTC module records the recording time. The results of the BH1750 sensor reading will be processed by the microcontroller and stored on the microSD card. The circuit block of the light intensity measuring instrument can be seen in Figure 5.

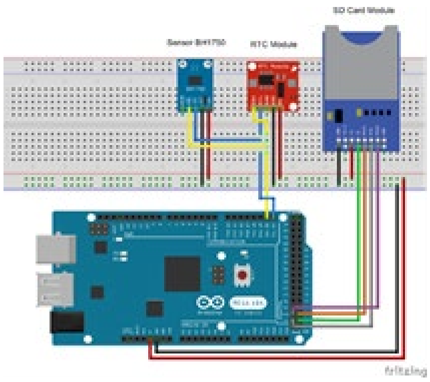

Figure 5. Schematic of a Light Intensity Measuring Instrument

2.3. Calculation of Energy Saving Potential

In this study, a graphical approach will be taken to calculate the lux deficiency required from each measurement time to reach the minimum lighting intensity set (350 lux). From each lux required, the power and energy requirements will be calculated. Assuming the relationship of lux produced is linear to the power produced, the power and energy requirements per day can be calculated. After that, the potential for energy savings requires calculating energy consumption daily. Energy consumption savings are obtained using equations (1) and (2).

Savings = Total current energy consumption - energy consumption with dimming strategy, (1)

$$\%\ \text{Savings} = \frac{\text{Total Energy Saving}}{\text{Total Current Energy Consumption}} \text{X}100\% \quad (2)$$

The value and percentage of potential energy savings are obtained based on reducing the total electrical energy consumption.

3. Results

3.1. Measuring the Light Intensity of the Room

Measurements were taken at each working node that had been previously determined. Measurements were carried out for one week from 08.00 to 16.00 WIB on 10 to 16 November 2023. The measurement results can be seen in Figure 8.

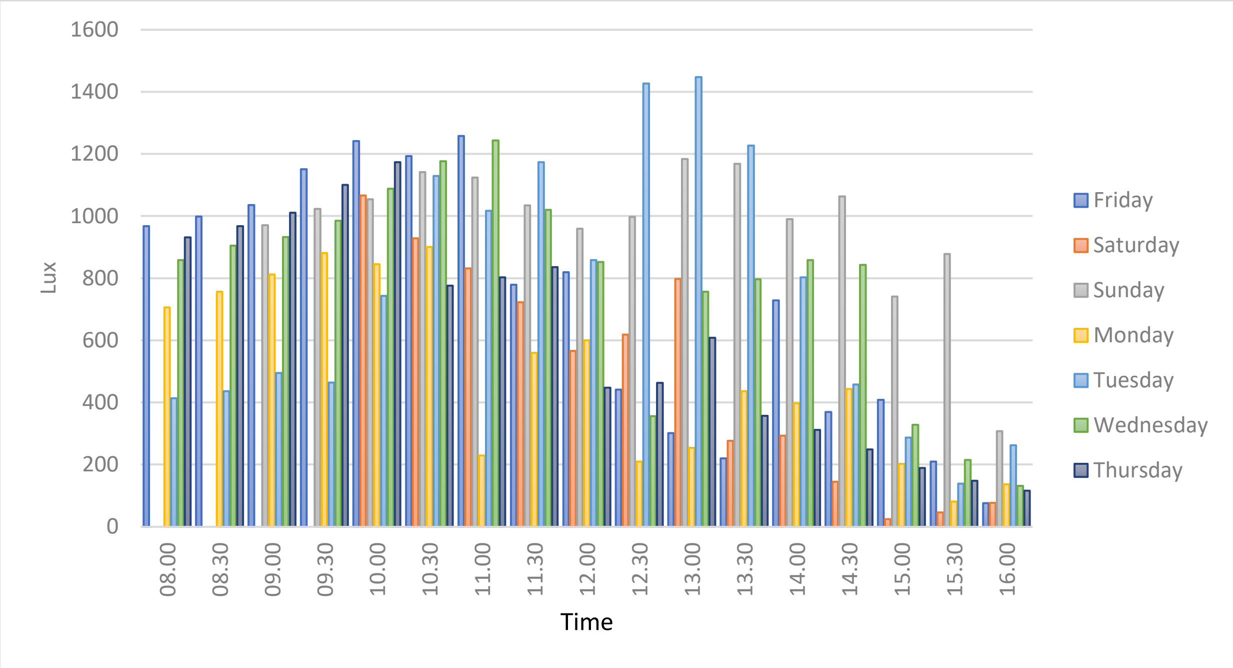

Figure 6. Results of room light intensity measurements during the measurement period

The maximum value reached 893 lux on Tuesday at 13:00 at node C, and the lowest was 3 lux on Saturday at 15:00 WIB at node A. Node C had an average light intensity of 402.298 lux, and node B had an average of 206.765 lux during the week. In contrast, node A has the lowest lux average, with 87,711 lux in one measurement week. It can be concluded that the light intensity value of node C tends to be high because this node gets more natural light sources from the windows on the east and northwest sides of the room. On Tuesday, 14 November 2023, the lux change at node C also tends to increase in the time range of 08.00 WIB to 13.30 WIB and tends to decrease after that. It shows that the lux change at node C is strongly affected by the sun's direction at that time, as shown in Figure 7.

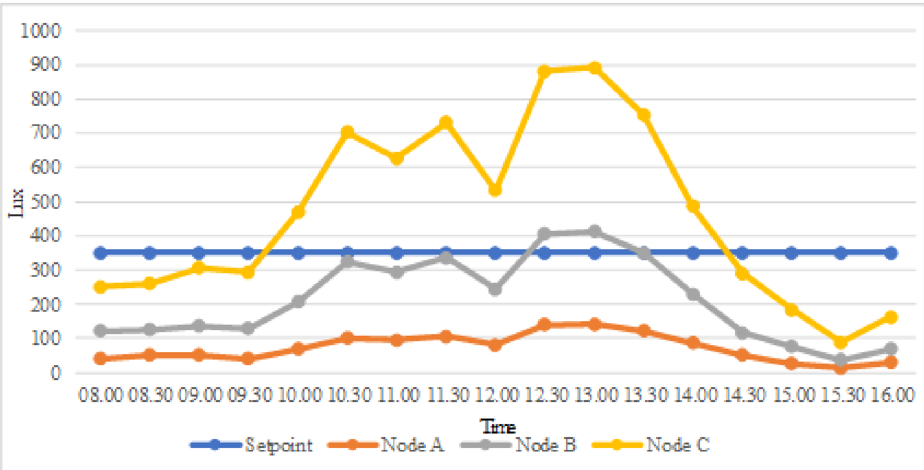

Figure 7. Results of light intensity measurements at all points on Tuesday, November 14 2023.

Different things happen at nodes A and B, which only have a lower average lux than node C because these two nodes only get natural light from one side. In addition, the lux changes every time at nodes A and B is insignificant compared to node C.

3.2. Lux Requirement

To compare the requirement and existing lux at each node over time using data on Tuesday, 14 November 2023, we can find it in Figure 9. The existing and required lux are compared in Figure 9 for nodes A, B, and C. Figure 8 is depicted in 2 bar graphs, each showing the current and required lux.

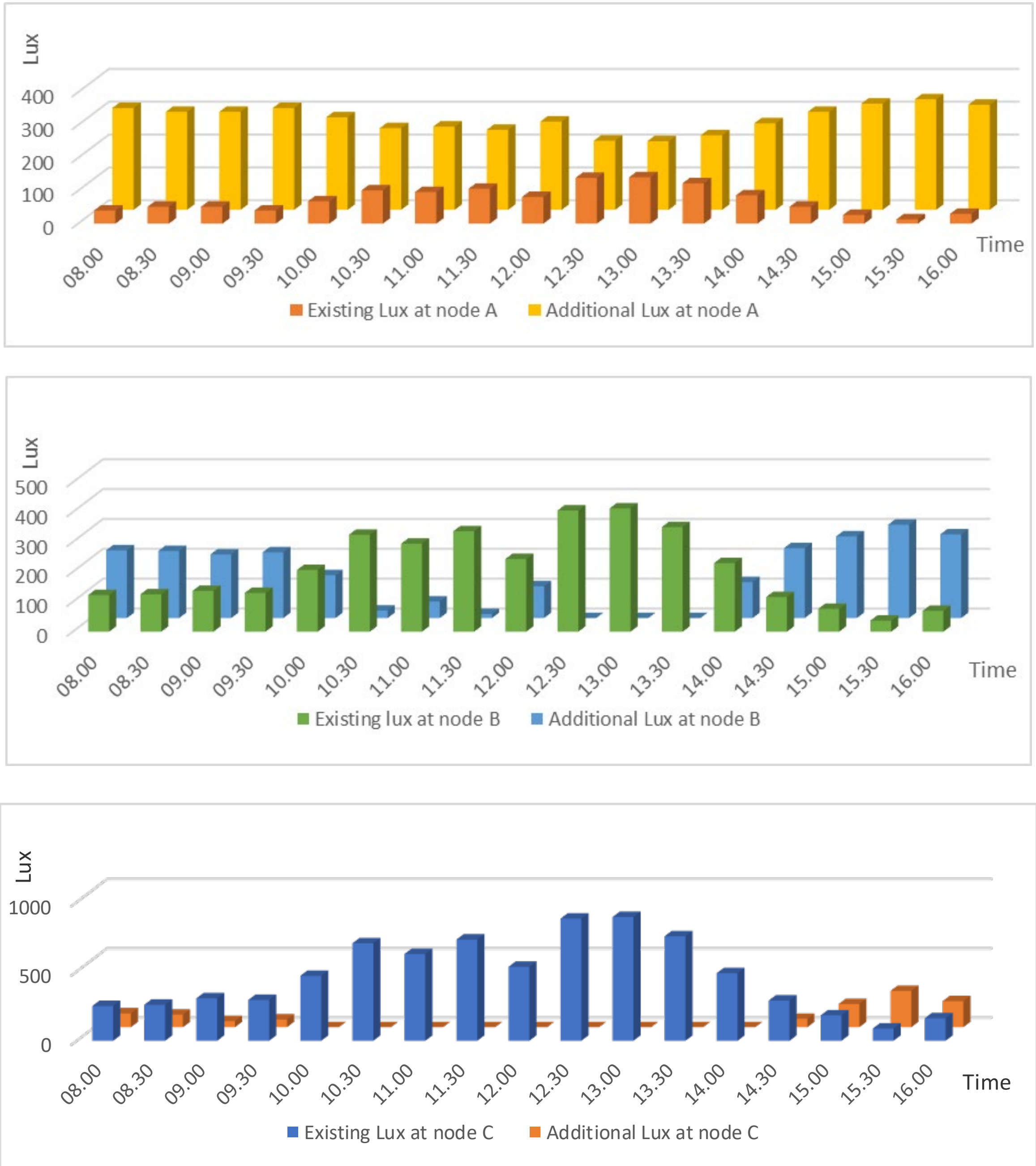

Figure 8. Existing and proposed additional lux at each node

3.3. Power Requirements Analysis

The power requirement at each node can be calculated from the lux requirement at each node. For example, the power requirement on Tuesday, 14 November 2023, is shown in Figure 10. To meet the changing lighting power requirements is indirectly proportional to the square of the voltage applied to each lamp if it is assumed that the lamp load is resistive. The strategy used in this study is dimming control with varying voltages required to perform the dimming control strategy.

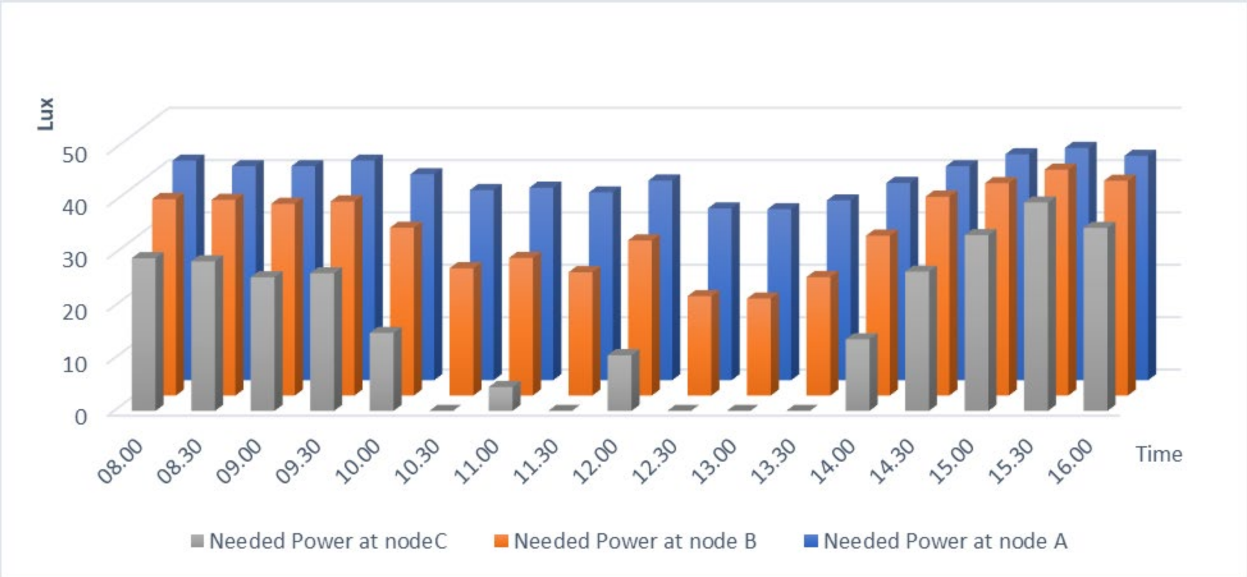

Figure 9. Result of power needed at each node

Using a 19-watt LED lamp, we can define R as equal to 2547.36842 Ω if we assume 220 V as an input voltage. Using the estimated value of R, we can also calculate the voltage given to each lamp. Figure 11 shows a graph of the voltage each lamp will use at each working node.

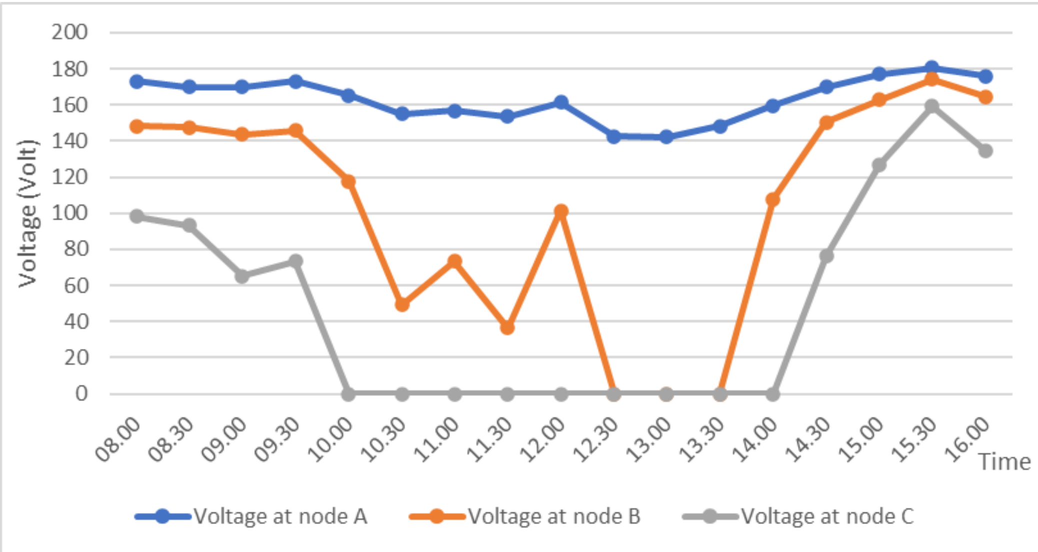

Figure 10. Result of Voltage needed for each lamp at node

The energy needed at any time can be calculated from the required power. In the tests that have been carried out with the initial condition of the room lux at 0, it is found that 250 lux is produced by a total of 38-watt installed lights (2 x 19-watt LED lights) at the sample node. Therefore, assuming the power is linear to lux at the test node, the relationship between power and lux is obtained in Equation 3.

$$\text{Power} \approx 0{,}152 \text{ X Lux} \quad (3)$$

By using equation 3, the power requirement at each node can be calculated. Figure 11 compares the power required at each time with the current power used. Based on the results of Figure 12, the energy used from 08.00 to 16.00 WIB can also be calculated.

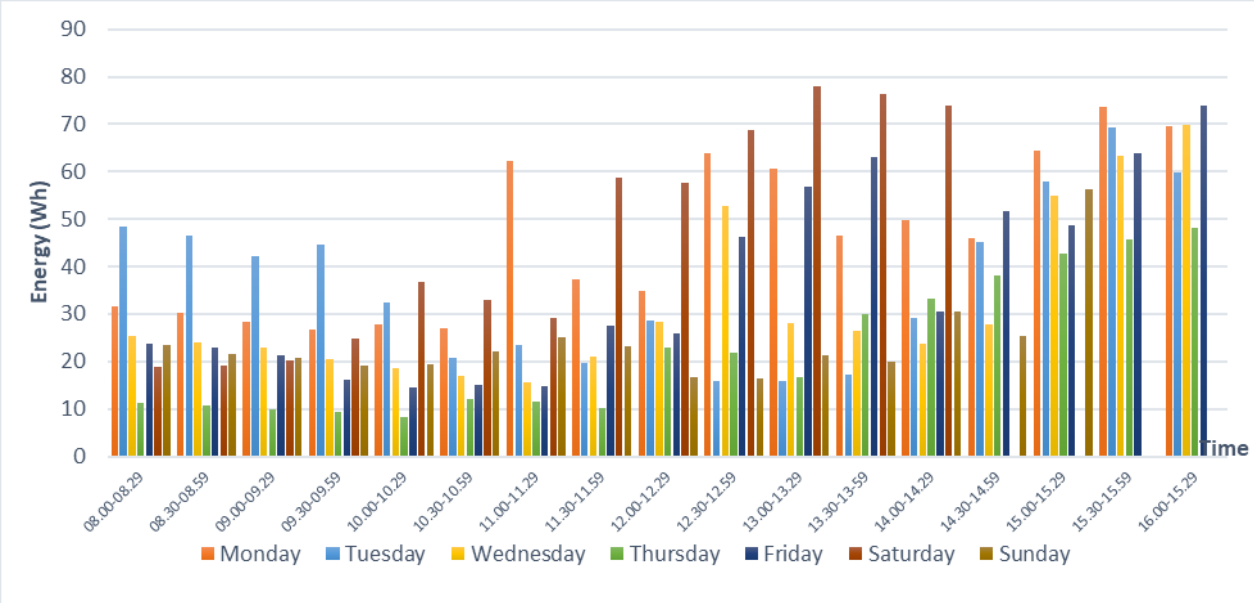

Figure 11. Energy consumption curre ntly used with energy consumption using dimming techniques

Table 1. Energy consumption efficiency with dimming control strategy per day

Node	Electric energy consumed at present (Wh)	Electric Energy consumed with dimming control (Wh)				Saving %
		Monday	Tuesday	Wednesday	Thursday	
A	3.211	381,93	357,45	325,16	219,55	32,303
B	3.211	269,71	186,21	154,07	97,43	64,222
C	3.211	129,00	73,33	61,26	65,78	82,188

Table 2. Energy consumption efficiency with dimming control strategy per day (Cont'd)

Node	Electric energy consumed at present (Wh)	Electric Energy consumed with dimming control (Wh)				Saving %
		Friday	Saturday	Sunday	Total	
A	3.211	340,04	287,64	261,99	2.173,76	32,303
B	3.211	175,10	179,93	86,38	1.148,83	64,222
C	3.211	101,74	127,79	13,02	571,93	82,188

Using equations (1) and (2), the efficiency carried out daily at all work nodes can be calculated. Table 1 shows that the most outstanding efficiency is at node C, with 82.18%, and the lowest is at node A with 32.30%. By maximizing the potential of existing natural light and regulating artificial light sources can save electrical energy consumption in the object of study.

4. Conclusions

This study concludes that the maximum value reached 893 lux on Tuesday at 13:00 at node C, and the lowest was 3 lux on Saturday at 15:00 WIB at node A. Node C had an average light intensity of 402.298 lux, and node B had an average of 206.765 lux during the week. In contrast, node A has the lowest lux average, with 87,711 lux in one measurement week. It can be concluded that the light intensity value of node C tends to be high because this node gets more natural light sources from the windows on the east and northwest sides of the room. In calculations with a combination of natural light sources and artificial light sources with dimming control strategies, the range of voltage values given to each lamp ranging from 0 to 180 VAC with dimming control strategies is obtained. Potential savings in energy consumption by combining natural and artificial light with dimming control strategies in the library room with three different nodes (A, B, C) are 32.3%, 64.2%, and 82.8%, respectively. The most significant potential is obtained at work nodes that get a lot of natural light from the glass windows around them. It applies vice versa for work nodes that earn little natural light source.

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