Analysis of the effect of environmental conditions on energy savings in lighting systems with dimming method in campus buildings

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ABSTRACT

Our research is introducing a lighting system using dimming lamps to utilize natural sunlight to save electrical energy in campus buildings. It began with designing an LED light-dimming system using AC chopper technology. It was tested in library rooms in campus buildings. Its room is divided into three zones (A, B, C) based on the intensity of natural light reaching the room and the location of the work points. We analyzed the influence of the environment around the research object, including the location of work points, weather conditions, the position of the sun, and electrical energy saving in lighting systems using dimming LED lights in campus buildings. The test results show that implementing the proposed dimming system can reduce room electricity consumption by an average of 50.31% in good weather conditions. The location of the work point in the room dramatically influences the amount of this savings. For work point locations in zone C, these savings can reach 93.707%, while for work points in zone A, the savings are only 12.177%. The results show that the percentage of electricity consumption savings from the lighting system can be increased by increasing the natural light that reaches the room.

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1. INTRODUCTION

The building sector is the second largest sector that consumes primary energy globally. This sector consumes 40% of the world's primary energy, slightly smaller than the transportation sector, which reaches 43%, while the industrial sector only consumes 17% of world energy [1]. Of the 40%, 12% comes from embodied carbon (EC) [2]. Due to the significant influence of the building sector on the world's energy supply, this will encourage intensive efforts to find new solutions to reduce energy needs in the building sector. Reducing energy needs in the building sector, globally and significantly, will play a role in overcoming the world energy crisis and, simultaneously, can reduce the greenhouse effect or CO_2 emissions. A measurement including management of embodied carbon has been elaborated on different probabilistic approaches. For companies or public institutions, reducing energy consumption in their buildings will reduce operational costs and, at the same time, increase the competitiveness of the company or institution.

Currently, several developed countries have made efforts to reduce building energy consumption by optimizing the use of local renewable energy sources around the building on the energy supply side combined with efforts to save or conserve energy on the energy use side of the building. The concept is known as the Zero Energy Building (ZEB) concept [3]-[5]). It can be divided into (i) nearly Zero Energy Building (nZEB) if there is still a tiny amount of energy supplied from outside the building, and (ii) Net Zero Energy Building (NZEB) if almost all the building's energy needs are met by itself. In Europe, starting in 2020, all newly constructed buildings are strongly encouraged to implement the nZEB concept [3], [6].

The application of the ZEB concept to buildings is influenced by many factors, including building location, climate and weather, characteristics of activities in the building, behavior of energy users, quality of energy distributed, and building structure. Climate and weather greatly influence the characteristics of buildings' energy consumption. Europe, which has a climate with four seasons (hot, cold, spring, and autumn), will have attributes of renewable energy sources and building energy consumption that are very different from Southeast Asia, which has a tropical climate. Apart from that, the energy used in European buildings is generally electrical and heat energy. In contrast, in tropical areas, it only uses electrical energy.

In campus buildings, the most extensive use of electrical energy is for room temperature conditioning, while the second most prominent use is for the lighting system. The lighting system's electrical energy reaches 25% of all electrical energy consumed by campus buildings [7]. It focuses on saving electrical energy use for campus building lighting systems. Studies on saving electricity consumption in building lighting systems have been carried out for a long time. Getu and Attia [8] studied energy savings by replacing ordinary lamps with LED lamps with efficient technology in campus lighting systems. Attia and Getu [9] designed a lighting system with LED lamps integrated with a timer to regulate their lifetime according to the lecture schedule. Baharum [10] used LDR and PIR sensors to reduce electricity consumption in lighting systems. Implementing energy management in campus lighting systems is a cheap solution for saving energy in campus buildings [11]. Kim *et al.* [12] proposed adjusting the location of sensors at work points to increase energy savings in lighting systems with daylight-responsive dimming systems (DRDS). However, further research regarding using natural light from sunlight to increase electrical energy savings in campus building lighting systems is still limited.

This study hypothesizes that using natural light in building lighting systems positively impacts electricity consumption in campus buildings. This research aims to utilize the abundant natural light on tropical campuses to increase savings in electricity consumption required for building lighting systems. We are motivated to conduct this research because the lighting system consumes 25% of electrical energy in campus buildings in tropical climates, and natural light sources are abundant in this region. In addition, the campus lighting system in the object of study is still conventional, without considering the potential for abundant natural light.

This paper analyzes the influence of the environment around the research object, such as the location of work points, weather conditions, and sun position, on saving electrical energy in lighting systems using the method of dimming lights in campus buildings. The study began with the development design of a light-dimming system in the room lighting system in campus buildings as an effort to utilize natural light from sunlight to save electrical energy. The test results of the developed system were analyzed to increase natural light illumination reaching work points in the room. The results of this analysis can be considered when improving the environmental conditions around the building or when selecting the location and structure of the building and planning the lighting system in a new building.

2. LITERATURE REVIEW

2.1. Zero energy building (ZEB) concepts and smart building

According to Hui [13], ZEB is how a building can produce its energy as much as it consumes in a year. From an architectural point of view, ZEB is a concept of how to design materials so that the energy required for the building is minimal (nZEB). It seems only to apply to buildings that are to be built. On the other hand, an approach is also needed for buildings that have been made by converting these buildings into intelligent buildings. According to Mayer and Enge-Rosenblatt [14], four aspects of energy management are required to implement this intelligent building concept:

a) Distributed sensors to obtain appropriate parameter measurements;
b) Data communication network within the building and connected to the environment parameters;
c) Reliable computing system to realize fast and precise control and regulation functions; and
d) Predictive algorithms that combine information to determine optimal control programs for energy systems.

The internet of things (IoT) is essential in this approach. IoT is an interconnection system between instrumentation (tools) each other, connected in an internet network, and capable of working to form a coherent system in carrying out work activities [15]. In the implementation of embedded system technology, IoT can support monitoring field conditions with the help of a sensor system. These physical parameters from readings and remote-control technology are becoming targets for IoT integration in creating intelligent buildings [16].

The concept of smart building has a general descriptive approach. One definition that can be taken is an integration system between technologies as a complementary unit in a building object, which can be a living space (house), office, or others. It also supports the functional performance of the building. Sensors can be used to measure temperature, humidity, and air quality. Apart from that, sensors can be used to determine how many people are in the building to calculate the impact on air conditioning in that room and use lighting and air conditioning only when needed. It can be achieved with various installed sensors.

Two steps are required to apply the ZEB concept to buildings. The first step is to reduce energy consumption through energy savings in buildings. The second step is to utilize renewable energy sources in the building environment, such as solar power, and wind power, to provide energy for the building. Renewable energy is free, pollution-free, and available everywhere [17]. The study conducted in this article focuses on saving electrical energy use in campus building lighting systems.

2.2. Energy conservation in buildings

At the building energy conservation stage, the most important thing to pay attention to is identifying sources of energy waste in the building. Baniyounes *et al.* [18] introduced energy savings by enumerating the outdoor and indoor illuminance to implement a photometric computer, which is also presented [18]. Energy savings of around 9-15% were also found in Applied Science Private University, Amman, Jordan, using a fuzzy logic controller as their building's control system [19]. Pujani *et al.* [11] have identified sources of electrical energy waste in campus buildings:

a) The factor of poor electrical power quality

In general, the quality of electrical power directly affects the waste of electrical energy, which takes the form of high harmonic current content, low power factor, and electrical load imbalance. These three forms of power quality will cause an increase in current in the power lines of the building, which will trigger an increase in electrical energy losses. The electrical load characteristics on the building trigger all forms of power quality mentioned above. Actions to reduce electrical energy waste are carried out by improving electrical power quality by installing harmonic filters, compensating for reactive power, and improving electrical load balance. A study of the effect of power quality on energy losses in campus buildings has been discussed in reference [20].

b) The factor of inefficient electrical equipment/load

In campus buildings, the dominant electrical load in energy consumption is air conditioning and room lighting equipment (lamps). In a previous study by Pujani, the percentage of electrical energy consumed by air conditioning was 32%, while the electrical energy consumed by lighting systems reached 25% of all electrical energy consumed by campus buildings [7]. One type of AC with efficient technology that is effective and popular in air conditioning systems is inverter AC. In inverter AC, the compressor motor is operated at variable speed while controlling the room temperature using a frequency control device. Meanwhile, in conventional AC, the compressor motor is operated on-off during room temperature control. By using an inverter AC in an air conditioning system, it will be possible to save the electrical energy consumed by 30% [21]. However, this type of AC is relatively more expensive than conventional AC.

Lighting technology is currently developing very rapidly in terms of the efficiency of converting electrical energy into light energy. Starting from incandescent lamps, which are very energy-intensive and were generally used at the beginning of their discovery, to LED lamps with efficient technology, which are most widely used in today's lighting systems. The electrical energy consumed by the lamp is converted into light energy and heat energy. In incandescent lamps, the heat energy is much greater than the light energy, while in LED lamps, the light energy is much greater than the heat energy. Therefore, if you look at the lighting system requirements, LED lights are very efficient compared to incandescent lights for lighting systems.

c) The factor of geometric shape and building structure

The geometric shape and physical structure will significantly impact building energy waste, especially in buildings operating for a long time. Generally, the most significant electricity consumption in buildings is used for room cooling according to comfort standards and room lighting according to health standards. Building structures with low thermal insulation will require high electrical energy consumption to condition the air temperature inside the building. Meanwhile, creating structures that can utilize natural illumination from sunlight will reduce the electricity consumption needed to condition the illumination in the building. The combination of LED lighting and natural lighting from sunlight using the daylight-responsive dimming system (DRDS) method has been described in the literature [12]. Osaka University, Japan, has also developed low-rise double-glazed windows to reduce building energy waste and increase its buildings' thermal insulation [22].

d) The factor of behavior of building users

The mission implemented in this research is to use electrical energy as needed. Human behavior as consumers of electrical energy greatly influences electrical energy consumption in buildings, especially when electrical energy is not required. Based on a study conducted at Kent University, England, increasing the motivation of student dormitory residents in energy conservation through a particular website and education delivered by energy delegates has reduced electrical energy consumption by 15% [23]. Human behavior is one of the main components influencing energy waste, but it could be improved in a better direction.

2.3. Energy efficiency in lighting systems

As stated in the previous section, the lighting system consumes campus buildings' second largest electrical energy. Therefore, reducing energy consumption in campus buildings' lighting systems must be taken seriously. As discussed below, several efforts have been made to reduce electrical energy consumption in lighting systems.

a) Replacement of lamps with more efficient technology

Currently, three types of lamp technology are commonly used as lighting sources, namely tube lights (TL), compact fluorescent lamps (CPL), and light-emitting diodes (LED). These three types of lamps have improved with more efficient technology, starting with TL, CFL, and LED lamps. Table 1 shows the efficiency and lifetime of Phillip brand lamps with different technologies [24].

As shown in Table 1, LED lamps are currently the most efficient technology and have the most extended lifespan, but the price is relatively high compared to other lamps. Besides that, this type of lamp can convert much more electrical energy into light than heat, so installing this lamp almost does not increase the room temperature. In 2012, Getu and Attia [8] studied energy savings by replacing ordinary lamps with efficient LED technology lamps in the campus lighting system.

b) A timer adjusts the lamp's turn-on schedule according to needs

Attia and Getu [9] have designed a lighting system with LED lights integrated with a timer to regulate its lifetime according to the lecture schedule. For example, in a classroom, the timer is set to turn on the light switch according to the lecture time and turn off the light switch outside lecture hours or when changing between 2 lecture schedules.

c) The use of sensors to regulate on/off lights

Two sensors are widely used in lighting systems today: motion and illumination [10]. Motion sensors usually use passive infrared (PIR) sensors to detect the presence of people in rooms and building corridors, which provides information for relays to turn on or turn off the lights. Meanwhile, illumination sensors usually use light-dependent resistor (LDR) sensors to detect the availability of sunlight, which is generally used to turn garden lights on or off.

d) The lighting system with a light-dimming method

A lighting system with a light-dimming method can utilize natural light from sunlight [12]. Using natural light can reduce the electrical energy needed for lights or increase electrical energy savings.

Table 1. The performance comparison for different types of lamps [24]

Performance indicators	Lamp technology		
	TL	CFL	LED
Efficiency (Lumen/Watt)	55 - 65	60 - 70	100 - 150
Lifetime (hours)	10000	10000	15000 - 30000

3. METHOD

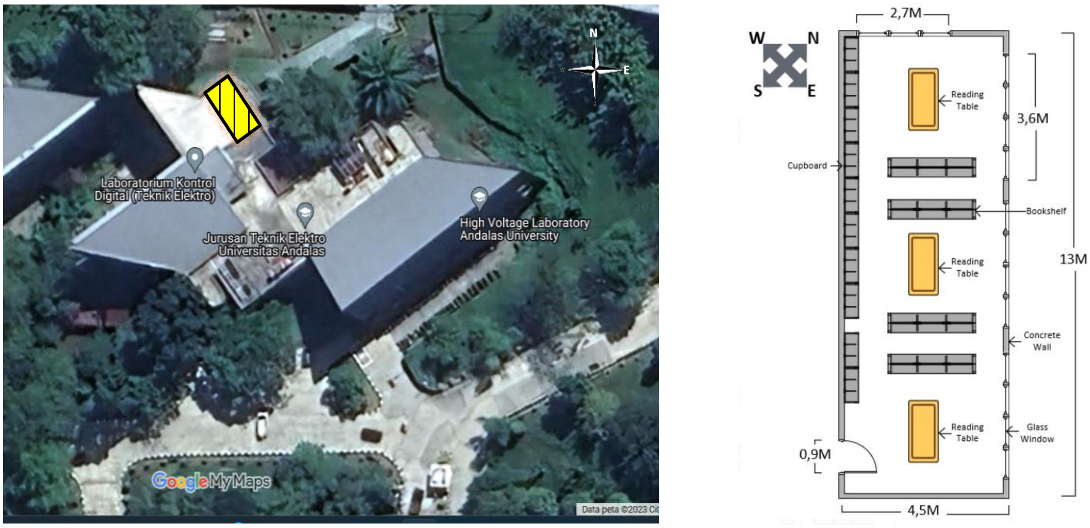
3.1. The object of study

The object of study for this research is the Electrical Engineering Department Building, Universitas Andalas, which is in the Limau Manih area, Padang, Indonesia. This building has a location with coordinates 0°54'50.5"S 100°27'54.0"E. Use the department's mini library (reading room) on the 3rd floor as a sample room in one corner of this building. Figure 1(a) shows an aerial photo and a floor sketch of the room, shaded with a yellow diagonal line. The reading room has shelves, bookshelves, and three reading tables, each with a capacity of 6 people, as shown in the sketch in Figure 1(b). The room with concrete walls is depicted with a shaded box, while the unshaded box is a window.

3.2. Measurement of natural lighting levels

To design the proposed lighting system, measuring the intensity of natural light arriving at the work point in the room is necessary. By considering field conditions that influence the intensity of natural light reaching the work point, the sample room is divided into three zones (A, B, and C), as shown in Figure 1(b). In zone A, natural light enters through glass windows from the east, but the spread of this light will be slightly disturbed due to the tree in front of the window. In zone B, natural light also enters freely from the east through the glass windows without anything blocking it. Meanwhile, natural light enters zone C freely through glass windows from the east and west. For each zone, one working point is determined, which is used as a reference point for measuring the level of natural light reaching the room. It is assumed that points that are around the work point and are still within the same zone always have close to the same level of natural light level.

Measurement of natural light levels reaching each work point using a digital lux meter type AS803 measuring instrument. The measuring device is placed on the reading table with the sensor facing upwards. Measurements were carried out during working hours from 08.00 AM to 04.00 PM for one week, with a data collection frequency of every 30 minutes. Weather conditions during data recording are classified into five criteria: sunny, clear cloudy, cloudy, drizzling, and rainy.



(a) (b)

Figure 1. The object of study: (a) aerial photo and (b) room sketch

3.3. Proposed system design

3.3.1. Lighting system design

The sample room used as the object of this research is a mini library room or what is usually called a reading room in the department building. The area of this room reaches 58.5 m^2, with a seating capacity of 18 people. Reading sources in textbooks, journals, or proceedings are limited to electrical engineering only. As explained in section 3.2, based on the intensity of natural light entering the room, the room is divided into zones A, B, and C. For this reason, the layout and number of lamps installed on the room's ceiling are rearranged (redesign). Based on lighting standards (SNI), the light intensity required in the reading room is 350 lux. Assuming no natural light is coming from outside the room, this is necessary for the room's illuminance level at night. This room's working hours are 08.00 – 16.00. From the results of measuring the illuminance level of natural light that reaches the working point during working hours, the smallest value of additional illuminance from outside the room comes to 100 lux, so the maximum need for artificial light from lighting lamps is 250 lux. Therefore, the standard room requirement is 350 lux. We installed six lamps per zone with 9W LED lamps, 806 lumens each, to fulfill the standard. It is based on calculations that we made [25]. We have cross-checked with direct measurements using a digital Luxmeter at each work point. For room use outside working hours, such as 1 hour before opening and 1 hour after closing, to clean the room, an artificial light intensity of 250 lux is sufficient for emergency purposes at night. The proposed lighting system design is shown in Figure 2. The room is divided into three zones based on the direction of natural light coming into every part of the room. Zone A has one window on the northeast side, but a large tree blocks light from entering the window. Zone B is where the natural light source comes from a window measuring 3.6 x 1.8 meters and is not obstructed by trees. Zone C is a zone that has two windows with two directions of natural light sources from the northeast and northwest sides so that the amount of natural light is the most.

3.3.2. Control system design

Figure 3 illustrates the concept of the proposed control system. V_{ref} represents the desired illumination target value. The value applied refers to the standard illumination value for a reading room of 350 lux. This value relates to the SNI standard [26]. The input from the plant is the difference value between V_{ref} and V from the sensor readings. The transfer function in the plant will determine the relationship between ΔV and the duty cycle that will be used in PWM. PWM will control the V_{AC} voltage originating from the utility supply by the AC Chopper to provide voltage to the lights (V_L). The intensity of light produced by the lamp (ε_L) added to the illuminance of natural light (ε_0) is the intensity of light in the room (ε_v). This light intensity will be measured again as feedback to the system. Utilizing a microcontroller makes all transfer functions from the plant, PWM, and sensors easier to implement as program code.

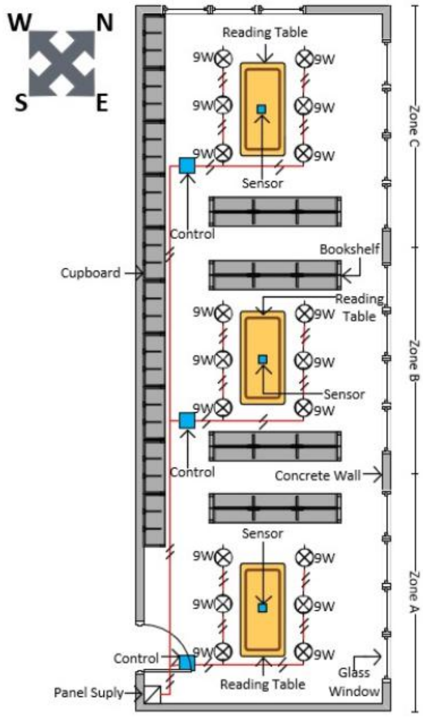


Figure 2. Lighting system design

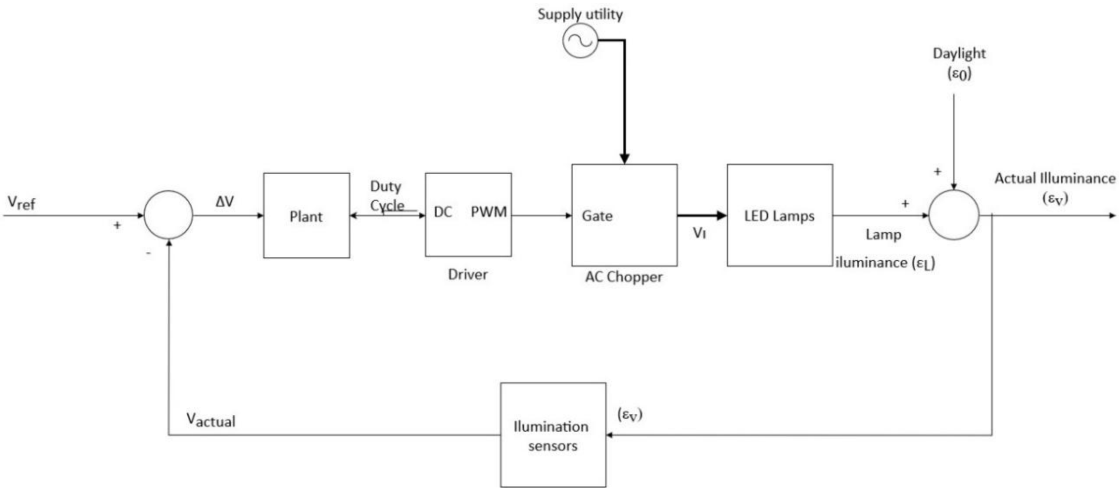


Figure 3. Block diagram of the proposed design control system

3.4. Calculation of electricity consumption savings

The main objective of using the proposed design system in the lighting system of the study object is to save electricity consumption. The first step is to calculate the amount of energy consumed by the lamp by integrating the power curve P(t) over working hours. The following equation expresses the electric energy equation for a lamp:

$$E_L = \int_{t0}^{tn} P_L(t)\, dt \qquad (1)$$

Where $E_L$is electricity consumed by the lamp during time t_0 to t_n; and P_L(t) is electric power required by the lamp at time *t.* The (1) can be solved numerically using the trapezoidal method [27]. The P_L(t) curve is divided into *n* segments with the same width *as* each, as shown in Figure 4. Each segment is a trapezoid-shaped plane with parallel sides $P(t_i)$ &$P(t_{i+1})$ and height *h*.

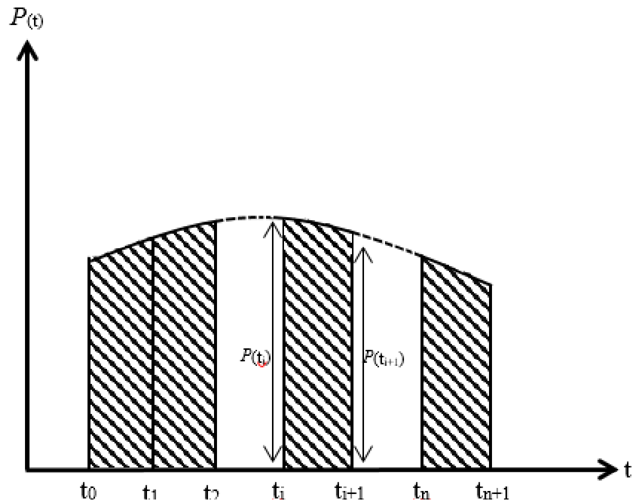


Figure 4. Integration of the lamp power function P_L(t) using the trapezoid method

The solution to (1) is solved by adding up the area of the trapezoid for all segments, as shown by (2).

$$E_L = \sum_{i=0}^{n} \frac{h\{f(t_i)+f(t_{i+1})\}}{2} \tag{2}$$

To calculate electricity consumption savings for each zone, we first need to determine electricity consumption before using the dimming method. The number of lights installed in each zone is six lamps with a power of 9 watts each, so the total power per zone is 54 Watts. Before using the dimming method, it is assumed that the lights are on continuously for 10 hours if the room is opened so that the electrical energy needed by the lights is 540 Wh; the voltage from the utility supply influences this value. It means that the percentage of electrical energy savings per day for each zone can be calculated from (3).

$$\Delta E_L = \frac{E_{old}-E_L}{E_{old}} \times 100\% \tag{3}$$

3.5. Experimental setup

The experimental setup of the control system that proposed design was carried out directly in the department reading room, which was used as a sample object of study. The test variables, which consist of room light intensity level (ε_v), duty cycle (δ), lamp voltage (V_L), and lamp power (P_L), are recorded on the data logger, as shown by the circuit in Figure 5. Recording test data is carried out every five minutes.

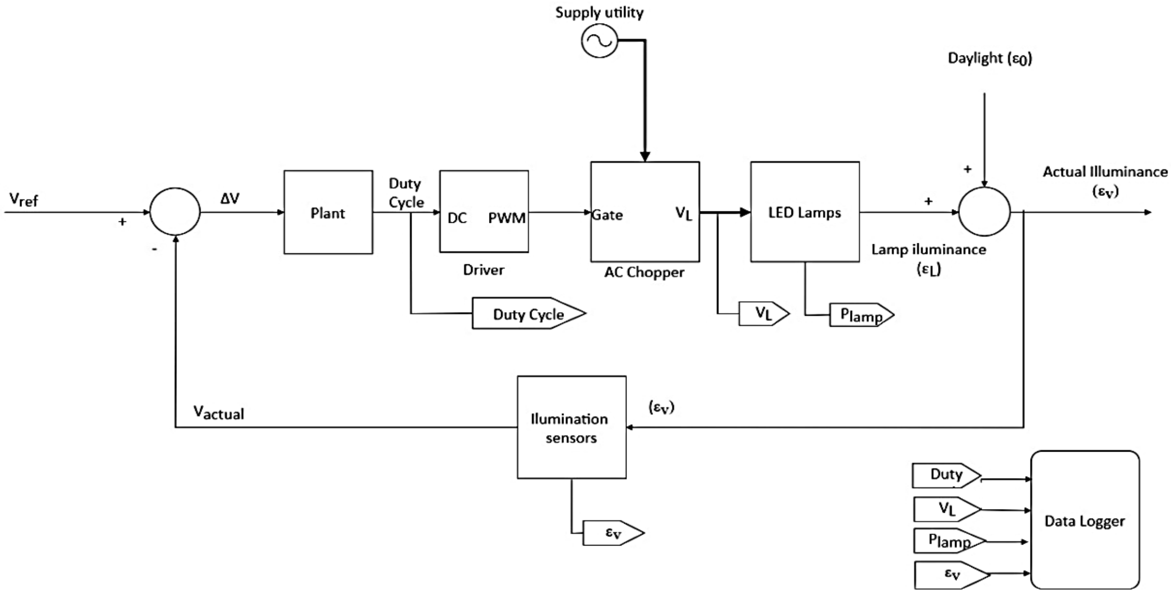
Figure 5(a) explains the system design. Meanwhile, the implementation results of the system design are seen in Figure 5(b). Figure 5(b) shows a picture of the control and sensor devices made and installed in the library room. Meanwhile, Figure 5(c) shows a lighting system with natural light equipped with lamp dimmer automation. It is seen that zone C had no artificial light from the lamps because 350 lux was met, while zone B and A still needed additional lamps.

4. RESULTS AND DISCUSSION

4.1. The measurement results of intensity natural light

Figure 6 shows the results of measuring the intensity of natural light arriving at work points in zones A, B, and C. The data in graph Figure 6 shows the measurement results on Tuesday, 14 November 2023, during working hours: 08.00 AM – 04.00 PM. As shown in Figure 6, the intensity of natural light arriving at the working point in zone C gives the most significant value. In contrast, the intensity of natural light at the working point in zone A shows the smallest value. This result follows the opportunity conditions for natural light to enter each zone. In zone C, natural light can enter from both sides of the glass window, and no objects or trees are blocking it from entering.

Meanwhile, in zone A, natural light enters only from one side of the glass window, and a tree in front blocks it. Weather conditions also greatly determine the intensity of natural light that reaches the work point. Sunny weather conditions will increase the natural light coming to the work point, while rainy weather conditions will reduce the intensity of natural light reaching the work point. The sun's elevation angle also influences the amount of natural light that reaches the work point. In the morning, when the sun is at a slight elevation angle, the natural light that comes to the work point is less than during the day when the sun's elevation angle is around 90^o. Likewise, in the afternoon, when the sun is at an elevation angle approaching 180 degrees, the intensity of natural light experiences a sharp decrease. Figure 7 shows the intensity of natural light reaching work points in zone C during working hours between 10 and 16 November 2023. As shown in Figure 7, for one week, the intensity of natural light reaching work points in the morning and afternoon is quite large, while the smallest natural light intensity occurs around 4 AM.



(a)

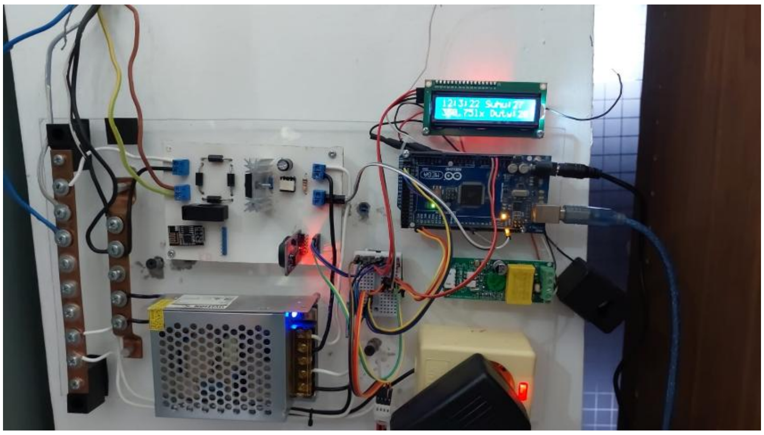
(b)  (c) 

Figure 5. Circuit and photograph tests: (a) circuit test, (b) hardware implementation of the control system that has been installed in the library room, and (c) a description of the condition of the library room with a lighting system

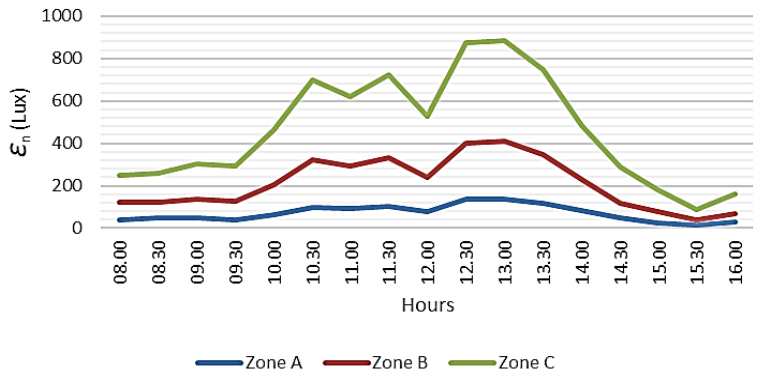


Figure 6. The intensity of natural light reaching the work point

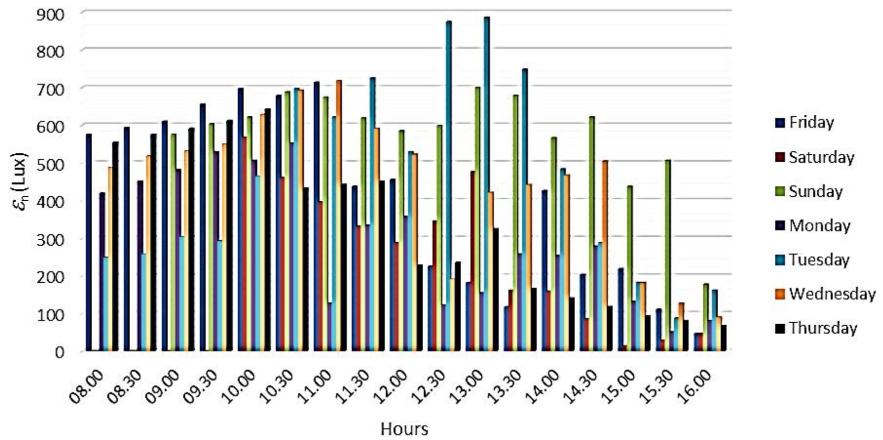


Figure 7. The distribution of natural light intensity reaching the working point in zone C for one week

4.2. Test results of proposed system design

4.2.1. Monitoring results of test variables

Four variables are monitored during the testing of the proposed design system, including light intensity level at the working point (ε_v) as the controlled variable, duty cycle (δ), and lamp voltage (V_L) as the controlling variable. In contrast, the lamp's electrical power (P_L) is a controlled variable. Figures 8(a) and 8(b) show the monitoring results of test variables on 5 December 2023 at zone B work point.

4.2.2. The effect of working point position on room light intensity and lamp power

The room used as the object of study is divided into zone A, zone B, and zone C. Figures 9(a), 9(b) and 9(c) show the test results of the proposed design system for each work point in zones A, B, and C on Friday, 1 December 2023. Today, the weather is sunny and cloudy from morning until noon, starting at 02.30 AM, and the weather becomes cloudy and rainy after 04.00 PM. As shown in Figure 9a and 9b, from 08.00 AM to 02.30 PM, on average, at working points in zones A and B, the light intensity according to the applicable standard can be achieved at 350 lux. In contrast, the light intensity consistently exceeds the applicable standard at the working point in zone C as seen in Figure 9(c). It is possible because the intensity of natural light arriving in zone C consistently exceeds the target, as discussed in section 4.1. From morning until noon, for working point zone A, the electrical power consumed by the lamp only slightly decreases from the maximum power used. At working point zone B, the decrease in lamp power is quite significant, while at working point zone C, the lamp power is always zero, or the light is always off. Then, during the afternoon, because the weather conditions changed to rain, the illuminance level (ε_v) at the working point for all zones did not meet the standard even though the lights were turned on at maximum power.

(a)

(b)

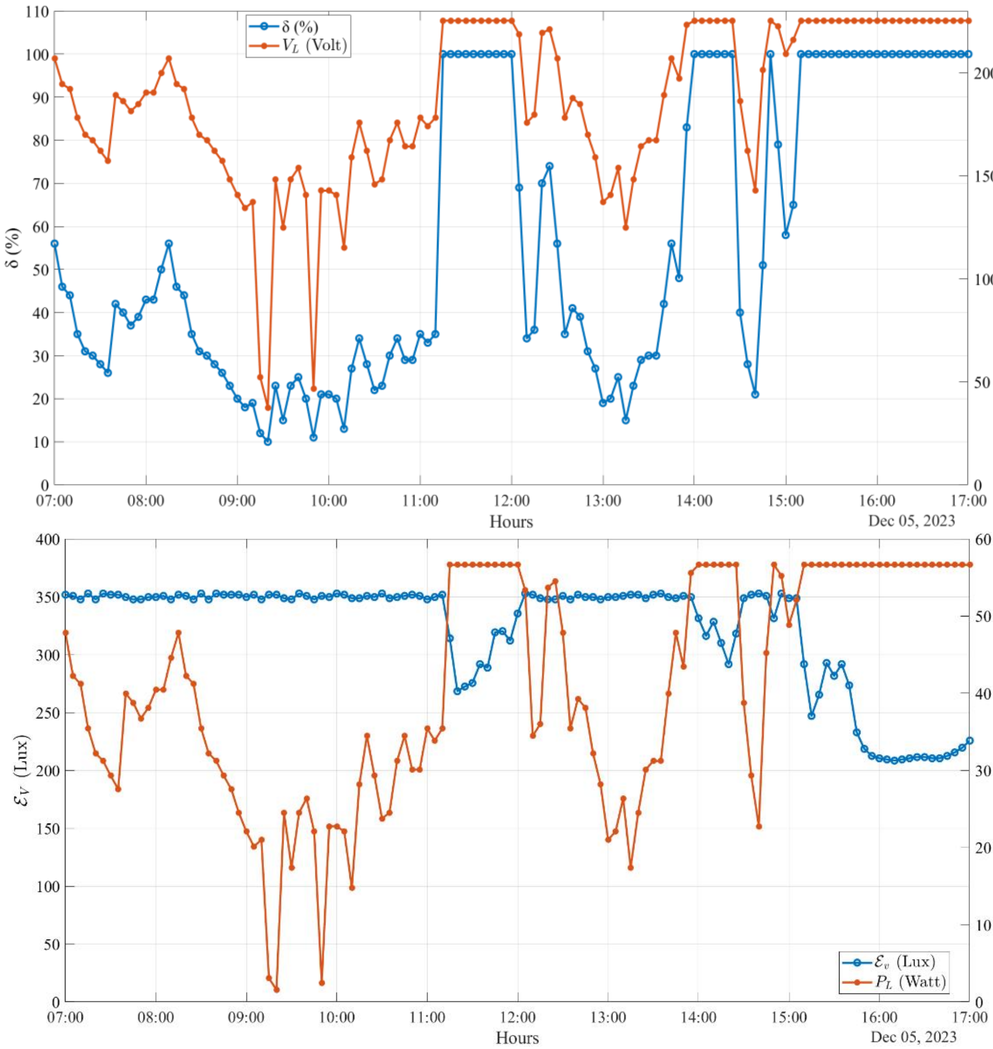


Figure 8. The results of measuring test variables: (a) duty cycle (δ) & lamp voltage (V_L) and (b) light intensity (ε_v) & lamp power (P_L)

4.2.3. The effect of weather conditions on room light intensity and lamp power

Figure 10 (see Appendix) shows the test results for the effect of different weather conditions on lamp power. Measurements were carried out consecutively for seven days, starting 28 November 2023 until 5 December 2023, which was carried out during working hours at zone C. The weather conditions during the test have been tabulated in Table 2. In clear, sunny, and cloudy weather conditions, the intensity of natural light reaching zone C consistently exceeds the standard requirement for room light intensity of 350 lux, so this condition will cause all the lamps to be off. This condition occurred on 28 November and 2 December 2023, in the morning and afternoon, as shown in Figures 10(a) and 10(b). In addition, when the room is opened in the morning, the lamps come on for a few minutes, then turn off after noon. It can be seen in Figures 10(a), 10(c), and 10(d). The sun's elevation angle is still tiny in the morning, so the intensity of natural light reaching the work point is below the required standard (350 lux). On 30 November 2023, as seen in Figure 10(e), the weather conditions will be cloudy in the morning, overcast and drizzly in the afternoon, and cloudy in the afternoon. It is the day during the testing period when the amount of natural light reaching the work point is the smallest, so the lighting in the whole zone is almost all day. During the test period, in the afternoon after 04.00 AM, the weather conditions were always cloudy and rainy, so this caused the light intensity level in the room not to reach the target even though all the lights were turned on, as shown in Figures 10(f) and 10(b).

(a)

(b)

(c)

Figure 9. Test results at each zone's working point: (a) Zona A, (b) Zona B, and (c) Zona C

4.3. Calculation Results for Electricity Consumption Savings

Calculation of daily electrical energy savings in each zone uses the lamp power curve *P*(t) and equations (2) and (3). The calculation results are shown in Table 3. As shown in Table 2, the most significant percentage of electrical energy savings is in zone C, which reached 93.707% on 11/28/2023. Maximum conditions occur because the weather is sunny from morning to noon and cloudy in the afternoon. On the other hand, electrical energy savings are not generated at all in zone A, which occurred on 11/30/2023. Unfavorable weather conditions mainly cause extreme conditions in zone A. On 11/30/2023, weather conditions in the morning and afternoon were cloudy, while in the afternoon, it was drizzling. Besides that, zone A only has access to natural light, and it is equipped with only one glass window, and there is a tree in front of the window. In zone C, even though clouds always cover the sun, natural light still contributes to the lighting system in the rooms in the zone. The presence of 2 glass windows supports this as access to natural light. Testing was carried out for seven days, starting from 11/28 until 11/28. 05/12/2023 except Sunday 03/12/2023 because it is a holiday.

Table 2. Weather conditions during a test

Test date	Test time	Weather condition
28 November 2023	Morning	Sunny
	Afternoon	Sunny
	Evening	Cloudy
29 November 2023	Morning	Sunny
	Afternoon	Clear Cloudy
	Evening	Cloudy
30 November 2023	Morning	Cloudy
	Afternoon	Cloudy & Drizzling
	Evening	Cloudy
01 December 2023	Morning	Sunny & Clear Cloudy
	Afternoon	Clear, Cloudy & Sunny
	Evening	Cloudy & Rainy
02 December 2023	Morning	Sunny & Clear Cloudy
	Afternoon	Sunny, Clear Cloudy, Cloudy
	Evening	Drizzling, Cloudy
04 December 2023	Morning	Sunny & Clear Cloudy
	Afternoon	Sunny
	Evening	Cloudy
05 December 2023	Morning	Sunny
	Afternoon	Clear Cloudy
	Evening	Cloudy

Table 3. The calculation results for electricity consumption savings

Date	Zone A		Zone B		Zone C		Energy saving per-day	
	DE_L (Wh)	DE_L (%)	DE_L (Wh)	DE_L (%)	DE_L (Wh)	DE_L (%)	Wh	%
28-11-23	69.918	12.177	251.94	44.481	530.757	93.707	852.616	50.305
29-11-23	7.402	1.289	241.143	42.575	446.575	80.566	695.12	41.012
30-11-23	0	0	50.091	8.844	254.574	45.927	254.623	15.022
01-12-23	78.858	15.92	248.584	43.888	444.003	80.102	771.445	45.516
02-12-23	20.608	3.589	206.393	36.439	372.989	67.29	599.991	35.4
04-12-23	19.696	3.43	279.181	49.29	516.385	93.16	815.262	48.101
05-12-23	0.378	0.066	160.947	28.416	400.348	72.226	561.673	33.139

4.4. Discussion

The position of the work point in the study object room dramatically determines the amount of natural light that reaches the work point (see graph in Figure 6), so it will influence the amount of artificial light that must be provided by the lamp so that the room can meet the target light intensity value (see graph in Figure 9). This condition will affect the electrical energy needed for the lamp or the amount of electrical energy savings that can be achieved, as shown in Table 3. As discussed in sections 4.2 and 4.3, the working point that provides the most significant energy savings is in zone C, followed by the point work points in zone B, while work points in zone A provide the most minor energy savings on the same day. It is possible due to the position of the working point in the room. In zone C, the intensity of natural light that enters the room directly from sunlight is most significant because: i) There are two glass windows, which are sources of natural light; and ii) There are no objects or trees that block the entry of sunlight in this zone. Meanwhile, the work point located in zone B provides the smallest energy savings due to the minor source of natural light reaching the room, which is triggered by: i) There is only one glass window which is the source of natural light, and ii) There is the tree in front of the glass window slightly blocks natural light from entering zone A. Savings on electricity consumption for each zone in the room are greatly influenced by the surrounding environmental conditions.

This study was carried out between September and December 2023. The study area includes areas with tropical climates and hot and rainy weather. The location of the research object contains a tropical climate, where the weather conditions during the study period were rainy. As discussed in section 4.3, weather greatly influences saving electricity consumption in campus building lighting systems. The influence of this weather is felt in all zones proportionally. As shown in Table 3, on 28 November 2023, electricity savings in the zone C area in good weather conditions can reach 93.707%. Meanwhile, on 30 November 2023, the weather conditions are not good. There are no electricity savings in zone A, but at work point locations in other zones, there are still savings in electrical energy.

5. CONCLUSION

In this study, a lamp dimmer system has been successfully designed for the room lighting system in campus buildings to utilize natural light from sunlight to save electrical energy. The system developed has been successfully tested in a mini library room at the electrical engineering department of Andalas University with a floor area of 58.5 m^2. The test was carried out by setting the target light intensity for the reading room at 350 lux with an accuracy of ±3 lux or ±0.8%. The test results show that the application of the proposed system can reduce room electricity consumption by 50.31% in good weather conditions. The location of the work point in the room dramatically influences these savings. For work point locations in zone C, these savings can reach 93,707%, while for work points in zone A, the savings are only 12.177%. From the analysis of the results, increasing the percentage of electricity consumption savings from the lighting system can be done by increasing the natural light that reaches the room. Efforts to increase the intensity of natural light are based on i) increasing the number of sources of natural light entering, ii) reducing trees/objects that block natural light from entering the room, and iii) arranging furniture in the room so that it does not block natural light from entering/being reflected. Especially for buildings to be built, apart from the suggestions above, the position of the building should consider the angle of elevation of the sun in a day and the path of the sun passing the equator in a year.

APPENDIX

(a)

(b)

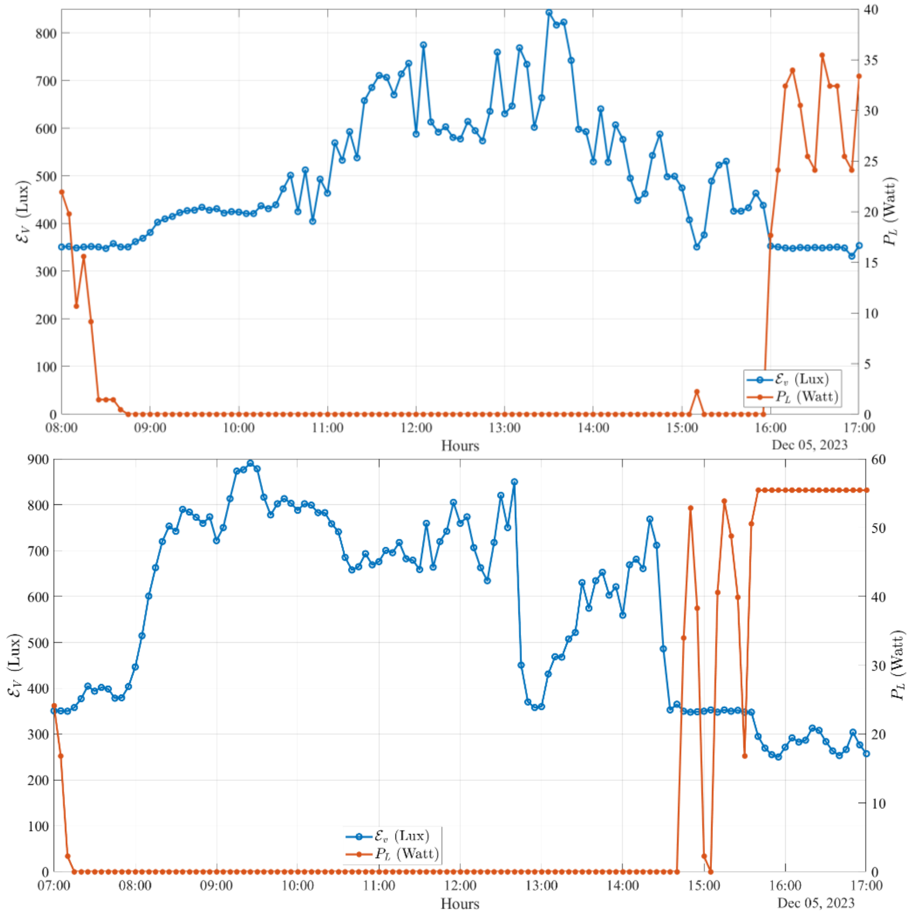
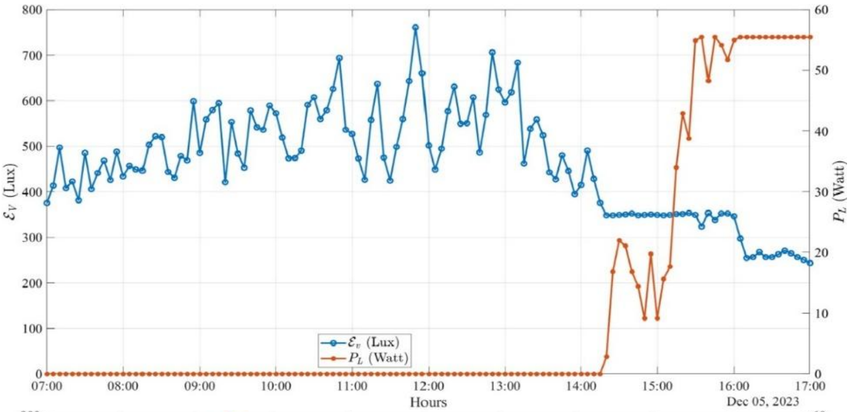
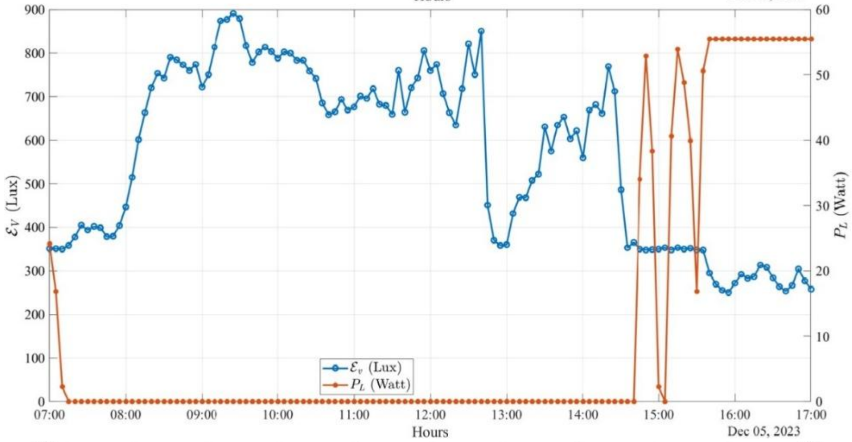


Figure 10. The effect of weather conditions on room illuminance level and lamp power tested on: (a) 28 November 2023 and (b) 1 December 2023

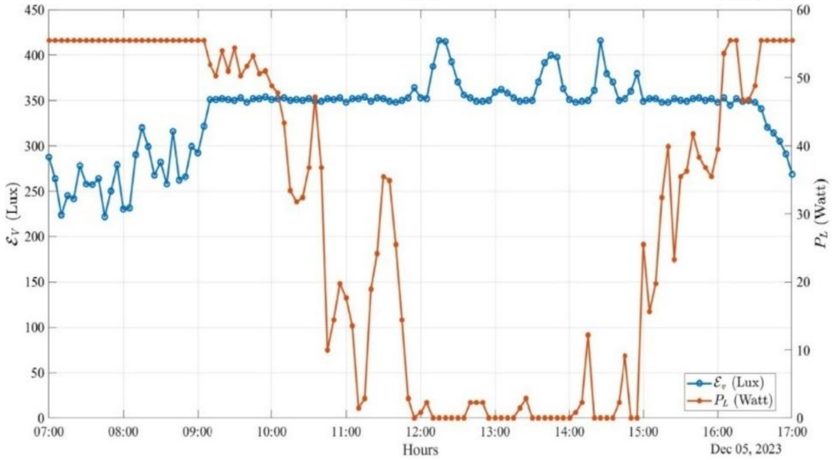
(c)



(d)



(e)



(f)

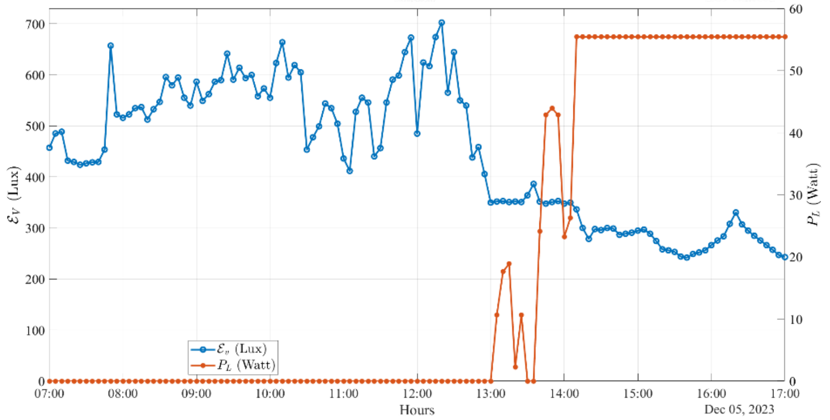


Figure 10. The effect of weather conditions on room illuminance level and lamp power tested on: (c) 29 November 2023, (d) 4 December 2023, (e) 30 November 2023, and (f) 2 December 2023 *(continued)*

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