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Research Article

Electric Load Modeling for Managing Electric Energy Consumption Through the PDCA Cycle in the Library Building of Andalas University

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A B S T R A C T

The need for electrical energy in the public building sector is quite dominant, reaching 33-40% of the total energy consumption of all sectors. To control electrical energy in buildings effectively, an Energy Management System (EMS) is needed. EMS stage consists of Plan-Do-Check-Act (PDCA). The study conducted in this research is on how to use the PDCA cycle method to model the consumption of electrical energy in campus buildings in a sustainable manner. Modeling of energy-efficient electrical loads is formed in several ways: modeling by replacing T8 fluorescent lamps and CFLs with LED, modeling by replacing non-inverter AC with inverter AC, modeling by the number of library visitors, modeling by improving the power factor, and finally, modeling with a combination of the four previous models. Modeling using LEDs results in savings of 1,464 kWh per month; inverter AC modeling saves 1742 kWh per month; modeling by adjusting the number of visitors saves 857 kWh per month; and modeling by improving the power factor saves 56 kWh per month. This electrical load modeling can save up to 8 kW of power outside of the library's operating hours. Meanwhile, during operational hours, the modeling library can save up to 30 kW of electric power.

INTRODUCTION

The need for electrical energy is very important for supporting all aspects of human activity. At present, the need for electrical energy in the public building sector is quite dominant, accounting for 33–40% of the total energy consumption of all sectors [1]–[3]. The increase in the use of electrical energy in this sector will have an impact on increasing the production of greenhouse gas emissions (CO2), the value of which will be proportional to the amount of electricity consumption in the building [4], [5]. Considering these facts, switching to a completely new sustainable building and the efficient use of building materials is costly, and many factors have to be considered to achieve it [6].

It is critical to conduct periodic energy audits in order to review energy consumption, determine the profile of energy use, and identify energy-saving opportunities in order to increase energy use efficiency [7]. Energy auditing is one method for achieving energy efficiency [8]. Improving the efficiency of electrical energy in buildings can be done by increasing the efficiency of electrical equipment, improving the power factor, and reducing the waste of electrical energy use [9].

To be able to control the consumption of electrical energy in buildings effectively, an Energy Management System (EMS) is needed [2]. Energy management system planning and energy audits in the building design process are one of the steps in evaluating energy consumption in buildings and identifying opportunities for energy savings [3]. The Energy Management System (EMS) stage consists of Plan-Do-Check-Act (PDCA) [10]. In the EMS cycle, control of energy consumption is usually planned and analyzed in the Plan (P) and Check (C) stages. While the method for determining the accuracy of buildings that produce energy savings and efficiency is an important topic and is considered for increasing investment costs for the world's energy conservation strategy [5].

Recently, many experts have focused their studies on predicting building energy consumption using various models and methods. Researchers from Hohai University in China proposed a *Robust Optimization* method that takes into account the factors of uncertainty that occur due to nature, such as the external illumination factor against lighting and the outside air temperature factor against the use of *Heating Ventilation and Air Conditioning* (HVAC) [1]. Another research have predicted a building energy consumption model using a Support Vector Machine (SVM), which takes into account several phenomena, such as the geometry and physical structure of buildings, human behavior, thermal comfort and water quality, climate conditions, and integrated energy sources in buildings [6]. Other research in Korea have proposed a method to predict energy demand in various situations using auto encoder-based deep learning models [10].

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The PDCA cycle is widely applied by industries in making innovations or improving performance, be it factory operational performance to company management systems. As Mick Donald and his team at PT. Semen Padang [11]. Demonstrated and presented at international conferences, the 45th International Convention on Quality Control Circles (ICQCC) in Dhaka, Bangladesh. The PDCA cycle used, begins with the plan stage, which is the planning for a new substation automation system, followed by the do, check, and finally action stages. Innovations made can result in savings of $300,000 USD [11].

The study carried out in this thesis is on how to model the consumption of electrical energy in campus buildings in a sustainable manner through the PDCA cycle. The buildings that are used as the object of study are buildings that are already in operation. Because the building under study is one that is already in use, the application of the PDCA cycle here starts from the Check (C) stage. At the check stage, a monitoring and evaluation process is carried out. To carry out the monitoring phase, a real-time monitoring system for electricity consumption has been built in several main university buildings. To evaluate the results of monitoring, field observations are needed from equipment in buildings that consume electrical energy. In the Action (A) stage, analysis is needed to find problems in the framework of improvement and sustainability actions. Improvements to reduce electricity consumption are planned at the Plan (P) stage. At this stage, a solution is planned to solve the problems identified in the previous stage. The repair plan is organized into priority scales based on cost feasibility and the difficulty of the repair technology used. Furthermore, the improvement plan is carried out in the Do (D) stage. In implementing the improvement plan, coordination with all parties related to controlling electricity consumption is required.

METHOD

This research was conducted with the research steps described in Figure 1.

PDCA Cycle Implementation

The PDCA cycle's basic principles are used in quality management systems in industrial sectors such as manufacturing, services, project areas, organizations, and so on, and were popularized in 1950 by Dr. Edward Deming, a quality management expert. The PDCA method is useful for making continuous improvements without stopping, with principles that are more future-oriented, flexible, logical, and reasonable to do, and contains explanations for all elements designed to [12].

The PDCA method for controlling and improving the management process consists of repeating four stages. The PDCA process ends with Planning, Conducting, Testing, and Implementation, which is known as the *Deming Phase*. Deming developed a four-stage problem-solving cycle known as the Plan-Do-Check-Action cycle [12].

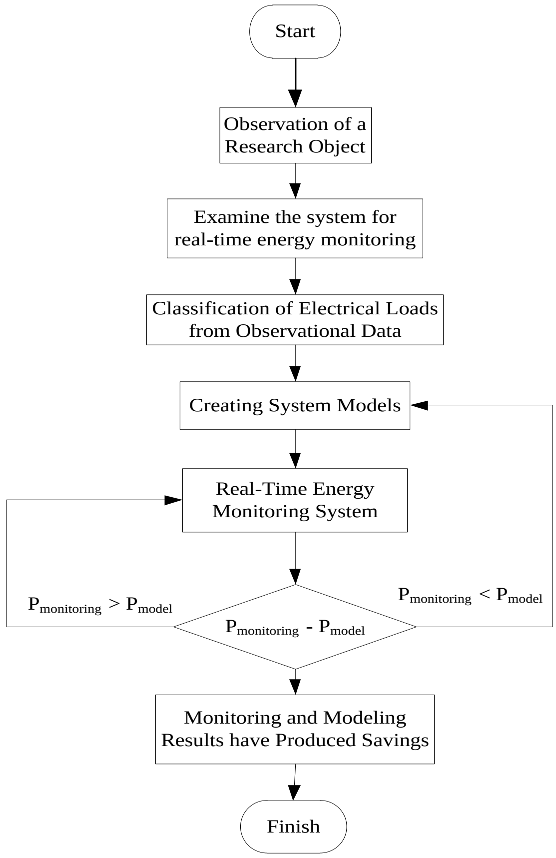

Figure 1. Flowchart of Research Methodology

- **Plan** – The Plan stage consists of setting goals and processes for the results to be achieved.
- **Do** –The Do stage does what was created before.
- **Check** – The Check phase conducts an inspection of the process stage, which is monitored and evaluated.
- **Action** – The Action phase is taken to increase the results.

In this study, the PDCA cycle begins with the Check stage, then moves on to Action, Plan, and finally Do.

Check

Because the research object has previously been operational, the check stage is performed first. The "check stage" is the stage of checking or monitoring the process. This stage is completed by observing the research object and testing the real-time monitoring system.

Action

The action stage is the stage in which the research object's results are increased. At this stage, it is carried out to determine savings opportunities that can be applied to the use of electrical energy in the Andalas University Library building.

Plan

This stage consists of planning, setting goals, and implementing processes for the results to be achieved in this research. It is at this stage that an energy-efficient electric load model is created, which is obtained from the savings opportunities in the action stage.

Do

The do stage is the implementation of the work that has been planned in the plan stage. In this study, the do stage was not carried out because the do stage had to involve many Andalas University officials because it was related to the large amount of money that would be incurred to carry out this do stage, so this do stage would take a long time.

Observation of Research Objects

Research Object Profile

This study uses a case study from the management of electricity consumption in the library building at Andalas University, Indonesia. In the structure of providing electrical energy on the Andalas University campus, this building receives electrical energy supply from the utility network of the national electricity company and is distributed over five floors in the library building.

Based on the activities in this building, this building can be divided into a reading room, an administration room, a storage room, and a meeting room. For the operational time of the Andalas University Library from the first floor to the fourth floor, Monday through Friday, the librarian enters at 7:00 a.m. to prepare for library operations, then from 8:00 a.m. to 5:00 p.m. the library opens for library visitors, and at 6:00 p.m. the librarian goes home. On Saturday, the library starts at 9 a.m. and closes at 4 p.m. The library is closed on Sunday. While the fifth floor is opened when there are certain events.

Observation of Electrical Equipment Usage

Field observations of equipment using electrical energy are needed to estimate and classify electrical energy consumption based on the type of load. In this observation, all equipment that uses electrical energy in the library building is recorded based on the amount, power capacity, and duration of use on weekdays and holidays. The grouping of electrical loads in the library building is divided into three load groups, namely lighting loads, AC loads, and loads other than lighting and AC.

Table 1. Lighting Electrical Expenses Classification

Equipment Name	Power (watt)	Quantity	Total Power (watt)
TL Lamps	36	508	18.288
TL Lamps	18	86	1.548
CFL Lamps	20	27	540
LED Lamps	3	200	600
Downlight	10	63	630
Total			**21.606**

Table 1 is an electrical load classifier for lighting loads. From the table, it is known that the consumption of electric power from the lighting load is 21,606 watts. On weekdays, the estimated consumption of electrical energy from the total lighting load is 293,832 kwh; on Saturday, the estimated consumption of electrical energy is 218,928 kwh; and on Sundays, the estimated consumption of electrical energy is 69,12 kwh. So that the total estimated consumption of electrical energy charged with lighting for a month is 2,915 kWh/month.

Table 2. Classification of AC Power Loads

Equipment Name	Power (watt)	Quantity	Total Power (watt)
AC 1 PK	800	24	19.200
AC 2 PK	1.600	21	33.600
AC Standing	4.500	0	0
		Total	**52.800**

Table 2 is an electrical load classifier for AC loads. From the table, it is known that the consumption of electric power from the AC load is 52,800 watts. On weekdays, the estimated consumption of electrical energy from the total lighting load is 637.2 kwh; on Saturday, the estimated consumption of electrical energy is 495.6 kwh. So that the total estimated consumption of electrical energy charged with lighting for a month is 5,806 kWh/month.

Table 3. Classification of Electrical Loads Other Than AC Lighting

Equipment Name	Power (watt)	Quantity	Total Power (watt)
Computer	75	47	3.525
Printer	220	6	1.320
Dispensers	185	5	925
Refrigerator	137	1	137
Attendance machine	36	1	36
Projector	270	3	810
Cannon IR 5020	1.500	2	3.000
TV LED	120	6	720
Blower	100	3	300
Rice Cooker	36	1	36
Water Kettle	300	1	300
Total			**11.109**

Table 3 is an electrical load classifier for loads other than lighting and air conditioning. From the table, it is known that the consumption of electric power from loads other than lighting and air conditioning is 11,109 watts.

Table 4. Total Electric Power Consumption of the Library Building from Observations on Electrical Equipment

Load Type	Power (watt)	Percentage (%)
Lighting	21.606	25,3
AC	52.800	61,7
Loads other than lighting and AC	11.109	13,0
Total	**85.515**	**100**

Table 4 is the total electricity consumption of the library building based on the results of observations of electrical equipment. From Table 4, it is known that the total electricity consumption in the library building is 85,800 watts. While the percentage of the lighting load group contributed 25.3% of the total load, the AC load accounted for 61.7% of the total load, and loads other than lighting and air conditioning accounted for 13% of the total load.

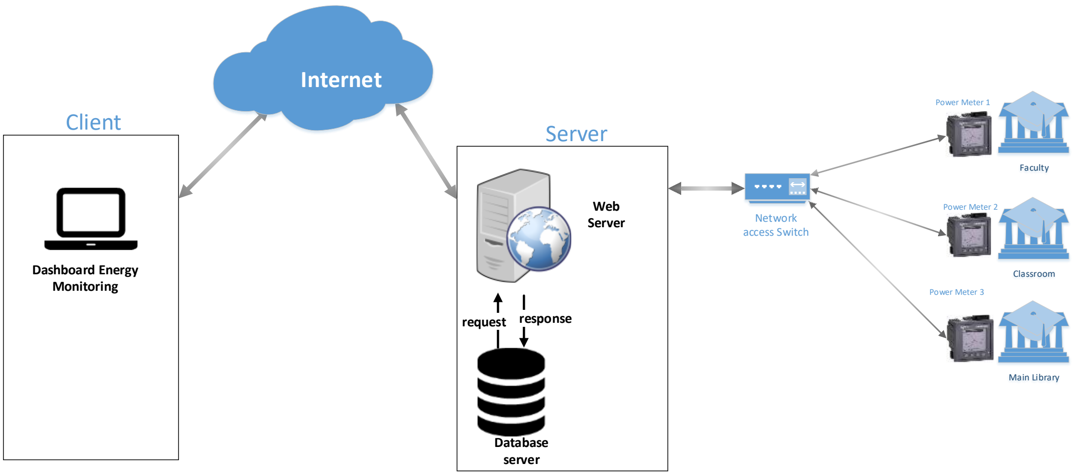

Figure 2. Energy information system architecture

Figure 3. Energy information system dashboard

Real Time Energy Monitoring System

The monitoring system is one way to identify the use of electrical energy in buildings on the Andalas University campus [2]. To support the implementation of the PDCA cycle in consumption control management in the library building, a Real-Time Energy Monitoring System was built. The real-time energy monitoring system in the Andalas University library building can already retrieve data every hour that is stored in the real-time energy monitoring system. Then count the number of visitors to the library, grouping the activities of these visitors. Following that, a comparison was made between the amount of electrical energy consumed and the number of visitors to the library.

Checking the Real-Time Energy Monitoring System is carried out every day, and then observing changes in electricity consumption in the library building every day with the number of visitors that is not constant, The current energy consumption can be seen from the previously developed energy information system dashboard based on a client-server architecture and a web-based application designed to collect and calculate energy consumption data over time. The system architecture of the energy dashboard can be seen in Figure 2, and Figure 3 shows the display of the energy information system dashboard.

Opportunities for Saving Electrical Energy Usage

In research conducted by [13] it is known that the total consumption of electrical energy in the Electrical Engineering Department building for the lighting system is 26,530.40 kWh, with a total cost of IDR 34,489,520 for one year. This is still the case with the current condition of lamps that do not use efficient lamps, according to SNI. From the results of the reduction carried out by [13] The current lamps in the Electrical Engineering Department building can be reduced to 18,559.84 kWh with a total cost of IDR 24,127,792 for one year. From these results, for one department building, there is a considerable savings opportunity. This can also be applied to the library building.

In this study, four opportunities were found to save electricity consumption in the library building. The savings opportunities are as follows:

Savings with LED Lamp Usage

Based on the research that has been done by [14] that a T8 fluorescent lamp with a power of 18 watts is equivalent to a Tube 8 LED lamp with a power of 10 watts. Table. 5 displays the efficiency and lifetime of various Philips lamp technologies [15]. From Table 5, it can be seen that LED lamps have a higher lumen/watt efficiency.

Table 5. The Efficiency and Lifetime of Philips lighting technology [15].

Lamp Type	T8 fluorescent	CFL	LED
Efficiency (Lumen/Watt)	55 - 65	60 - 70	100 - 150
Lifetime(Hour)	10.000	10.000	15.000

Based on Table 4, an empirical formula for replacing T8 fluorescent and CFL lamps can be made using the equation (1).

$$P_{led} = \left(P_l N\right) * 0{,}6 \tag{1}$$

where P_{led} is the total power produced by the LED lamp, P_l is the lamp power before replacement, and N is the total number of lights used

Savings with Inverter AC usage

The development of efficient technology in air conditioning (AC) with the use of inverters. In air conditioners with non-inverter (conventional) technology, the operation of the compressor motor is carried out using the on-off method to get the room temperature at the desired value. Whereas in air conditioners with inverter technology (efficient technology), the operation of the compressor motor is carried out using the variable speed method to get the room temperature at the desired value so that the set room temperature can be maintained with precision [16]. By using AC with inverter technology, it is estimated that the energy consumed can be saved by up to 30% [17], [18].

The potential for savings from the difference in energy use when replacing conventional AC with energy-saving inverter AC for buildings is very important. To get a savings model from replacing non-inverter AC with inverter AC, equation (2) can be used.

$$P_{AI} = P_A \times 0{,}7 \tag{2}$$

where P_{AI} is the AC inverter power consumption and P_A `is the non-inverter AC power consumption

Savings with Power Factor Improvement Thus eliminating System Losses

Power factor (PF) is defined in several ways. PF can be defined as follows: the ratio of active power (P) to apparent power (S) [19] The PF equation can be seen in the equation (3).

$$cos\varphi = \frac{P}{S} = \frac{P}{V.I'} \tag{3}$$

where $cos\varphi$ is power factor, P is active power and S is apparent power.

The use of inductive loads, such as water pumps, air conditioners, fans, etc., will cause a decrease in the power factor of the system. A decrease in the power factor will cause an increase in the line current, as shown by equation (4) below [9].

$$I_L(i) = \frac{P_L(i)}{\sqrt{3}V_{LN}(i)TPF(i)} \tag{4}$$

where TPF(i) is original power factor at the time of measurement to (i) ; and P_L is three-phase active power on measurement (i) in Watt

Savings by Adjusting the Number of Visitors

In this savings model, we can do it by observing the library and mapping the number of visitors. This mapping can be done when the library visitors are quiet or busy. From the pattern of the number of visitors, an SOP can be made that can be applied to the officer in charge of the library to save electricity if visitors to the library are quiet by turning off electrical equipment that is not in use.

Savings with a Combination of the Four Previous

The modeling is done by adding up the four models that have been done before and adding the estimated electricity consumption by library visitors who bring laptops and mobile phones. Energy-efficient electrical load modeling is done in the form of an estimation curve for energy-efficient electricity for 24 hours in the Andalas University library building. To get the shape of this curve, the authors make an empirical equation that can be seen in the equation (5).

$$P_T = P_{Led} + P_{AI} + P_{Equipment} + P_{Visitor} \tag{5}$$

where P_T is the estimated total power, P_{Led} is the power obtained from the LED lamp model, P_{AI} is the power generated by the inverter AC model, $P_{Equipment}$ is the total power of the library's electrical equipment other than lights and air conditioners, and $P_{Visitor}$ is the total power used by visitors using personal laptops and mobile phones.

To get the $P_{Visitor}$ using the equation (6).

$$P_{Visitor} = 0{,}7 \times \text{Total Visitors} \times \left(P_{laptops} + P_{\text{mobile phones}}\right) \tag{6}$$

After all the savings opportunities obtained from Step 2.4, an empirical equation model is created, followed by a prediction curve for saving energy consumption. From this prediction curve, monitoring can be carried out in real time on the real-time energy monitoring system that has been implemented in the future. When the prediction curve is still below the real-time usage curve, the user (the library) can still save electricity. Figure 4 is a comparison curve of load usage for 24 hours between real-time monitoring and estimation.

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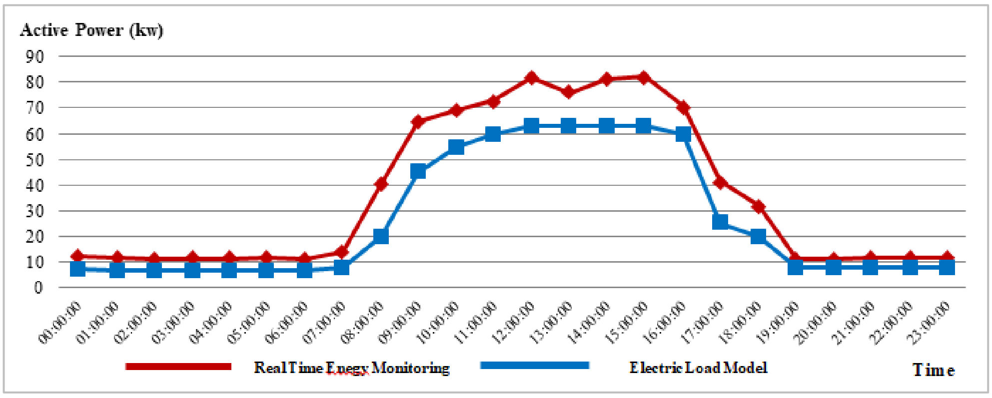

Figure 4. Real Time VS Estimated Load Usage Curve

RESULTS AND DISCUSSION

From the results of the data collected by means of observation, which can be seen in tables 1 through 4, the characteristics of the electric power consumption in the Andalas University Library building are obtained. Furthermore, observations were made on the real-time energy monitoring system for the Andalas University Library Building to see trends in the use of electrical energy over a month, a week, and a day. Finally, an energy-efficient electrical load model is developed.

Andalas University Library Building Real-Time Energy Monitoring System

The data obtained from the results of this monitoring was grouped into several groupings. The authors grouped electrical energy data for each month in the first; in the second, they grouped energy usage for each week, grouped energy for each day, and day-to-week power factor data. This grouping aims to see patterns of energy use in the Andalas University Library Building in 2022.

Figure 5 is a reading of electricity energy (kwh) in the Andalas University Library Building from January 2022 to October 2022. From Figure 5, it can be seen that the use of electrical energy every month is almost evenly distributed. The lowest usage was in February 2022 at 14,266 kWh, while the highest was in September 2022 at 18,078 kWh. This difference in usage is due to the addition of their own electrical equipment, such as cellphones and laptops, used by students who visit the library.

Figure 6 is a recording of daily electricity consumption for one week in each month taken from the electrical energy monitoring system data storage at the Andalas University Library Building. From Figure 6, it can be seen that the pattern of daily electricity consumption in one week is almost the same in each month. The average use of electrical energy is 600–800 kWh per day on normal working days, namely Monday, Tuesday, Wednesday, Thursday, and Friday. Saturdays use energy between 200 and 600 kWh per day. This is because on Saturdays the library's operational schedule is only from 09:00 to 15:00 WIB, and activities held by student units in the library are not routine. On Sundays, the use of electrical energy in one day is around 200 kWh per day. This is because the library does not operate on Sundays and only lights lamps as an electric load.

Figure 7 depicts the trend of daily electricity usage in the library building during one week in January. From the figure, it can be seen that from Monday to Friday, which is a normal working day, the use of electricity in the library starts at 08.00 and the electricity consumption in the library starts to increase by 42 kW. Then 09.00 to 16.00 is the highest load of 55kW because library staff and library visitors are already in the library. Whereas at 17.00, the library's electricity usage decreased due to the library staff returning home at the end of the 40kW electricity period. Outside of the library's operational hours, the electricity consumption in the library is 10 kW. The library is closed on Saturdays and Sundays in January, so its electricity consumption is 10 kW. In January, conditions were still pandemic, so there were restrictions on activities in the library.

Figure 8 depicts the daily electricity usage trend in the library building during one week in July. From the figure, it can be seen that Monday to Friday have a pattern that is almost the same as Figure 7, but this July the curve starts to rise at 07.00. This is due to the cleaning service (CS) of the library starting at 07.00 and going home at 18.00. This is because in July the COVID-19 pandemic was deemed non-existent, so the operating hours for library cleaning services were 07.00–18.00. At 07.00, the library's electricity consumption is 29 kW, because at 07.00 the library cleaning service starts to turn on the lights in the library room. At 08.00–17.00, the library's electricity consumption is 48 kW. Meanwhile, at 18.00, the electricity consumption was 16 kW. At this point, the library's CS began to turn off the lights and leave. Outside the operational hours of the library, the electric power used is 10kW. Whereas on Saturday in July it is different from January, in July from 09.00 to 16.00 the library is open because of this, and the trend of the power curve goes up from 09.00 to 16.00. As a result, electricity consumption on this Saturday is at its peak of 35 kW. On Sundays, the use of electricity in the library is 10 kW. As a side note, the author includes the month of July in the trend of this analyst curve because July is student holiday time and is also not in a pandemic situation.

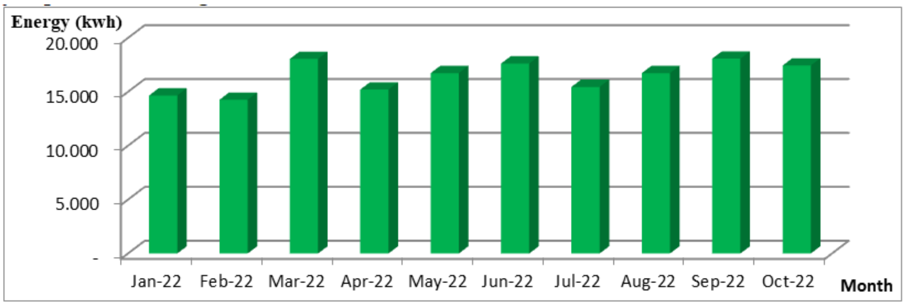

Figure 5. Every Month (kWh) for the Library Building in 2022

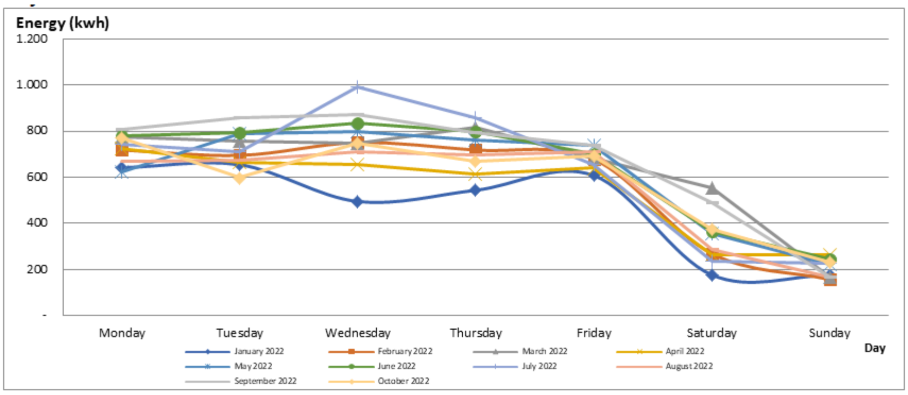

Figure 6. Trending Daily Use of Electrical Energy in One Week in Every Month from January 2022 to October 2022

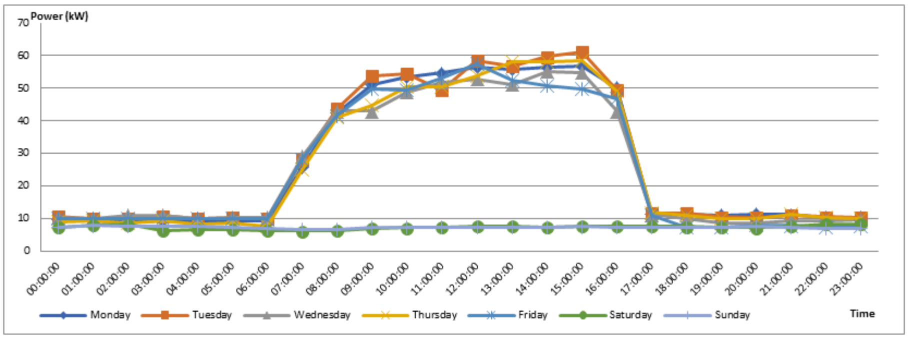

Figure 7. Trends in Daily Electricity Usage in One Week of Library Building in January

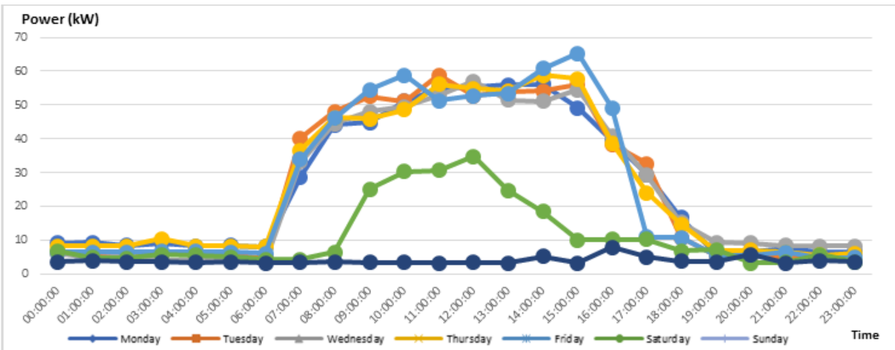

Figure 8. Trends in Daily Electricity Usage in One Week of Library Building in July

Figure 9 depicts the daily electricity usage trend in the library building during one week in September. In September, students have started doing normal lectures, so there are more library visitors this September than in previous months. From Figure 9, it can be seen that Monday through Friday have almost the same pattern, but each day has a different peak. This is due to the use of laptops or smart phones by library visitors. At 7:00, the electricity consumption of the library is 30 kW. The library's electricity consumption ranges from 60 kW to 80 kW from 8:00 a.m. to 17:00 a.m. The library's electricity consumption is 40 kW at 18.00. And outside of the library's operating hours, the library's electricity consumption is 10 kW. On Saturday, the electricity consumption increases from 09:00 to 16:00, which is 40–50 kW. While on Sunday it is 10kW. During normal lectures, all student activities in the library are operating, and many students use library electricity to charge laptop and cell phone batteries, which results in high library power.

Figure 10 shows the trend of the power factor of the library's electrical load for one week. From Figure 10, it is known that the library's power factor is low during library operating hours. The low power factor is due to the operational time required by the library to turn on the equipment that absorbs reactive power. Examples of equipment that absorbs reactive power are air conditioners, blowers, and so on. power factor at the time of library operations with a range of 0.5 to 0.8. Outside the operational hours of the library, the power factor generated by the high system meets the permitted standards. The power factor that meets the permitted standards is >0.85.

Energy-efficient Electrical Expense Modeling

Following observation of the object and monitoring of the system, the next stage is the creation of an energy-efficient electric load model. There are five models of energy-saving electric loads examined in this study. The energy-saving electric load model in this study is as follows:

Electrical load modeling by replacing T8 fluorescent and CFL lamps with LED lamps

From Table 3, it can be seen that electricity consumption for lighting contributes quite a lot, around 25.3% of the total usage. After the check stage of the PDCA method is carried out, there is an opportunity to save electrical energy here. Opportunities for saving electrical energy can be made by replacing T8 fluorescent and CFL lamps with LEDs. Savings on lighting can be made by replacing T8 fluorescents with a power of 36 watts, T8 LEDs with a power of 18 watts, T8 fluorescents with a power of 18 Watts with a 10 Watt T8 LED, and 20 Watt CFLs with a 12 watt LED bulb.

Table 6 shows the consumption of electrical energy for lighting the library building by modeling the electric load using LEDs. From the table, it is known that the electric power consumption of the model is 11,558 watts. so that electricity consumption using LEDs can save 10,050 watts. On weekdays, the estimated consumption of electrical energy from the total load of LED lights is 129,248 kwh; on Saturday, the estimated consumption of electrical energy is 103,424 kwh; and on Sundays, the estimated consumption of electrical energy is 34,56 kwh. As a result, the total estimated monthly consumption of electrical energy charged with lighting is 1,327 kWh.

Table 6. Electric Power Consumption with Electrical Load Modeling Using LEDs

Equipment Name	Power (watt)	Quantity	Total Power (watt)
LED Tube	18	508	9,144
LED Tube	10	86	860
LED Bulb	12	27	324
LED Lamps	3	200	600
Downlight	10	63	630
Total			**11,558**

Modeling with l LEDs can save 1,588 kWh of electricity per month. By saving electricity, Andalas University will also save on electricity bills for the Andalas University Library building. Andalas University is included in the S3 category [20] who have to pay for electricity 740/kWh. So that Andalas University can save electricity bills of Rp. 1,175,120 / month.

Electrical load modeling by replacing non-inverter AC with inverter AC

The second model of electric load is the replacement of non-inverter AC with inverter AC. Using an inverter AC can save up to 30% of electricity compared to using a non-inverter AC [17]. To see the AC inverter load model installed in one day for one week, it can be seen in Figure 11.

Figure 11 depicts a model of the AC power curve for a used load in one day for one week. The model curve provides information that on weekdays, Monday to Friday, the room air conditioner is turned on from 08.00 to 17.00, which is for 9 hours with a power of 17.36 kW, so that the energy consumption of the AC load on weekdays in one day is 156.24 kWh. On Saturday, the room air conditioner is turned on from 09.00 to 16.00, that is, for 7 hours with a power of 17.36 kW, so that the energy consumption of the AC load on weekdays in one day is 121.52 kWh, so that the total electricity consumption in one month is 1,424 kWh. Electrical energy savings can be produced using the model for the used inverter AC load. Savings in electrical energy resulting from the use of an inverter AC for an installed load of 610 kWh per month. Saving electrical energy means also being able to save on the monthly electricity costs that are paid. With this inverter AC load model, Andalas University saves Rp. 451,755 every month.

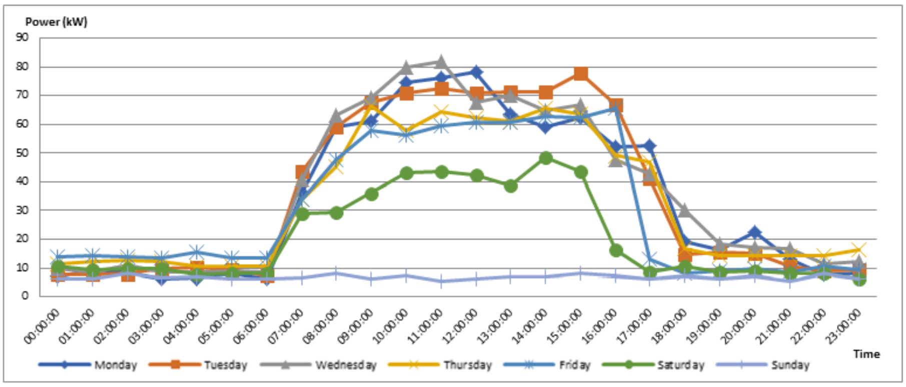

Figure 9. Daily Electrical Power Usage Trends in a One-Week Library Building in September

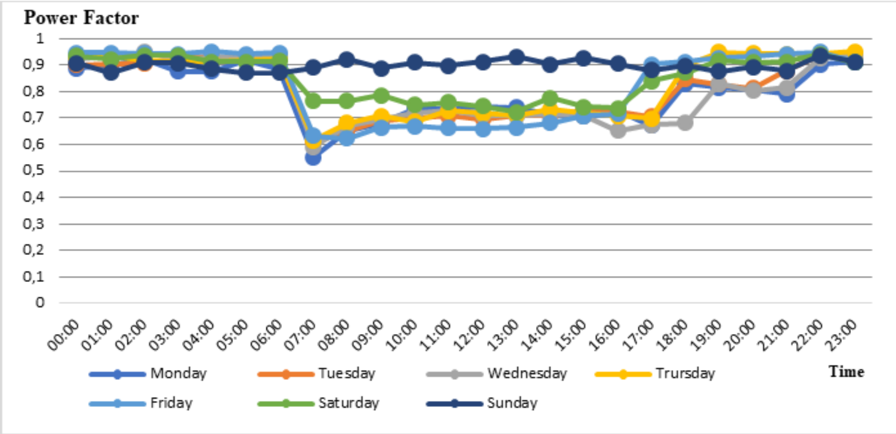

Figure 10. The Power Factor of the Library's Electrical Load One Day for One Week

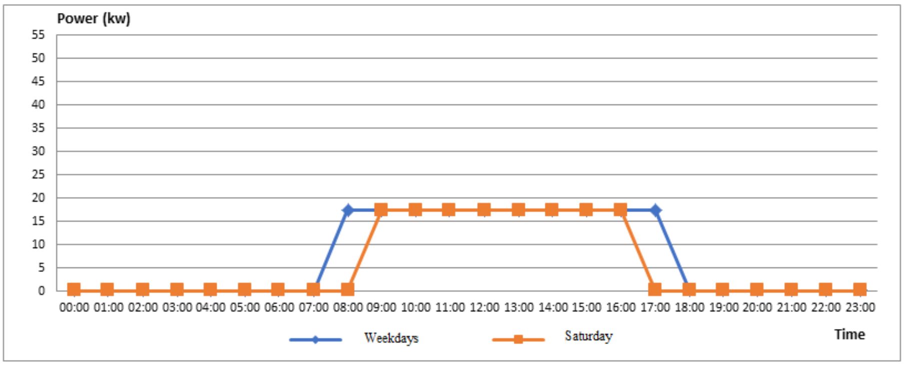

Figure 11. Electric power modeling curve using an AC inverter

Electrical load modeling by improving the power factor

There are several ways to improve the power factor. One way to do this is to use a capacitor bank. Modeling the electric load by improving the system power factor can be seen in equation (2). The savings results obtained from modeling the electric load by improving the power factor can be seen in Table 7. Table 7 is a table of electricity savings generated by improving the power factor by one day a week. In this study, the authors modeled the system power factor to be 1. From the table, it can be seen that improving the low power factor can save energy, which is used more. From this modeling, energy savings were obtained by improving the power factor by 56 kWh per month. so that it can save electricity costs of Rp. 41,440 per month.

Modeling the electric load with the adjusted number of library visitors

Human behavior greatly influences the value of electrical energy consumption in buildings, especially the attitude of humans toward ignoring the use of energy when and where it is not needed. According to Figures 7, 8, and 9, the trend of daily electricity consumption in one week of the library building shows that the electricity used from 07.00 to 17.00 on Monday through Friday and Saturday has an almost flat pattern. In January, the conditions were still pandemic, so there were restrictions on activities in the library. July is student holiday time and is also not in a pandemic situation. In September, during normal lectures, all student activities in the library have been operating, and many students are using the library's electricity to charge laptop and cell phone batteries, which has resulted in high library power consumption. Judging from the trend of the load usage curve in these three conditions, it is almost the same. So that the authors get an opportunity to save energy by adjusting the number of library visitors.

Observations made by the author show that the current use of the lighting load is the optimal number of lights at this time. The number of lamps currently in use is adequate for operational lighting in the library. For the use of electrical energy when the library is closed, there is a lot of waste. The use of electrical energy when the library is closed reaches 10 kW. The library's alleged electrical energy consumption is only 1.44 kW. So there is a waste of 7 kW.

The electrical energy used when the library is closed, based on the monitoring results for a month, is 1035 kWh per month, while the energy generated from the electricity savings model when the library is closed is 178.56 kWh. The savings obtained from this model are 857 kWh per month. Saving electrical energy can also reduce the electricity expenses paid by Andalas University. The savings obtained from this model are Rp. 634,180 per month.

Electrical load modeling with a combination of the four models

Equations (5) and (6) can be used to calculate the electric load. To get a PT, we must first get 4 parameters: P_{Led}, P_{AI}, $P_{equipment}$, and $P_{visitor}$. For three parameters, they have already been obtained, namely P_{Led}, P_{AI}, and $P_{equipment}$, in the previous discussions. Then, we have to calculate the value of the current $P_{Visitor}$.

Table 7. Electrical Energy Savings Generated by Power Factor Improvements in One Day for a Week

Time	Energy Saving by Improving Power Factor						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0:00	2.37	3.73	4.95	7.68	13.05	7.40	2.07
1:00	5.18	3.59	4.10	9.51	13.10	5.05	2.11
2:00	4.40	3.71	6.73	9.09	12.63	6.80	4.23
3:00	2.10	6.28	4.01	8.44	12.33	6.75	2.12
4:00	2.10	6.60	3.99	6.21	15.09	3.64	2.34
5:00	4.20	6.25	4.37	6.53	12.21	4.11	2.07
6:00	2.08	3.44	3.99	6.38	12.76	4.00	2.05
7:00	70.47	99.74	83.99	60.64	62.18	43.00	2.29
8:00	192.67	186.17	213.06	106.58	121.74	44.88	4.33
9:00	216.56	248.28	269.00	238.41	179.07	66.68	2.16
10:00	323.60	275.41	347.36	183.46	169.25	96.13	2.99
11:00	331.23	286.15	364.49	222.36	190.27	100.47	1.96
12:00	346.86	269.16	249.22	209.66	195.34	93.33	2.59
13:00	233.83	278.47	270.74	203.99	194.12	77.47	3.98
14:00	191.47	278.47	226.97	236.71	210.99	121.35	2.72
15:00	211.21	331.46	239.21	222.28	207.00	96.97	4.45
16:00	143.43	234.62	116.85	129.80	235.74	13.68	2.88
17:00	142.20	88.23	92.35	117.37	8.92	3.75	2.06
18:00	18.94	10.98	46.53	16.04	3.99	6.06	2.77
19:00	13.42	12.17	17.52	13.84	4.52	4.37	2.06
20:00	28.97	11.43	14.57	13.10	6.91	4.76	2.81
21:00	9.94	5.48	14.24	12.98	4.24	4.27	1.81
22:00	3.59	4.26	7.59	12.82	7.21	4.35	4.22
23:00	3.81	4.87	9.61	16.35	4.92	2.07	2.01
Total	**2504.63**	**2658.95**	**2615.44**	**2070.23**	**1897.58**	**821.34**	**65.08**

We use equation (6) to calculate $P_{Visitors}$. The results of observing the maximum total number of visitors to the library on weekdays are 250 visitors, and the power for mobile phone is 15 watts, while the average laptop power is 100 watts. During the library's operating hours of 10.00 to 16.00, $P_{Visitors}$ will be included in the energy savings estimation curve.

$P_{Visitors}$ $= 0{,}7 \times 250 \times (100+15)$
$P_{Visitors}$ $= 20.125$ watt $= 20{,}125$ kW

After obtaining all the parameters, we can calculate the P_T value. The P_T value will be plotted in the daily library power curve in a week, which can be seen in Figure 12. Figure 12 is a modeling curve for energy-efficient electric power for 24 hours. From the curve, it is found that on working days at the library, namely Monday–Friday, the maximum power generated is 58.64 kW, starting from 10.00–17.00. On Saturday, the electric power consumed was 38.52 kW. Meanwhile, outside the operational hours of the library, the electric power consumed is only 1.44 kW.

After obtaining the power curve of the model for saving electrical energy, a comparison of the model curve with the power curve obtained from the monitoring results is carried out. In this study, the authors compared the model's power curve with the monitoring results curve in September 2022. It was this comparison curve that became the result of this study. The power comparison curve between modeling and monitoring results can be seen in Figures 13, 14, and 15.

Figure 13 is a power comparison curve between load modeling and system monitoring from Monday to Friday for 24 hours. From this curve, it can be seen that the modeling was correct because the estimated model curve is smaller than the monitoring result curve. At 00.00 - 07.00 and 18.00 - 23.00 the power from the model is only 1.44 kW, while the electric power monitored reaches 10 kW, so modeling saves 8 kW at this hour. During library operating hours, the shape of the curve is almost the same, but modeling can save up to 30 kW of electric power at its peak. This means that there is still waste in the use of electrical equipment. The value of the monitoring results curve is taken from the average results from Monday to Friday to represent the comparative value between the modeling curve and monitoring results on working days.

Figure 14 is a power comparison curve between the load modeling and the monitoring system on Saturday for 24 hours. From this curve, it can be seen that the modeling was correct because the estimated model curve is smaller than the monitoring result curve. At 00.00 - 07.00 and 16.00 - 23.00 the power from the modeling is only 1.44 kW, while the electric power in the monitoring system reaches 10 kW, so the modeling saves 8 kW at this hour. During operational hours, the modeling library can save up to 15 kW of electric power at its peak. This means that many pieces of electrical equipment are still alive but not in use.

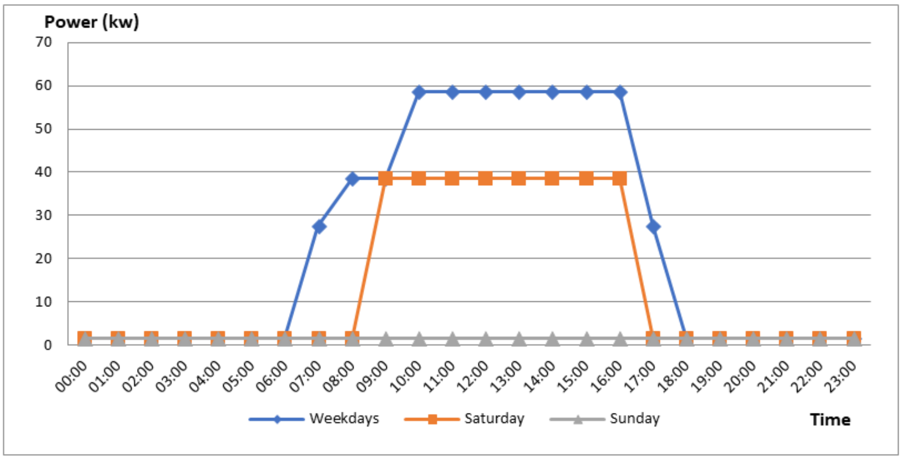

Figure 12. 24-Hour Energy-Saving Electrical Power Modeling Curve

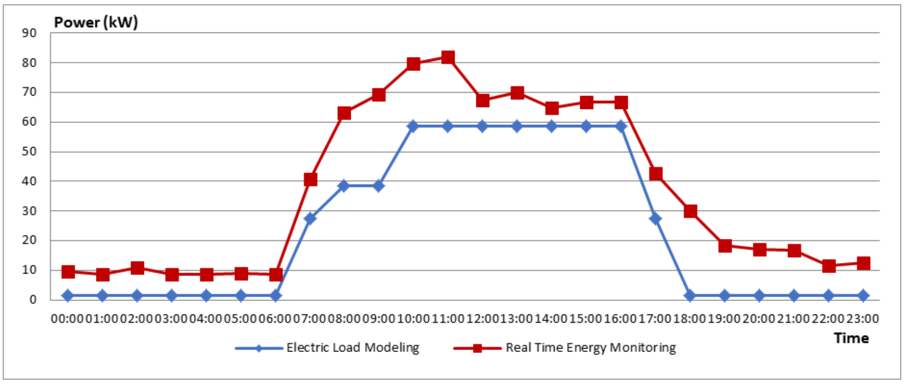

Figure 13. Comparison of the Modeling Power Curve with the Monitoring System on Monday through Friday

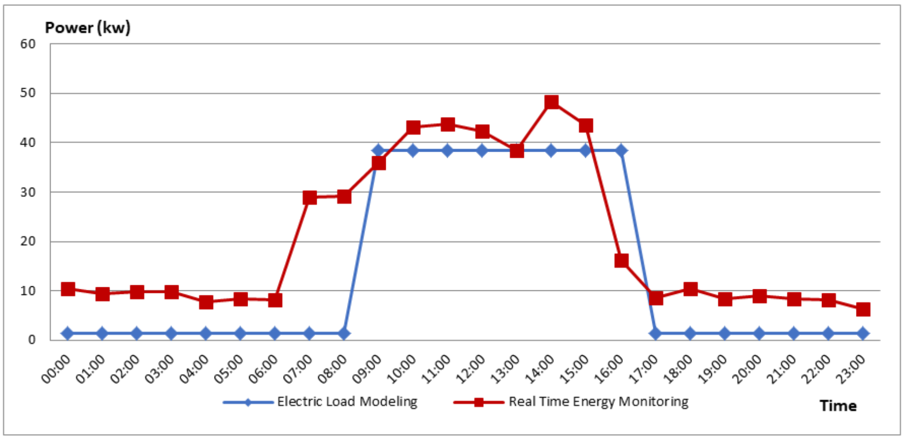

Figure 14. Comparison of Modeling Power Curve with Monitoring System on Saturday

Figure 15 is a power comparison curve between the load modeling and the monitoring system on Sundays for 24 hours. Sundays should use very little electricity in the library. From Figure 15, it is known that the modeling done is correct, only producing 1.44 kW of electric power. It is assumed that only a few light loads are on. Meanwhile, from the monitoring system, it can be seen that electricity consumption on Sundays is still high, reaching 10 kW. This happens because there is still electrical equipment that should be off but is still on, such as air conditioners, lights, and so on.

 https://doi.org/10.25077/ajeeet.v3i1.35

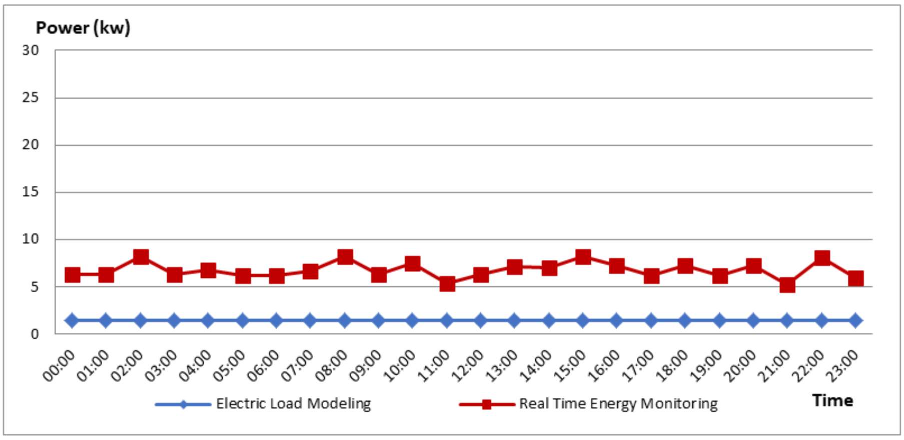

Figure 15. Comparison of the Modeling Power Curve with the Sunday Monitoring System

CONCLUSIONS

Modeling the use of efficient electrical energy in the Andalas University Library building has been successfully completed. Electrical load modeling is done by replacing T8 fluorescent and CFL lamps with LED lamps. The savings obtained from this model amount to an installed load of 23,428 Watts and a load used of 10,048 Watts. So that it can save 2,872 kWh of electricity per month and Rp. 2,125,280 per month in electricity costs. Modeling the electric load by replacing non-inverter AC with inverter AC saves 30% of electric power, so that the electricity savings resulting from the use of inverter AC is 1,742 kWh per month. Saving electrical energy means also being able to save on the monthly electricity costs that are paid. With this inverter load model, Andalas University saves Rp. 1,289,139 every month. Modeling the electric load with an adjusted number of library visitors. The savings obtained from this model are 857 kWh per month. Saving electrical energy can also reduce the electricity expenses paid by Andalas University. The savings obtained from this model are Rp. 634,180 per month. Modeling the electric load and improving the power factor of this model results in energy savings of 56 kWh per month. So that it can save electricity costs of Rp. 41,440 per month.

The application of the model that has been made is then compared with the real-time monitoring system divided into three time periods, namely weekdays, Saturdays, and Sundays. Modeling predictions for saving electricity use in the library building at Andalas University monitoring system from Monday to Friday modeling is 8 kW more efficient this hour. During library operating hours, the shape of the curve is almost the same, but modeling can save up to 30 kW of electric power at its peak. When modeling predictions for reducing electricity use in the Andalas University library building, the monitoring system on Saturday, modeling is 8 kW more efficient this hour. During operational hours, the modeling library can save up to 15 kW of electric power at its peak. Modeling predictions for saving electricity use in the Andalas University library building monitoring system on Sundays modeling is more efficient 8 kW this hour.

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NOMENCLATURE

$cos\varphi$	Power Factor
P	Active Power
S	Apparent Power
$I_L(i)$	Line Current at on measurement to (i)
$V_{LN}(i)$	Phase Voltage on measurement to (i)
$P_L(i)$	Three Phase Active Power on measurement to (i)
TPF(i)	Original Power Factor on measurement to (i)
$P_{monitoring}$	Active Power from Real Time Monitoring System
P_{model}	Active Power from Electric Load Modeling
P_{Led}	Led Active Power
P_L	Lamps Active Power
P_{AI}	Inverter AC Active Power
P_A	Non Inverter AC Active Power
P_T	Total Active Power
$P_{Equipment}$	The total active power of the library's electrical equipment other than lights and air conditioners
$P_{Visitors}$	Total Active power used by visitors using personal laptops and mobile phones.