

Development of an Energy-Efficient Electrical Load Model for Optimizing Electricity Consumption in the Headquarters Building using the PDCA Approach

Refki Budiman^{1*}, Jhonny Faizal²

¹ Department of Electrical Engineering, Engineering Faculty, Universitas Andalas, Padang, Indonesia.

²WHRPG and Utility Unit, PT Semen Padang, Padang, Indonesia.

*Corresponding author, e-mail: refkibudiman@eng.unand.ac.id

Abstract— The increasing electricity consumption in the public building sector has a significant impact on greenhouse gas (CO₂) emissions, which is proportional to the volume of energy used. This study aims to develop an energy-efficient electrical load model to optimize electricity consumption in the headquarters building of PT Semen Padang using the Plan-Do-Check-Action (PDCA) approach. In the Plan stage, problem identification was conducted through a Pareto diagram and root cause analysis using a fishbone diagram. The dominant issue identified was energy waste in the lighting system. The solution implemented included the installation of motion sensor-based switch control devices to regulate lighting use automatically. In the Do phase, the devices were installed and tested, while in the Check phase, the evaluation showed a reduction in electricity consumption from over 85,000 kWh per month to below 80,000 kWh per month, resulting in an electricity cost savings of IDR 31 million per month. The Action phase established standards for inputs, processes, and outputs to ensure the sustainability of the improvements made. This study not only provides financial benefits but also supports the company's Energy Management System policy. With the PDCA approach, improvement processes can be carried out systematically and continuously, making a tangible contribution to energy efficiency in the public building sector.

Keywords: *Energy efficiency, PDCA, Electrical Load Model, Energy Management.*

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1. Introduction

The demand for electrical energy plays a crucial role in supporting various aspects of human activities. Currently, the public building sector significantly contributes to this demand, accounting for approximately 33–40% of the total energy consumption across all sectors [1, 2, 3]. The growing utilization of electrical energy in this sector is expected to contribute to a rise in greenhouse gas emissions (CO₂), with the emission levels directly correlating to the volume of electricity consumed in buildings [4, 5]. Given these circumstances, transitioning to entirely new sustainable buildings and optimizing the use of building materials involves significant costs and requires careful consideration of various factors to achieve feasibility [6].

Conducting regular energy audits is essential for assessing energy consumption, analyzing energy usage patterns, and identifying opportunities for energy savings to enhance energy efficiency [7]. Energy auditing serves as an effective approach to achieving energy efficiency [8]. Enhancing electrical energy efficiency in buildings can be achieved by optimizing the efficiency of electrical equipment, improving the power factor, and minimizing energy wastage [9].

An Energy Management System (EMS) is essential for effectively managing and controlling electrical energy consumption in buildings [3]. Incorporating energy management system planning and conducting energy audits during the building design process are key steps in assessing energy consumption and identifying potential energy-saving opportunities [2]. The Energy Management System (EMS) process follows the Plan-Do-Check-Act (PDCA) cycle. [10]. In the EMS cycle, energy consumption control is typically planned and evaluated during the Plan (P) and Check (C) stages. Meanwhile, methods for assessing the effectiveness of buildings in achieving energy savings and efficiency are crucial considerations, especially in light of increased investment costs for global energy conservation strategies [4].

In recent times, numerous experts have concentrated their research on forecasting building energy usage through a variety of models and approaches. Researchers introduced a Robust Optimization method that considers uncertainties arising from natural factors, such as external illumination affecting lighting systems and outdoor air temperature influencing the use of Heating, Ventilation, and Air Conditioning (HVAC) [1]. Another study developed a building energy consumption model using a Support Vector Machine (SVM), incorporating various factors such as building geometry and physical structure, occupant behavior, thermal comfort, water quality, climatic conditions, and integrated energy sources within buildings [6]. Other studies proposed a method for predicting energy demand across different scenarios using deep learning models based on autoencoders [10].

The aim of this research is to develop an energy-efficient electrical system to optimize electricity consumption in sustainable office buildings using the Plan, Do, Check, Action (PDCA) approach. The PDCA cycle is often likened to a ball that must be propelled toward a specific target [11]. The PDCA cycle is extensively utilized by industries to drive innovation and enhance performance, ranging from factory operations to company management systems [12]. Enhancing quality requires various efforts to ensure the PDCA cycle consistently facilitates ongoing quality improvement. [13].

2. Method

This research followed the series of steps outlined in the flowchart below:

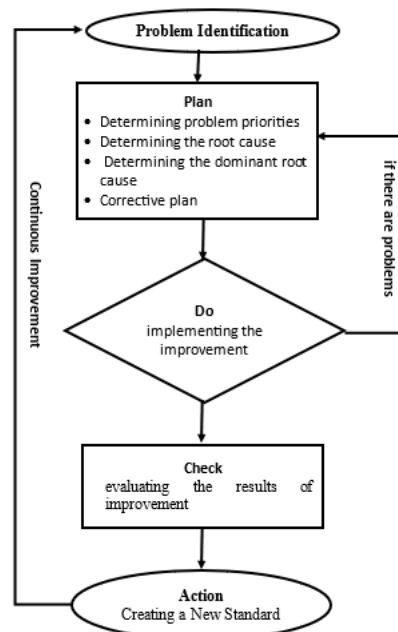


Figure 1. Research Methodology Flowchart

This research begins by identifying the problems found in the the headquarters of PT Semen Padang. During Plan stage, the priority of the problems is determined, the root causes are identified, and the most significant root cause is chosen from these identified causes. If challenges arise during the Do stage, a corrective action plan is created in the Plan stage. In the Do stage, the improvement is implemented. If problems arise, the process returns to the Plan stage for a repair plan; if not, it moves on to the Check stage. In the Check stage, the results of the improvement are evaluated, followed by the final stage, the Action stage. In this stage, a new standard is established based on the improvements that have been implemented. After some time, the the headquarters of PT Semen Padang should continue to make improvements, ensuring that the PDCA cycle remains sustainable [12].

2.1 PDCA Cycle Implementation

This The fundamental principles of the PDCA cycle are applied in quality management systems across various industrial sectors, including manufacturing, services, project management, and organizations. These principles were introduced in 1950 by Dr. Edward Deming, a renowned quality management expert. The PDCA approach is valuable for driving continuous improvements in a seamless manner, with principles that are forward-looking, adaptable, rational, and practical, offering detailed explanations for all its components [14].

The PDCA method for managing and enhancing processes involves a repetitive cycle of four stages. This process concludes with Planning, Conducting, Testing, and Implementation, collectively referred to as the Deming Phase. Deming created this four-step problem-solving cycle, commonly known as the Plan-Do-Check-Action cycle [14].

- **Plan** - The Plan stage involves defining objectives and establishing processes to achieve the desired outcomes.
- **Do** - The Do stage involves executing what was previously planned
- **Check** - The Check stage involves reviewing and assessing the process stage, which is monitored and evaluated
- **Action** - The Action stage focuses on implementing measures to enhance the results

2.2 Problem Identification

The headquarters of PT. Semen Padang is one of the most important buildings. The electricity usage at the headquarters is divided into three categories: electricity for lighting, electricity for Heating, Ventilation, and Air Conditioning (HVAC), and electricity for office equipment such as computers, printers, and others. Among these three categories, HVAC and lighting are the largest contributors to electricity consumption.

Electricity wastage during operations at the headquarters is unavoidable. This wastage can occur due to the use of non-energy-efficient electrical equipment as well as behaviors, whether intentional or unintentional. Responsibility for electricity usage lies with the WHRPG and Utilities unit, but the actual users are the employees and workers at the site.

In line with the description above, and in support of the company's Energy Management System Policy points 1, 2, and 5—namely energy efficiency, energy consumption, and equipment design and planning based on energy efficiency and savings—the following initiatives are proposed.

The problems that arise from this background are listed in table 1

Table 1. Problem Identification

No	Problem Identification	Information
1	Energy Wastage in Lighting	Energy Wastage Due to Lighting Usage When Not Needed

2	Energy Wastage in HVAC	Energy Wastage Due to HVAC Usage When Not Needed
3	Energy Wastage in Computer Usage	Energy Wastage Due to Computer Usage When Not Needed

3. Result and Discussion

In the Results and Discussion section, all PDCA cycles conducted in this study are discussed. The first cycle begins with the plan stages.

3.1 Plan Stages

The Plan stage represents the starting phase of the PDCA cycle. It involves prioritizing the problems, investigating their underlying causes, and formulating a strategy for improvement.

a. Determining problem priorities

To determine the priority issues of this study, a Pareto diagram was used, based on observations conducted over one month. The priority issues for this study are presented in the table 2 and figure 1. Using the Pareto diagram, the team agreed to address issues with a percentage above 50%, namely "Energy Waste in Lighting," which accounts for a total percentage of 65%.

Table 2 Priority of the Problem

No	Problem Identification	Frequency of Occurrence	Percentage (%)	Cumulative (%)
1	Energy Wastage in Lighting	24	65	65
2	Energy Wastage in HVAC	10	27	92
3	Energy Wastage in Computer Usage	3	8	100
Total		37	100	

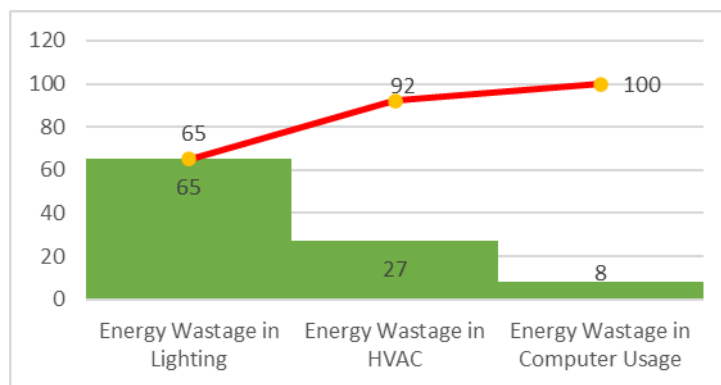


Figure 1 Pareto Diagram of the Problem Priority

b. Determining the root cause

Once the priority problem is identified, the root cause is examined through a fishbone diagram to identify its contributing factors [15] [16]. This study highlights five root causes: human

factors, tools, environmental factors, methods, and procedures, and materials. A detailed breakdown of these causes is shown in the fishbone diagram in Figure 2 below.

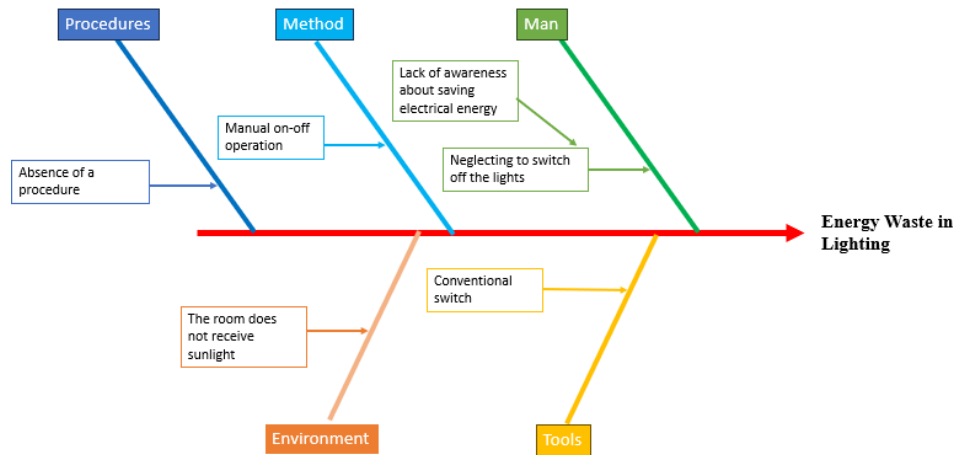


Figure 2. Fishbone Diagram of the Root Cause Analysis

- c. Determine the dominant root cause

In determining the dominant cause, the team employs the nominal group technique (NGT) [17]. As presented in table 3.

Tabel 3. NGT table

NO	Root Cause	Fasilitator	Team Leader	Team Secretary	Team Member 1	Team Member 2	Total
1	Neglecting to switch off the lights	4	4	4	4	5	21
2	Conventional switch	3	2	2	3	3	13
3	Manual on-off operation	5	5	5	5	4	24
4	The room does not receive sunlight	2	1	1	1	2	7
5	Absence of a procedure	1	3	3	2	1	10

The NGT value from Table 3 can be obtained by calculating it using the equation (1)

$$\begin{aligned} \text{NGT} &= (\frac{1}{2} \times \text{Number of Issues} \times \text{Number of Voters}) + 1 \\ \text{NGT} &= (\frac{1}{2} \times 5 \times 5) + 1 \\ \text{NGT} &= 13,5 \end{aligned} \quad (1)$$

As a result, the team agreed to focus on solving the dominant issues scoring $\geq 13,5$, particularly causes number 1 (Neglecting to switch off the lights) and 3 (Manual on-off operation).

To address the identified dominant causes, a solution has been devised: implementing the installation of motion sensors as automatic switches to control the use of lighting in the office rooms of the headquarters PT. Semen Padang.

- d. Corrective plan

To attain the best outcomes, the repair strategy is designed using the 5W and 2H framework, which includes What, Why, When, Where, Who, How, and How Much. The plan is further strengthened by the participation of skilled personnel who can efficiently execute the enhancements. The next stage is the do stage.

3.2 Do Stages

The second stage of the PDCA cycle, known as the "Do" stage, encompasses various problem-solving tasks. It starts with the preparatory step, which includes identifying the issue, gathering relevant data, designing the necessary equipment, acquiring the required materials and tools, and ultimately sharing information with team members.

After completing the preparations, the next step is implementation. This involves installing the equipment and materials based on the design specifications. Following installation, testing or commissioning is performed. If the commissioning is successful and meets the intended design requirements, a new standard is set to reflect the improvement.

3.3 Check Stages

The check stage represents the third phase of the PDCA cycle, where the implemented improvements are assessed and evaluated. This innovation, as scheduled, was implemented starting on June 25, 2024. The improvement implemented in this study involved installing switch control devices for lighting in all rooms at the headquarters of PT. Semen Padang. This switch control device functions as a motion sensor in the rooms. If no movement is detected, the sensor automatically turns off the lights in the respective room. With this sensor, electricity usage in the rooms can be effectively managed, as the lights will automatically turn off when no activity is detected in the room.

Based on Table 4, it is evident that electricity consumption prior to the implementation of this innovation exceeded 85,000 kWh per month, while after implementation, electricity consumption decreased to below 80,000 kWh per month. Therefore, it can be concluded that this innovation has been successful in reducing electricity consumption at the headquarters.

Table 4. Table of Electricity Consumption at the Headquarters PT. Semen Padang

Month 2024	Headquarters KWH Meter	Electricity Bills at the Headquarters (Rp)
January	95.538,46	95.538.460
February	97.250,00	97.250.000
March	107.910,75	107.910.750
April	94.380,00	94.380.000
May	98.678,87	98.678.870
June	79.876,54	79.876.540
July	78.983,28	78.983.280
August	79.391,60	79.391.600
September	77.846,93	77.846.930
October	78.387,37	78.387.370
November	79.476,62	79.476.620
December	78.631,82	78.631.820

a. Financial benefits

The financial benefit gained from this innovation is the reduction in electricity costs at the headquarters. Based on the kWh meter reports for November and December 2023, compared to the kWh meter readings prior to the implementation of this innovation, an energy saving of 31,000 kWh per month was achieved. This resulted in electricity cost savings of IDR 31,000,000 per month.

b. Non-Financial benefits

Has supported the company's Energy Management System Policy in points 1, 2, and 5, which focus on energy efficiency and consumption, as well as the design and planning of equipment based on energy efficiency and savings.

3.4 Action Stages

The final stage of the PDCA cycle is the action phase. During this stage, standards are created following the implementation of improvements. These standards are classified into three categories: input standards, process standards, and output standards.

a. Input Standard

Input standards refer to the criteria utilized as the basis for implementing improvements. These standards are outlined in Table 5.

Table 5. Input Standard

No	Equipment	Function
1	Motion Sensor	A motion sensor functions to detect movement within its covered area. When motion is detected, the sensor will command the contactor to operate
2	Contactor	A contactor functions to open and close an electrical circuit. When the motion sensor detects movement, the contactor will close; otherwise, it will remain open
3	Circuit Breaker	A circuit breaker functions to disconnect the electrical circuit when a fault occurs

b. Process Standard

Process standards include Standard Operating Procedures (SOPs) and maintenance guidelines, which act as references for operators in performing operational and maintenance tasks.

c. Output Standard

The output standard serves as a reference to assess whether the equipment is operating effectively and accurately. In this improvement, the standard output is the control of lighting usage in the headquarters offices. If a room is not in use, the lights will turn off automatically due to the absence of any movement detected in the room.

4. Conclusion

This study successfully developed an energy-efficient electrical load model to optimize electricity consumption in the headquarters building of PT Semen Padang using the PDCA (Plan-Do-Check-Action) approach. The implementation of the PDCA cycle began with identifying the main issue, which was energy waste in lighting systems, HVAC, and office equipment. The most significant problem, energy waste in lighting, was addressed by installing motion sensor-based switch control devices. The evaluation results showed that this innovation reduced electricity consumption from over 85,000 kWh per month to below 80,000 kWh per month, saving electricity costs by IDR 31 million per month. In addition to financial benefits, this innovation also supports the company's Energy Management System policy, particularly in energy efficiency and energy-saving equipment planning.

The standardization of processes, inputs, and outputs generated from this study provides a sustainable guide for energy management in office buildings, ensuring that energy savings can continue to be applied and improved in the future. This research demonstrates the effectiveness of the PDCA approach as an adaptive and practical tool for achieving sustainable energy management.

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