



Integrated Energy Audit for Workshop and Learning Systems

Aminatus Sa'diyah¹, Mohamad Hakam¹, Evi Nafiatus Sholikhah², Mey Rohma Dhani³,
Muhammad Anis Mustaghfirin¹, George Endri Kusuma¹, Muchammad Nidhor Fairuza¹

¹Sustainable Energy Engineering, Politeknik Perkapalan Negeri Surabaya, Indonesia

²Electrical Engineering, Politeknik Perkapalan Negeri Surabaya, Indonesia

³Safety Engineering, Politeknik Perkapalan Negeri Surabaya, Indonesia

*Corresponding Author: Aminatus Sa'diyah

Email: am.sadiyah@ppns.ac.id



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Abstract

The south workshop building is utilized for practical activities involving high machine loads, while the learning building is designated for theoretical activities. In order to optimize energy efficiency, a comprehensive audit of the lighting and electrical systems. A comparative case study approach was utilized for the analysis. A comprehensive audit of the lighting and electrical systems in both environments was conducted. An Internet of Things (IoT) monitoring system was utilized to track power consumption in both buildings. Illumination measurements were obtained using a lux meter and were subsequently compared with the Standard of Lighting (SNI) and the Permenaker standards. The average level of illumination was measured at 128.4 lux in the southern workshop and below 150 lux in some classrooms of the learning building. An electrical analysis revealed that the dominant load in the south workshop was from welding machines (10.9 kVA), whereas in the learning building, it was from the cooling system and electronic equipment. A comparative analysis of the south workshop building and the learning building reveals that both structures possess considerable potential for energy conservation. Recommendations for improvement include upgrading the lighting system and implementing an IoT system to support specific electrical load management for each building.

Introduction

The global increase in energy consumption underscores the imperative for enhancing energy efficiency across diverse sectors, including education (Johri et al., 2025; Bera et al., 2025; Adewumi et al., 2024). University and polytechnic buildings are complex facilities with high energy consumption due to the large number of activities within them, accounting for a significant portion of the energy consumption (Shahidan et al., 2017; Almasri et al., 2024; Ortiz-Peña et al., 2025). The endeavor to enhance energy efficiency within the campus environment is of paramount importance, as it not only contributes to the reduction of operational expenses but also serves as a crucial support for the national sustainability targets (Syachreza Himawan & Sudiarto, 2022; Adanma & Ogunbiyi, 2024; Fitrianto et al., 2024). Energy audits constitute an initial systematic approach for the evaluation and identification of opportunities for implementing energy conservation measures (ECMs) (et al., 2024) (Sukmawati & Lingkungan, 2021).

Surabaya State Shipbuilding Polytechnic (PPNS) is characterized by two distinct facility environments, each exhibiting unique energy consumption patterns. The South Workshop

Building is where equipment-intensive practical activities such as welding machines, CNC machines, boiler machines, lighting, and HVAC systems (equipment-intensive) have diverse energy consumption patterns, and the Learning Building is where occupant-intensive theoretical activities are conducted. The learning building that is the subject of the energy audit is Building M. This discrepancy necessitates an energy audit to address the specific issues of each environment (Almusaed et al., 2024; Ahmed et al., 2025; Lawal et al., 2024).

The primary objective of an energy audit is to assess the efficacy of the lighting system. As demonstrated in the extant literature, lighting systems have been shown to exert a substantial influence on total electricity consumption (Naimah, 2021; Mahmood et al., 2024) and to impact visual comfort, productivity, and user safety (Kralikova & Wessely, 2016; Ortiz-Peña et al., 2025). Insufficient lighting conditions have been demonstrated to induce ocular fatigue and elevate the probability of accidents. Conversely, electrical loads from non-lighting equipment, such as practical machinery in southern workshops and cooling systems (HVAC) in classrooms, frequently constitute the primary source of energy dissipation. In the absence of a comprehensive monitoring system, the identification of potential energy efficiency issues for loads in operation can be a formidable challenge

The advent of Internet of Things (IoT) systems has precipitated the evolution of sophisticated methodologies for addressing the intricacies inherent in monitoring systems (Zualkernan et al., 2017; Ramani et al., 2025; Sayed, 2024). The utilization of IoT-based monitoring systems facilitates the acquisition of real-time data, thereby significantly enhancing the efficacy of the audit process and decision-making processes that are informed by data (Sulistiyanto et al., 2019; Andri Atmoko et al., 2024; Pandey et al., 2025). The findings of numerous studies demonstrate the efficacy of implementing Internet of Things (IoT)-based monitoring systems in smart buildings (Kelly & Knottenbelt, 2015; García-Monge et al., 2023; Poyyamozhi et al., 2024). However, the paucity of studies that have been conducted on this subject is striking. Specifically, the integration of lighting audits, electrical load analysis, and IoT monitoring system design comparatively between workshop buildings and learning buildings within the scope of polytechnic spaces in Indonesia is an area of research that has yet to be extensively explored. Therefore, the objective of this research is to address this knowledge gap by conducting a comparative evaluation to formulate comprehensive yet targeted energy efficiency recommendations in the PPNS environment

Methods

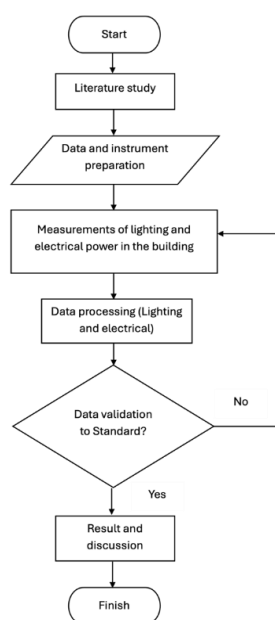


Figure 1. The following is a flowchart illustrating the implementation of the research study.

The research methodology was meticulously formulated employing a multi-case study approach to systematically analyze and compare the energy consumption of two functionally distinct building types. The present research employs a comparative case study design, utilizing a quantitative approach. The research process encompasses a systematic sequence of steps, including a comprehensive review of the existing literature, observational studies, design development, data collection, data analysis, and the formulation of conclusions, which are presented in the flow chart in Figure 1.

Literature study

A comprehensive review of the relevant literature was conducted, encompassing the collection and analysis of pertinent data. The utilization of references in the literature study is derived from a variety of sources, including books and journals of both domestic and international repute. These references are obtained from prominent databases such as Google Scholar, IEEE, and Scencedirect, among others.

Preparation

This stage constitutes an inaugural observation activity, the objective of which is to amass data. The scope of this data encompasses the layout of electrical panels, electrical loads, and lighting systems utilized in the South Workshop Building and Building M PPNS.

System Design

The design of an Internet of Things (IoT)-based system commences with the determination of system requirements, including the type of sensor to measure electrical parameters (current, voltage, power), a microcontroller as a data processor, and a communication module for network connectivity. Subsequently, the system architecture design is executed, encompassing the relationship between hardware, software, and cloud platforms for data storage and analysis. The programming of microcontrollers is executed for the purpose of reading data from sensors, calculating energy parameters, and transmitting data to the IoT server in real time. The design of the data visualization system is accomplished through a dashboard that displays graphs, reports, and notifications to efficiently monitor energy consumption. This stage is instrumental in ensuring the seamless integration of components, thereby facilitating the establishment of a reliable and responsive system.

Data retrieval (processing)

At this stage, the energy audit process involves the direct collection of data on lighting systems and electrical systems using an Envimetro instrument.

Results and Data Analysis

At this stage, the raw data obtained is subjected to a thorough analysis, with a focus on the lighting and electrical systems of each building. The findings of the analysis were then juxtaposed with established energy efficiency standards to assess levels of wastage and formulate strategies for cost savings. These strategies encompassed a range of approaches, including equipment operational reset, device replacement, and the installation of automatic controllers. The evaluation process entailed a meticulous examination of the reliability of the monitoring system and the efficacy of the dashboard visualization in ensuring that users can readily comprehend the information presented. The implementation of these recommendations is expected to enhance energy efficiency and reduce waste in the South Workshop Building and Building M of PPNS.

Conclusion and Recommendation

The objective of this stage is to synthesize the findings of the research study, encompassing energy consumption data, waste analysis, and recommendations for savings in both the lighting and electrical systems.

Objects, Location, and Research Plan

The focal point of the research study pertained to the examination of lighting and electrical systems. The following research locations are under consideration:

Location 1: Learning Building (building M)

The subsequent section contains a comprehensive delineation of the floor plan for each room, as illustrated in Figure 2.

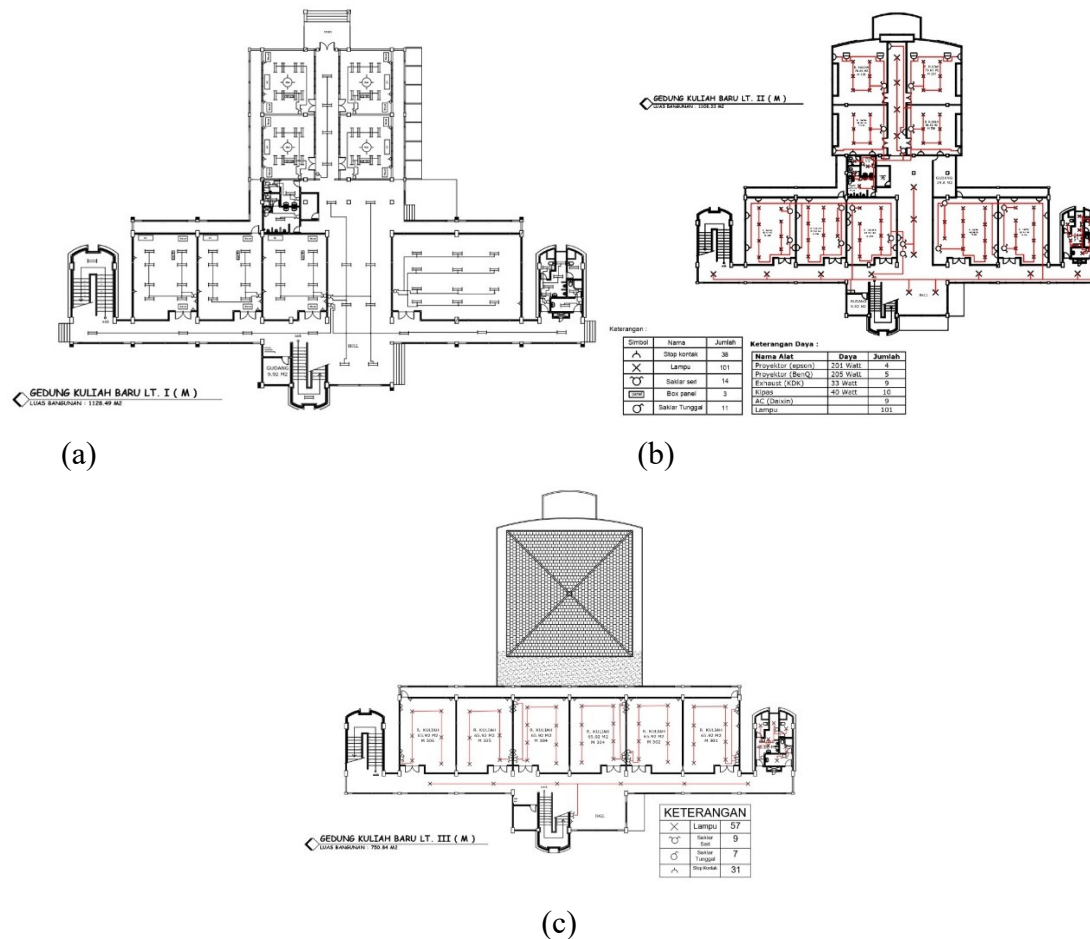


Figure 2. a) Plan of M building 1st floor, b) Plan of M building 2nd floor, c) Plan of M building 3rd floor

Classroom identification:

The measurements and classroom identification were conducted based on the layout illustrated in Figure 2. Data collection took place in one of the designated rooms, identified as Classroom M-304. The room has a length of 8.4 meters, a width of 6.8 meters, and a height of 3.4 meters, which provides a clear spatial description of the environment where observations and measurements were carried out.

Overview of the walls, ceiling, and floor:

Table 1. Overview of the walls, ceiling, and floor

Overview	Material	Color	Texture	Surface Condition
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				Clean	Medium	Dirty
Wall	Cement	Grey	Flat	√		
Ceiling	Plavon	White	Flat	√		
Work Surface	Wood Glass	Brown/White Clear	Flat		√	
Floor	Ceramic	cream	Flat	√		

Lamp type : Fluorescent lamp

Number of lamps : 1

Number of armatures : 8

Armature state : Clean

Armature layout drawing of classroom:

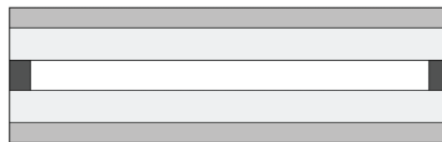


Figure 3. Lamp armature overview

Location 2: South Workshop Building (Welding workshop and Construction workshop)

The subsequent section contains a comprehensive floor plan for each room, as illustrated in Figure 4.

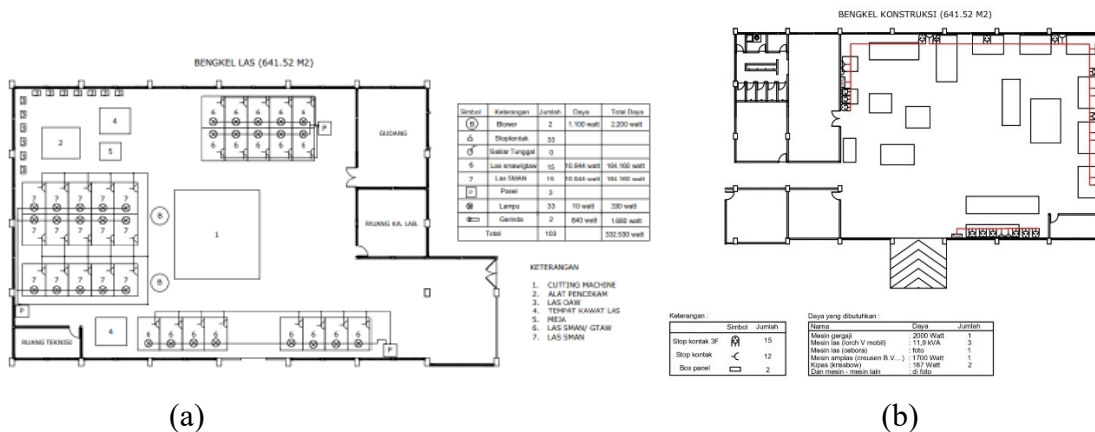


Figure 4. a) a) Wiring diagram of welding workshop, b) Wiring diagram of construction workshop

Research Equipment

The main equipment used in this research includes:

Digital Lux Meter (Tipe : MS6612)

Digital lux meters are instruments employed in the context of lighting audits to ensure precise measurement of illumination levels (lux). These devices are designed to detect and quantify light intensity within a given area, allowing researchers to evaluate whether the lighting conditions meet recommended standards for visual comfort and productivity. Their use is essential for obtaining accurate and reliable data, particularly in studies assessing lighting quality in classroom environments.



Figure 5. Lux meter MS6612

The digital lux meter used in this research paper has some major parts that have been integrated to help in the accurate measurement of illumination. A protection cover of an opto-sensor provides a physical shield, which protects the photodetector against unintentional damage or over-exposure. Below this cover is the main opto-sensor that forms the main detection item that measures and records the intensity of light. Outputs are displayed in an LCD display, making them to monitor real-time readings. This instrument is operated by pressing a power switch to switch it on and off, and special maximum and minimum buttons allow direct access to the maximum and minimum illumination value recorded within the measurement period.

Unit conversion is assisted by a special lux/foot candles (fc) switch where the unit of illumination can be switched to metric or imperial as needed. The hold operation allows temporary freezing of the displayed data and the reentry into the measurement mode by a short press. Calibration is performed by a zero button which must be pressed once a second to reset the sensor in order to achieve better fidelity. A short actuation on the rel button shows relative measurement values and a one-second actuation on the peak function shows the illumination reading of the maximum range recorded by the sensor.

The device also has a range select which is marked ran. The measured range is sequentially scanned through 20.00 0 lux, 200.0 0 lux, 2000 0 lux and 20000 0 lux, by a short press, and is therefore equivalent to 20.00 0 fc, 200.0 0 fc, 2000 0 fc, and 20000 0 fc. The range selection mode is ended by the prolonged holding of the button of one second. All these qualities together make the lux meter flexible, accurate and appropriate in different lighting conditions, which occur in the course of experimental measurement.

IoT Monitoring System Components

The components in question comprise a microcontroller (ESP32), an energy sensor (PZEM-004T), data visualization platform software (Grafana), and several supporting electronic elements utilized in the design of a prototype. The ESP32 functions as the core controller responsible for processing input signals and managing data communication, while the PZEM-004T serves as the primary measurement module that captures electrical parameters such as voltage, current, power, and energy consumption. The collected data are subsequently transmitted and visualized through Grafana, enabling real-time monitoring and analytical interpretation of energy usage patterns in a more accessible and interpretable format. Additional complementary components, such as wiring, connectors, and a supporting circuit system, were integrated to ensure stable operation of the prototype. As illustrated in Figure 6, the subsequent analysis will proceed with the following structure, guiding the explanation of the working mechanism, data flow process, and system performance evaluation.

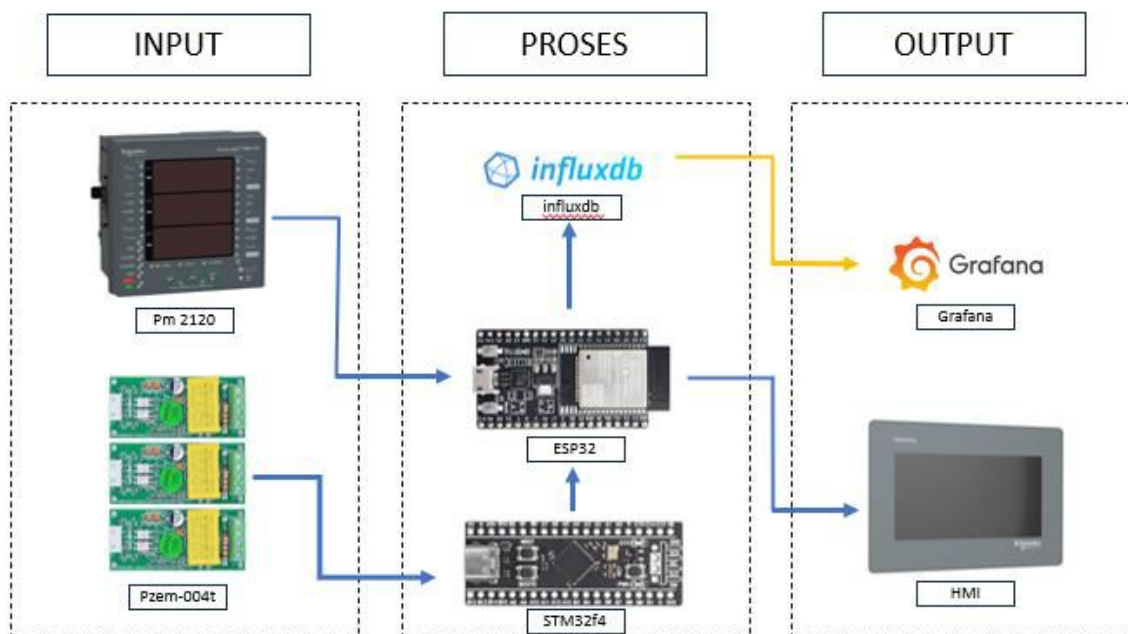


Figure 6. Block diagram of the system

The system used in the current study entails a number of inbuilt components that work in unison to detect and track, measure, process, store and display electrical information. The PM 2120 is the main power meter, which is used to measure various electrical parameters, especially voltage, current, and active power and thus is used as an important tool in the capture of baseline power consumption data. The ESP32 will act as an intermediary device that is used to bridge the PM 2120 to a cloud-based system and therefore facilitates smooth communication and transfer of measurement data to remote storage and processing units.

In parallel with this setup, the PZEM-004T is employed as the central sensor, which conducts the real-time measurement of electrical quantities, particularly voltage and current, and this provides unwinding sensor in the measurement process of the later analysis. It also has the STM32F4 microcontroller, an ARM Cortex-M4-based chip complete with a floating-point unit and the ability to do digital signal processing, which allows the computational work to be done more efficiently, especially processing sampled data to analyse power quality.

The information sent by the PM 2120 is stored in the InfluxDB time-series database that arranges information in a chronological order, which makes it suitable to track temporal changes in electrical parameters. Grafana is used to aid the interpretation and easy monitoring of the results, as a visualization platform whereby the archived data are represented in the form of dashboards and graphical representations, hence making the interpretation easy and holistic during the course of the research.

Research Procedure

The research procedure is divided according to the audit focus of each location, including:

Lighting System Audit

In this study, the measurement of the illumination level (lux) was carried out using a Lux meter at a predetermined point according to the plan. The method of determining the measuring point is consistent with the national standard, namely SNI-7062-2019, and aligns with established practices in related studies (Syamsi et al., 2024)(Hangga et al., 2024). The measurement results that have been obtained will then be compared with the standards set in Permenaker No. 5 of 2018 and SNI 03-6575 of 2001 to evaluate their suitability.

The room possesses a surface area that exceeds 100 square meters. The horizontal intersection point of the length and width of the room is situated at a distance of 6 meters. The aforementioned example constitutes a general lighting intensity measurement plan for a room with an area greater than 100 square meters.

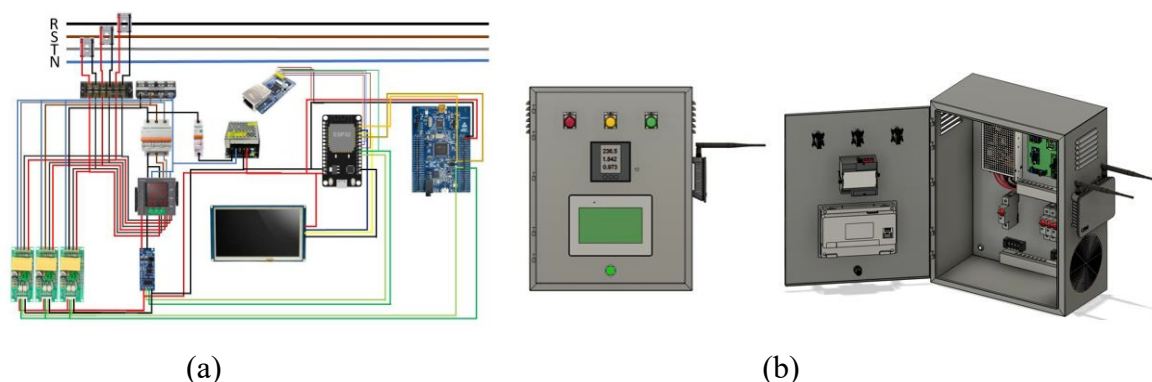
For rooms ranging in size from 10 to 100 square meters, the intersection point of the horizontal line representing the length and width of the room is situated at a distance of three meters for every three meters. The following example illustrates a general lighting intensity measurement plan for a room area ranging from 10 to 100 square meters..

Electrical System Audit

The electrical load analysis in this study was conducted by meticulously documenting the power specifications of the equipment's nameplate and wiring diagram in each location. This method constitutes a fundamental step in an energy audit, as it pertains to mapping the load distribution (Syahri et al., 2024). A comprehensive set of real-time energy consumption data is systematically collected from all locations equipped with monitoring systems. This data set is then subjected to rigorous analysis to derive meaningful insights. The standard of energy consumption in the building is

IoT Monitoring System Design

In the context of the electricity audit process, the IoT monitoring system is designed to serve as a solution, necessitating a visual and complex design. The system design, comprising the input, process, and output layers, is illustrated in Figure 6. The design employs an effective general design for energy management systems(Arifianto & Prasetyani, 2022)(Manowska et al., 2023). The system's wiring diagram and the 3D design visualization of the monitoring panel portotype (see Figure 7) are provided to provide an overview of its physical implementation.



Gambar 7. a) Wiring diagram of monitoring system, b) 3D Visualization Design of System Prototype

Results and Discussion

Energy Performance in Learning Building (Building M)

Lighting System Audit Result

Table 1. Lighting luminair standard

Kelas Luminer	Jumlah Cahaya Ke Arah Atas (%)	Jumlah Cahaya Ke Arah Bawah (%)
Langsung (Direct)	0 – 10	100 – 90
Semi langsung (Semi-Direct)	10 – 40	90 – 60
Langsung – tidak langsung (Direct–Indirect)	50	50
Difus (Diffuse)	40 – 60	60 – 40

Semi tidak langsung (Semi Indirect)	60 – 90	40 – 10
Tidak langsung (Indirect)	90 – 100	10 – 0

The results of the lighting audit measurements conducted in several classrooms within the learning building (Building M) indicate that the average illumination level remains significantly below the standards stipulated in SNI 03-6575-2001. For instance, the measurement data in classroom M-304 indicates an average lux value of 119.8 lux, while classroom M-305 displays an average value of 120.9 lux. The findings indicate that the measured value is less than the minimum standard of 250 lux established for the classroom. Figure 10 presents a visual representation of this finding.

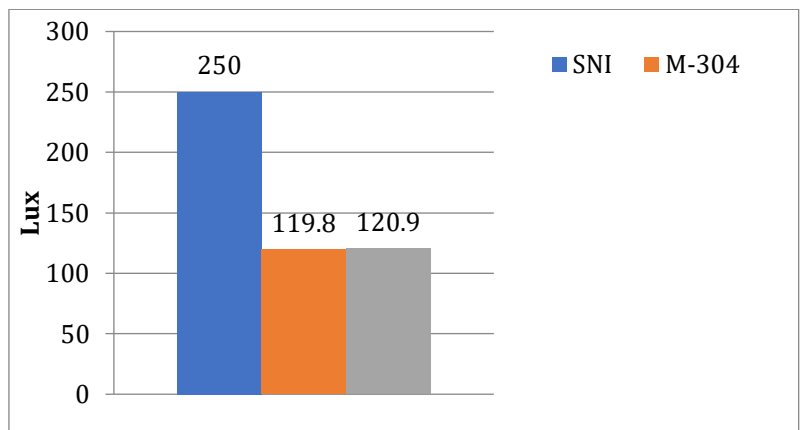


Figure 10. Comparison chart of measured illuminance levels with the standard

Electrical Load Monitoring Results

Table 2. Standard of Energi Consumption Indeks (IKE)

IKE for office (commercial)	20 kWh/m ² per bulan
IKE for shopping center	27,5 kWh/m ² per bulan
IKE for hotel / apartment	25 kWh/m ² per bulan
IKE for hospital	31,6 kWh/m ² per bulan

The implementation of the IoT monitoring system in building M was met with success, as it effectively recorded the power consumption data utilized on a daily basis. The collected data demonstrate the capability of the system to operate continuously, capturing real-time energy usage and storing it in a structured format suitable for further analysis. Based on the readings obtained, the daily consumption pattern exhibits noticeable fluctuations, with a peak of 1,228.77 kWh typically occurring on weekdays, which is likely associated with higher operational activities such as classroom use, lighting demand, and equipment utilization. In contrast, weekend energy consumption shows a significant decrease and remains relatively stable, suggesting reduced building occupancy and minimal electrical load. These variations highlight the importance of continuous monitoring in identifying usage trends and potential areas for energy efficiency improvements. The daily consumption data in building M is presented in the form of a graph in Figure 11, providing a visual representation of the load dynamics throughout the week.

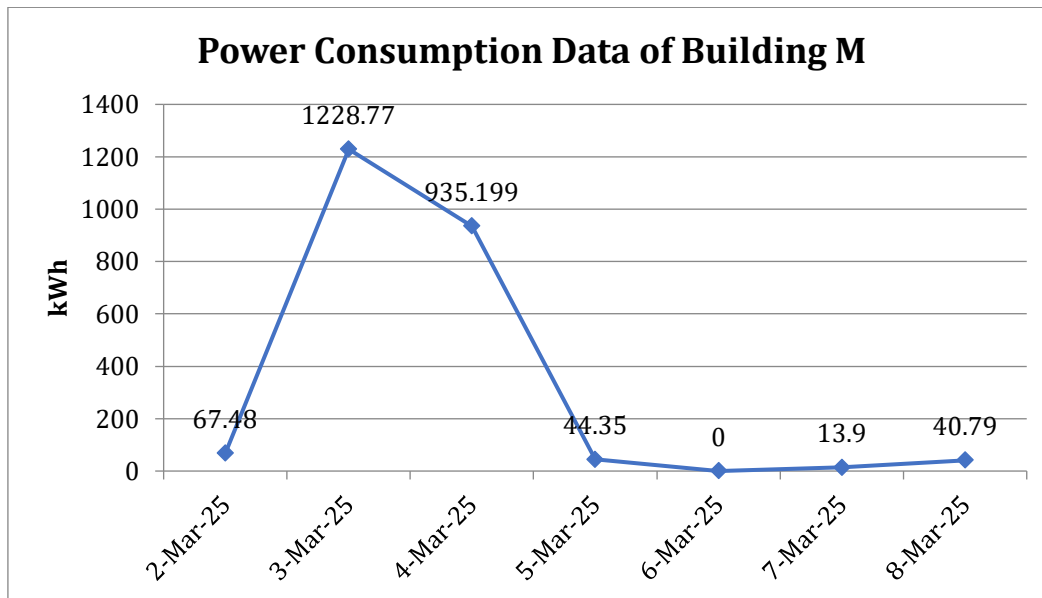


Figure 11. Line graph of daily energy consumption (kWh) in building M

Table 3. Energi Consumption Indeks (IKE) of M building

No	Month	IKE (kWh/m ² /mo)	IKE Standard (kWh/m ² /mo)	IKE to standard ratio (%)
1	April	1,618	20	8,09
2	Mei	1,283	20	6,415
3	Juni	1,582	20	7,91

Discussion on the Learning Building

As illustrated in Figure 10, a substantial variation in illumination levels was observed among the classrooms that were examined. As demonstrated in research, low illumination levels have been shown to have a detrimental effect on visual comfort and student concentration (Haryawan et al., 2023). In a workspace, adequate lighting is paramount, and the standards for such lighting have been determined (Wijanarko et al., 2024). A satisfactory lighting system must satisfy three fundamental criteria: quality, quantity, and the established guidelines for illumination (Aghajari & Chen, 2025). Conversely, Figure 11 illustrates a pattern of electricity consumption characterized by elevated spikes during weekdays, suggesting that the air conditioning system (HVAC) is likely the predominant load. This phenomenon is particularly prevalent in academic buildings situated in tropical climates, where the HVAC load can account for up to 50% of the total building energy consumption (Shahidan et al., 2017). This data underscores the necessity for energy management strategies that prioritize HVAC control, such as the implementation of smart controllers or centralized scheduling.

As illustrated in Figure 11, technical constraints were identified, resulting in data loss on March 6, 2025, due to network connection issues. The long-term implementation process of the Internet of Things (IoT) is predicated on the successful navigation of several technical constraints, including the inevitable challenge of data loss. This underscores the significance of dependable network infrastructure and the implementation of regular maintenance protocols for the effective monitoring of systems (Kelly & Knottenbelt, 2015).

Energy Performance of South Workshop Building (Welding and Construction Workshop)

Results of Lighting Audit in Construction Workshop

A thorough examination of the collected data reveals that the lighting conditions in the south workshop are suboptimal. For instance, in the construction workshop, the illumination level is 128.4 lux. This area only reaches 42% of the minimum standard of 300 lux set in Permenaker No. 5 of 2018 for assembly workers. The primary contributing factors to this situation are as follows: seven non-functional light units, unclear amateur conditions, and an inherently insufficient number of light points. The following is a presentation of the layout of the lighting measurement points in the construction workshop, as illustrated in Figure 12.

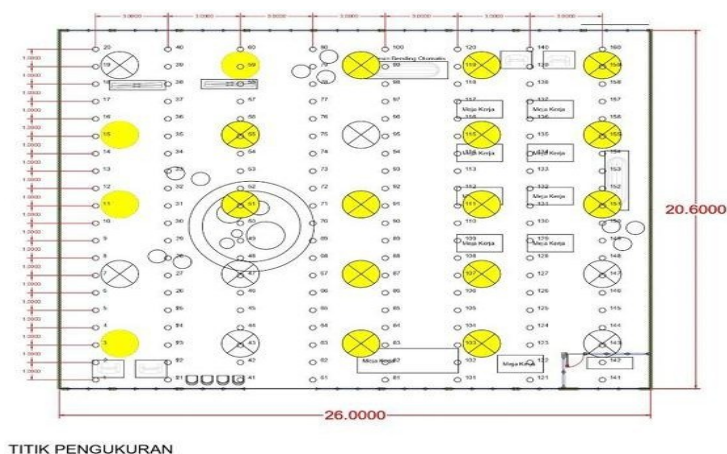


Figure 12. Layout of PPNS construction workshop

Electrical Load Monitoring Results at the welding shop

The monitoring results indicate a substantial discrepancy between the two buildings, as evidenced by the graph in Figure 13, which displays the daily energy consumption data.

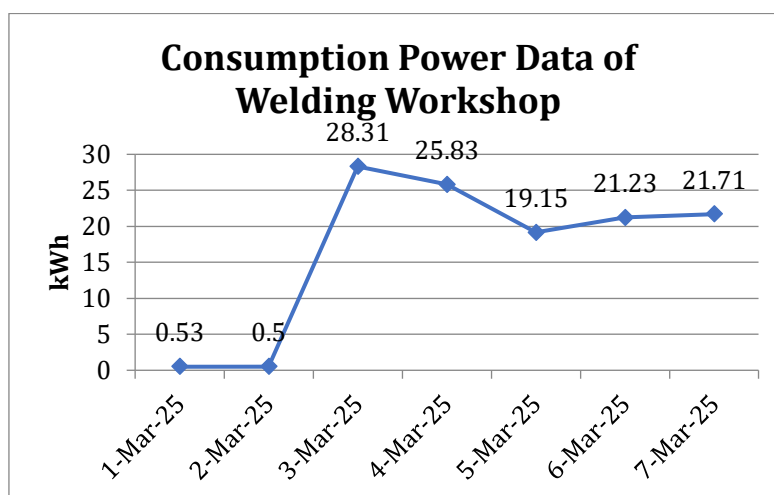


Figure 13. Line graph of daily energy consumption (kWh) in the Welding Workshop

Table 4. Energi Consumption Indeks (IKE) of Welding workshop

No	Month	IKE (kWh/m ² /mo)	IKE Standard (kWh/m ² /mo)	IKE to standard ratio (%)
1	April	0,749	20	3,745
2	Mei	0,712	20	3,56
3	Juni	1,024	20	5,12

As illustrated in Figure 13, the welding shop's consumption pattern exhibits a notably low weekend base load of 0.5 kWh, with a peak weekday load of 28.31 kWh. This finding indicates a strong correlation between the energy consumption in the workshop and the schedule of practical activities. The monitoring system has been installed to measure power quality parameters, including the Current Unbalance Factor and the Voltage Unbalance Factor. These factors are of particular importance in machine-loaded environments.

Discussion on the Workshop Building

The finding regarding the suboptimal illumination levels in construction workshops is of particular pertinence in the context of occupational safety and health (OSH). Inadequate lighting in work areas with heavy machinery has been demonstrated to directly increase the risk of accidents. The improvement recommendations encompassed not only the installation of lamps but also a comprehensive redesign of the lighting layout to ensure uniform illumination at each workstation. The replacement of more efficient LED technology lamps in all locations has proven to be an effective measure in many case studies.(Hussin et al., 2021)(Kerem, 2022).

The electricity consumption profile of a welding shop, which is driven by the use of machines, is common to manufacturing or workshop environments. Efficiency strategies should prioritize operational management, including the scheduling of machine usage to avoid simultaneous peak loads, a method that has demonstrated efficacy(Hwang et al., 2020). Of particular significance is the necessity of power quality monitoring. Welding machines have been shown to generate significant harmonic distortion. If this issue is not mitigated, it can potentially damage other equipment in the campus power grid(Kumar, 2022).

Comparative Analysis and Strategic Implications

A comparison of the measurement results in terms of lighting and electricity clearly shows the difference between the two conditions of energy problems in the PPNS environment. The learning building (Building M) faces efficiency challenges related to comfort loads, especially lighting and HVAC with long duration. Conversely, the south workshop building is confronted with challenges related to production loads, particularly in regard to lighting and machine power with high intensity.

This finding demonstrates that a universally applicable energy management strategy is unlikely to yield optimal outcomes. The proposed strategy should be characterized by a dual nature, that is to say: The primary objective for the Learning Building is to enhance the efficacy of intelligent control systems, such as occupancy sensors, which are utilized in classrooms to regulate air conditioning and lighting(Diddeniya et al., 2020)(Seo & Yun, 2022). This initiative is guided by the standards outlined in SNI 03-6575-2001, which stipulates the requirements for energy efficiency and accessibility in educational facilities. The proposed improvements to lighting systems are intended to align with these standards, ensuring compliance and contributing to the overall sustainability of the building.

The primary objective of the South Workshop Building project is to enhance the efficiency of heavy equipment operation schedules. This objective is pursued through the implementation of comprehensive monitoring systems that evaluate power quality and the optimization of lighting systems. The project is guided by the standards outlined in Permenaker No. 5/2018, which serves as a benchmark for industry regulations. Consequently, an integrated energy audit, substantiated by substantial data visualization, furnishes a lucid roadmap for PPNS management to execute a quantifiable, efficacious, and targeted energy efficiency program.

Conclusion

An integrated energy audit of the Learning Building (Building M) and the South Workshop Building of Surabaya State Polytechnic of Shipping revealed substantial discrepancies in consumption patterns and energy efficiency challenges. In the Learning Building, the primary issue is the substandard classroom illumination levels, which significantly deviate from the stipulated SNI 03-6575-2001 standard. Additionally, the prevailing presence of air conditioning (HVAC) loads during weekdays contributes to the overall challenges. Concurrently, within the South Workshop Building, a close correlation was identified between energy expenditure and the execution of practical activities. Additionally, concerns regarding lighting quality and harmonic distortion, attributable to the operation of substantial machinery such as welding equipment, were documented.

The implementation of an Internet of Things (IoT)-based monitoring system demonstrated its capacity to provide real-time data on energy consumption and power quality parameters. However, network constraints were identified during the implementation process. The data obtained can be used to design energy efficiency strategies with a high degree of specificity. The Learning Building is advised to employ smart control devices, such as occupancy sensors for air conditioning and lighting settings, while the South Workshop is recommended for scheduling machine operations and replacing lighting systems with LED technology.

The present study demonstrates that a "one-size-fits-all" approach is ineffective in the development of energy management systems. Consequently, a scalable, data-driven, energy efficiency strategy is required that is customized to the functional characteristics of each building.

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