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Optimizing Energy Efficiency: Case Study of a Steel and Iron Distributor Building

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Abstract: The swiftly growing demand for electricity in Indonesia, expected to increase substantially by 2025, requires the adoption of efficient energy conservation measures within the commercial sector. This study offers a thorough electrical energy audit of a Steel and Iron Distributor Building situated in West Java, with the objective of assessing actual energy performance and identifying Energy Conservation Opportunities (ECOs). The research methodology adheres to a comprehensive audit framework, employing secondary data from 2024 electricity invoices and primary data obtained through on-site field measurements conducted in October 2023 to analyses load profiles and consumption patterns. The principal metric employed for evaluation was Energy Consumption Intensity (ECI). The analysis indicated that the building's ECI, calculated from historical data, was 54.26 kWh/m²/year, whereas the value obtained from comprehensive load estimation was 65.54 kWh/m²/year. Both figures are considerably lower than the standard benchmark of 180.95 kWh/m²/year set by the Agency for the Assessment and Application of Technology (BPPT) for office buildings. Consequently, the facility is designated as "Very Efficient" in accordance with Minister of Energy and Mineral Resources Regulation No. 13 of 2012. Despite this high-performance rating, the audit suggests targeted enhancements to promote sustainability, such as a full transition to LED technology, the implementation of rigorous preventive maintenance protocols for air conditioning units, and the deployment of real-time energy monitoring systems to observe future consumption patterns.

Keywords: Energy Conservation Opportunities, Energy Consumption Intensity, Efficient Energy, Energy Audit.

INTRODUCTION

Electricity is a fundamental necessity supporting all human activities. The increasing demand for energy, particularly electricity, is a global concern, with various studies highlighting the critical need for efficient energy management (Mayen et al., 2024). In Indonesia, the government has prioritized increasing electricity generation, evidenced by the 35,000 Megawatt (MW) program led by the Ministry of Energy and Mineral Resources

(ESDM) (ESDM, 2016). Annually, the demand for electricity continues to rise, outpacing the available supply due to limitations, with projections indicating an increase from 216.8 Terawatt Hour (TWh) in 2016 to 457.0 TWh by 2025 (ESDM, 2016). This growing energy demand, especially in commercial buildings, necessitates effective energy conservation strategies (Saputra et al., 2022). In response to these challenges, national regulations emphasize energy conservation. Government Regulation No. 70 of 2009 on energy conservation mandates energy users to conserve energy (Pemerintah Republik Indonesia, 2009). This regulation requires all energy users, including individuals, businesses, government, and non government institutions, to implement energy conservation through systematic energy management (Wardhana & Damarwan, 2023). Key aspects of this mandate include conducting regular energy audits, implementing audit recommendations, and reporting conservation efforts annually to the authorities (Fahlevi et al., 2024). Studies have shown that energy audits are crucial for identifying potential savings and improving environmental performance in various sectors, including hospitality and commercial buildings(Saputra et al., 2022). Commercial buildings, such as office spaces and distribution centers, are significant For Consequently, optimizing these systems through measures like replacing conventional lighting with LED technology and proper AC maintenance is a common recommendation in energy audit findings (Ruliyanta et al., 2023). Furthermore, power quality issues, such as voltage and current imbalances, can contribute to energy losses and inefficiency, highlighting the importance of including power quality analysis in energy audits Benchmarking energy consumption intensity (ECI) against national standards, such as those provided by BPPT (Badan Pengkajian dan Penerapan Teknologi, 2023) and SNI 03-0196:2010, is essential to assess a building's energy efficiency performance (Ruliyanta et al., 2023). This energy audit aims to determine the actual energy usage of the Steel and Iron Distribution Building and identify the most suitable Energy Conservation Opportunities (ECOs) without compromising quality, comfort, or service levels(Liu et al., 2023). The objective is to provide stakeholders with crucial input for policy determination regarding building energy consumption energy efficiency in the context of optimal energy provision and management (Fahlevi et al., 2024). The scope of this audit covered all rooms and areas of the office building, focusing on energy-consuming devices, user behavior demand, and energy sources supply. The success of such top-down energy audit initiatives heavily depends on allocated resources. Additionally, power quality, a contributing factor to energy inefficiency, was a specific subject of this audit (Rahman et al., 2024).

METHOD

Energy Audit Methodology

An energy audit is a systematic procedure used to determine how energy is being consumed within a building or facility and to identify opportunities for reducing energy consumption while maintaining or improving operational performance. The audit process typically involves several stages:

1. Preliminary Audit (Walk-through Audit)
   This initial assessment identifies obvious areas of energy waste and potential savings. It involves collecting basic data, conducting interviews, and performing visual inspections(Sánchez et al., 2019).
2. Detailed Audit (Diagnostic Audit)
   This stage involves more in-depth data collection and analysis, including metering specific loads, analyzing historical energy bills, and evaluating building systems (HVAC,
   lighting, etc.) in detail. It aims to quantify energy consumption and pinpoint areas for improvement(Rahman et al., 2024).
3. Investment Grade Audit (IGA)

The most comprehensive type of audit, an IGA provides a detailed financial analysis of proposed ECOs, including life-cycle costs, payback periods, and return on investment, to facilitate decision-making for major capital investments(Saputra et al., 2022).

4. This study primarily aligns with the principles of a detailed energy audit, focusing on quantitative analysis of historical data and on-site measurements to identify specific ECOs (Wardhana & Damarwan, 2023).

Energy Consumption Intensity (ECI)

Energy Consumption Intensity (ECI) is a key performance indicator (KPI) used to evaluate the energy efficiency of a building or facility. It normalizes energy consumption by a relevant unit, most commonly per unit area, to allow for comparison between different buildings or over time for the same building. ECI is typically expressed in kWh/m2/year or kWh/m^2/month. A lower ECI generally indicates higher energy efficiency. Regulatory bodies and industry standards often provide benchmark ECI values for different building types, enabling facilities to assess their performance against established norms(Rupesh et al., 2015).

The calculation for ECI is given by:

$$ECI_m = \frac{Total\ kWh\ per\ month}{Gross\ Area\ (m^2)} \quad (1)$$

For a given period (e.g., month or year). This metric is crucial for identifying buildings that consume energy inefficiently and for tracking the impact of energy conservation measures. The significance of ECI in energy management is powerfully captured by the common adage, "What gets measured gets managed." Amory Lovins, co-founder and Chief Scientist of the Rocky Mountain Institute, reinforces this idea, stating, "Efficient use of energy does not mean doing without, it means doing better." In the context of buildings, a lower ECI directly translates to "doing better" in terms of energy performance(Mishra, 2020).

Electrical Load Types and Characteristics

Electrical loads in a building can be broadly categorized into:

1. Lighting Loads
   Comprise all devices used for illumination, such as incandescent lamps, fluorescent lamps, and LED lamps. The energy consumption of lighting systems is influenced by lamp type, wattage, operating hours, and control strategies(Dilawar & Qayoum, 2022).
2. Heating, Ventilation, and Air Conditioning (HVAC) Loads:
   These are often the largest energy consumers in commercial buildings, particularly in tropical climates. HVAC systems include air conditioners, fans, and ventilation equipment. Their energy consumption depends on factors like unit efficiency (EER/COP), operating hours, thermostat settings, and building insulation. Dr. Steven Nadel, Executive Director of the American Council for an Energy-Efficient Economy (ACEEE), consistently highlights that HVAC systems typically represent the largest energy end-use in commercial buildings, making their optimization critical for achieving substantial energy savings(Shah et al., 2017).
3. Other Electrical Loads
   This category includes a wide range of equipment such as computers, printers, refrigerators, water dispensers, and other plug-in appliances. While individual devices may have relatively low power consumption, their cumulative effect, especially when numerous, can
   be significant. The U.S. Department of Energy (DOE) emphasizes that while

individual plug loads may seem small, their cumulative effect can be substantial, especially in office environments, pointing to the potential for significant savings through smart power strips and efficient appliances(Wardhana, 2019).

4. Understanding the distribution and characteristics of these loads is vital for identifying areas with high energy consumption and prioritizing ECOs(Wardhana & Damarwan, 2023).

Power Quality

Power quality refers to the steady state operation of the electrical power system, ensuring that voltage, frequency, and waveform are within acceptable limits. Poor power quality can lead to several issues, including(Saengsikhiao et al., 2020):

1. Harmonics**:** Distortions in the current and voltage waveforms caused by non-linear loads (e.g., electronic devices, variable speed drives). Harmonics can cause increased losses in transformers and motors, overheating, and premature equipment failure.
2. Voltage Sags and Swells: Momentary decreases or increases in voltage.
3. Transients: Very short, high-energy voltage spikes.
4. Low Power Factor: Occurs when the current and voltage waveforms are out of phase, often due to inductive loads (motors, transformers). A low power factor increases the apparent power drawn from the grid, leading to higher electricity bills (if penalized) and reduced system capacity.

While the provided data does not explicitly detail power quality measurements, recognizing its impact is crucial for comprehensive energy management. **Dr. Alexander Eigeles Emanuel**, a renowned specialist in power quality, demonstrates that, Poor power quality often manifests as increased energy consumption, reduced equipment lifespan, and operational disruptions(Emanuel, 2004). Therefore, improving power quality, for instance, through power factor correction, can significantly reduce energy losses and improve overall system efficiency(Emanuel, 2004).

Scope of Activities

This chapter details the systematic approach employed for the electrical energy audit conducted at the Steel and Iron Distribution Building. The audit was meticulously designed to thoroughly investigate the building's current energy consumption patterns, pinpoint areas of inefficiency, and formulate practical, actionable recommendations for significant improvements in energy efficiency(Radityatama et al., 2021). Objectives of this research is:

1. Analysis of electrical quality.
   This involved a comprehensive assessment of various electrical parameters, such as voltage stability, frequency consistency, and the presence of harmonics or low power factor. Identifying these issues is paramount as they can lead to not only wasted energy but also premature equipment failure and operational disruptions(Murdiyansyah et al., 2024).
2. Recommendations for potential energy savings.
   This involved a detailed investigation of all significant electrical loads within the building to identify specific opportunities where energy consumption could be reduced. This includes exploring upgrades to more efficient technologies, optimizing operational schedules, and implementing smart control strategies(Mayen et al., 2024)
3. Recommendations for electrical system improvements
   Beyond mere energy consumption, these objective encompassed proposals to enhance the overall reliability, safety, and long-term sustainability of the

building's entire electrical infrastructure, ensuring it meets current standards and future demands(Hermawan et al., 2023).

Phase & Schedule

The energy audit was executed through a structured, multi-phase process, designed to maximize both thoroughness and efficiency. This systematic approach ensured that all critical aspects of the building's energy usage were meticulously examined. The audit process involved the following stages(Fahlevi et al., 2024):

1. Opening Meeting.
   This initial gathering involved the audit team, building management, and key stakeholders. The primary purpose was to establish clear lines of communication, define the precise scope of the audit, reiterate the objectives, and discuss the anticipated timeline and deliverables. This ensured all parties were aligned from the outset.
2. Coordination with the Owner.
   This phase was vital for securing full cooperation and access to essential resources. It involved obtaining all relevant documentation, such as architectural drawings, electrical schematics, equipment specifications, and historical energy bills for previous periods (e.g., 2024 data as mentioned in the abstract). Furthermore, it ensured access to operational schedules and permitted on-site visits for direct observation.
3. Data Collection & Field Survey.
   During this critical stage, the audit team performed on-site measurements using specialized equipment (e.g., power quality analyzers, lux meters, thermal imagers if applicable) to gather real-time data on electrical loads, power consumption, and environmental conditions. Concurrently, a comprehensive inventory of all energy-consuming equipment was compiled, encompassing lighting fixtures, HVAC units, and various plug-in appliances. Detailed observations of operational practices, such as equipment usage patterns and thermostat settings, were also meticulously recorded.
4. Data Analysis.
   This involved processing the consumption figures, identifying baseline energy usage, analyzing load profiles for peak demands and off-peak consumption, and applying established engineering principles to quantify inefficiencies. Energy consumption intensity (ECI) calculations were performed and benchmarked against national or industry standards (as indicated by the reference to national standards in the abstract) to identify areas performing below expectations. Financial viability of potential energy conservation measures was also assessed during this phase.
5. Conclusion and Recommendations.
   Based on the comprehensive data analysis, detailed findings were consolidated into a clear and concise report. Specific, actionable recommendations for energy conservation opportunities (ECOs) and electrical system improvements were then presented. These recommendations included practical steps such as implementing LED technology, routine AC maintenance, managing other electrical loads, promoting energy awareness among occupants, installing real-time monitoring systems, developing internal energy policies, and fostering continuous education on energy efficiency, aligning with the "Recommendations" section in the abstract of your provided document. This structured delivery aimed to empower the building owner with the necessary insights and strategies for effective energy management.

Data Collection

Steel and iron distribution building is geographically located at West Java Province, Indonesia. The building has a land area of ±1,400 m2, with a building area of 720 m2. The building consists of several areas: administration room, retail area, and terrace. The operational hours are typically from 07:00 to 17:00 WIB, six days a week.

Historical Data

Secondary data on energy consumption from monthly electricity bills for 2023 was collected for the energy audit of steel and iron distribution building. Table 1 and figure 2 illustrate the electricity consumption data for 2024. From the table and graph, it can be observed that monthly electricity consumption in 2024 ranged from 2,870 kWh to 3,590 kWh, with an average monthly consumption of 3,255 kWh. The average electricity cost was Rp. 1,444.70 per kWh.

Table 1 Electricity Consumption Data

Month	kW/h	Tarif (Rp)
January	2.982	4.308.095
February	3.590	5.186.473
March	3.280	4.738.616
Apr	3.380	4.883.086
May	2.980	4.305.206
June	3.497	5.052.116
July	3.070	4.435.229
August	3.450	4.984.215
September	3.180	4.594.146
October	3.540	5.114.238
November	3.250	4.695.275
December	2.870	4.146.289

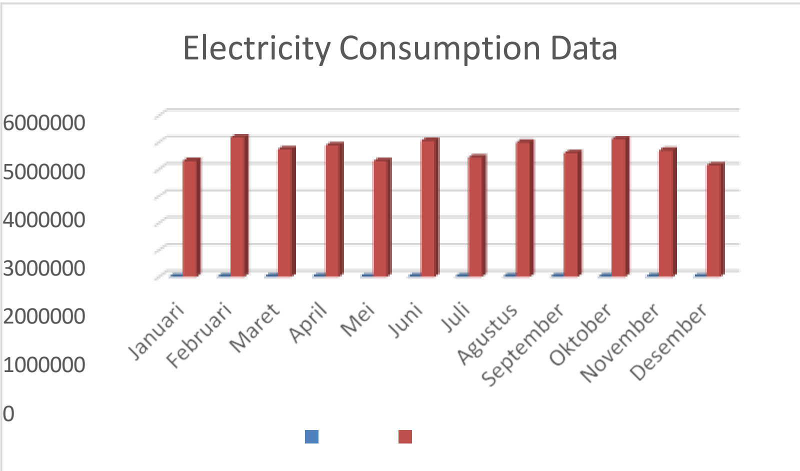

Figure 1. Electricity Consumption Graph

Site Survey

Steel and iron distribution building utilizes three air conditioning units for indoor cooling. These units significantly contribute to the overall electrical load, particularly in the AC- controlled areas.

Figure 2. Steel and iron distribution building Air Conditioning System

The artificial lighting system in steel and iron distribution building consists of 21 lamps in AC-controlled rooms and 8 lamps in non-AC rooms. The average indoor illumination intensity, measured with a lux meter, was 179 lux. According to Permenkes No. 70 of 2016 [5], the recommended illumination for storage areas is around 200 lux, suggesting a need for slight additional lighting or optimization of existing fixtures.

Activity Schedule

Figure 3. Light Intensity Measurement

The site survey and measurement activities were conducted over one day in October 2023, ensuring that data captured reflected typical operational conditions.

RESULTS AND DISCUSSION

Sampling Method

Random sampling was employed for measurement points, ensuring a representative assessment of electrical parameters and environmental conditions across different areas of the building.

Calculation of Electrical Energy Consumption Intensity (ECI)

The Energy Consumption Intensity (ECI) value is a critical metric for evaluating energy efficiency and is expressed in kWh/m^2 per year. Table 2 provides recommended ECI values from the Agency for the Assessment and Application of Technology (BPPT) for various building types, serving as benchmarks for comparison.

Table 2. Recommended ECI Values from BPPT

Building Type	Recommended ECI (kWh/m^2/year
Office Building	180.95
Hotels	208.15
Hospitals	180.81
Shopping Centers	286.54

Monthly Energy Consumption Intensity (ECI$_m$) is calculated using Equation (Liu et al., 2023):

$$ECI_m = \frac{Total\ kWh\ per\ month}{Gross\ Area\ (m^2)} \qquad (2)$$

Calculating ECI for January 2024 using data from Table 1(Liu et al., 2023):

$$ECI = \frac{2.982\ kWh}{720\ (m^2)} = \frac{4.14\ kWh}{month} \qquad (3)$$

Annual Energy Consumption Intensity (ECI) is calculated using Equation (Liu et al., 2023):

$$ECI_y = \frac{Total\ kWh\ per\ month}{Gross\ Area\ (m^2)} \qquad (4)$$

Calculating ECI for the entire year 2024 based on the total annual consumption:

$$\sum kWh = 39.069 kWh \qquad (5)$$

$$ECI_y = \frac{39.069\ kWh}{720\ (m^2)} = 54.26 \quad kWh/m^2\ per\ year \qquad (6)$$

Comparing this to the target ECI for commercial office buildings recommended by BPPT (Table 2), which is 180.95 kWh/m^2 per year, the calculated ECI of 54.26 kWh/m^2 per year based on 2024 electricity bill data is significantly below the standard. This indicates that the building's energy consumption, based on historical billing data, is already considered efficient. Further analysis involved estimating energy consumption based on installed electrical loads and operational hours. The installed electrical load for AC-controlled rooms includes a lighting load of 1,617 watts (1.617 kW), an Air Conditioner (AC) load of 5,760 watts (5.760 kW), and other loads estimated at 3.50 kW. Thus, the total electrical load (lighting + AC + other loads) in the AC-controlled area is 1.617+5.760+3.50=10.877 kW. Assuming 10 hours of operation per day (07:00 to 17:00 WIB) and a load factor of 70%, the estimated daily energy consumption for this load is

$$10{,}877\ kW \times 10\ hours \times 0.70 = 76.14\ kWh/day \qquad (7)$$

Assuming 30 effective days in a month, the monthly electricity consumption is 76.14×30=2,284.2 kWh/month, or 2,284.2×12=27,410.4 kWh/year. The AC-controlled area is approximately 500 m2. Therefore, the Energy Consumption Intensity (ECI) for the AC-controlled room is (2,284.2 kWh/month/500 m2) = 4.57 kWh/m2/month, or (27,410.4 kWh/year/500 m^2) = 54.84 kWh/m^2/year. These calculations are summarized in Table 3.

Table 3. ECI Calculation for AC Controlled Rooms

Lighting (kWh/day)	AC (kWh/day)	Other Load (kWh/day)	Total (kWh/day)	Area (m^2)	ECI/month	ECI/year
11.32	40.32	24.5	76.14	500	4.57	54.84

For non-AC rooms, with an approximate area of 220 m^2, the lighting load is estimated at 0.184 kW and other loads at 1.05 kW. Thus, the total load is 0.184 + 1.05 = 1.234 kW. The estimated daily consumption is 1.234 kW×10 hours×0.70 = 8.638 kWh/day. Assuming 30 days/month, this is 259.14 kWh/month, resulting in an ECI of (259.14 kWh/month/220 m2) = 1.18 kWh/m^2/month. This is summarized in Table 4.

Table 4. ECI Calculation for Non AC Rooms

Lighting (kWh/day)	AC (kWh/day)	Other Load (kWh/day)	Total (kWh/day)	Area (m^2)	ECI/month	ECI/year
1.29	-	5.25	6.54	220	0.89	10.7

Combining the loads and areas for both AC-controlled and non AC rooms provides an overall ECI for the building, as presented in Table 5. The total estimated daily consumption is 76.14 + 6.54 = 82.68 kWh/day. For 720 m^2 building area, this leads to an ECI of (82.68 × 30/720) is 3.445 kWh/m2/month or (82.68×365/720) = 41.87 kWh/m2/year.

Table 5. ECI Calculation for Combined AC and Non AC Rooms

Lighting (kWh/day)	AC (kWh/day)	Other Load (kWh/day)	Total (kWh/day)	Area (m^2)	ECI/month	ECI/year
12.61	40.32	29.75	82.68	720	5.46	65.54

To benchmark these findings, ECI standards from the Minister of Energy and Mineral Resources Regulation No. 13 of 2012 on Electricity Saving are used (Table 6).

Table 6. ECI Standards

No	Criteria	Office Building with AC (kWh/m^2/month)	Office Building without AC (kWh/m^2/month)
1	Very Efficient	< 8,5	<3,4
2	Efficient	8,5 - 14	3,4 - 5,6
3	Fairly Efficient	14 - 18,5	5,6 - 7,4
4	Wasteful	>18,5	> 7,4

Source: Minister of Energy and Mineral Resources Regulation No. 13 of 2012 on Electricity Saving

Based on the calculations above, the ECI value for the AC-controlled building (4.57 kWh/m2/month) falls into the very efficient category according to Minister of Energy and Mineral Resources Regulation No. 13 of 2012. The total ECI of 65.54 kWh/m2/year (from the combined calculation) is still below the determined standard (target ECI), reinforcing that the building's ECI value is considered efficient.

CONCLUSION

The following conclusions are drawn from the energy audit of steel and iron distribution building:

Energy Consumption Intensity (ECI)

Based on historical data from 2024, the ECI value of 54.26 kWh/m^2 per year is significantly below the target efficiency of 180.95 kWh/m2 per year set by the Agency for the Assessment and Application of Technology (BPPT), indicating a strong existing level of energy efficiency. The calculated ECI value of 65.54 kWh/m2 per year, derived from detailed load analysis, also falls well below the BPPT efficiency target and is classified as very efficient by national standards, affirming the good energy performance of the facility.

Electrical Load in AC-Controlled Rooms

The estimated daily energy consumption for the AC controlled areas, encompassing lighting, AC units, and other loads, is 76.14 kWh/day. This translates to an estimated monthly consumption of 2,284.2 kWh and an annual consumption of 27,410.4 kWh, highlighting the significant contribution of these areas to overall consumption.

ECI of AC-Controlled Rooms

For the approximately 500 m^2 AC-controlled area, the Energy Consumption Intensity (ECI) is 4.57 kWh/m2/month or 54.84 kWh/m^2/year. This ECI value is notably classified as very efficient according to the Minister of Energy and Mineral Resources Regulation No. 13 of 2012, emphasizing efficient operation within these primary energy-consuming zones.

Recommendations

While the current energy performance is good, the following recommendations are provided to further enhance energy efficiency and ensure sustained optimal operation, lED Technology Implementation, systematically replace any remaining conventional lighting fixtures with more energy- efficient LED lamps. This offers significant potential for reducing lighting energy consumption and maintenance costs. Routine AC Maintained, Implement a strict schedule for routine and preventive maintenance of all air conditioning units. This includes cleaning filters, checking refrigerant levels, and ensuring proper airflow, which are crucial for maintaining AC efficiency and extending equipment lifespan. Optimized Management of Other Loads, Conduct an inventory and assessment of all other electrical loads (e.g., office equipment, appliances). Encourage the use of energy-efficient models, ensure proper shutdown during non-operational hours, and consider implementing smart power strips to reduce standby power consumption. Energy Awareness Training, Develop and regularly conduct training programs to enhance energy awareness among all building occupants (staff and management). Educate them on the importance of energy conservation, simple energy-saving practices (e.g., turning off lights/AC when not needed, setting appropriate thermostat temperatures), and the collective impact of their actions. Real-Time Energy Monitoring System, Implement a real-time energy monitoring system with sub-metering capabilities for key areas (e.g., AC circuits, lighting circuits). This system would allow for continuous tracking and analysis of energy consumption patterns, rapid identification of anomalies, and evaluation of the effectiveness of implemented ECOs. Development of Internal Energy Policy, Formulate and enforce clear internal policies that support efficient energy use. This could include guidelines for thermostat settings, rules for turning off equipment after hours, and targets for energy consumption reduction. Such policies provide a framework for consistent energy management. Continuous Education and Feedback, Establish a continuous education program on energy efficiency. Provide regular feedback to occupants on energy consumption trends and the impact of their conservation efforts. This continuous engagement can foster a culture of energy responsibility within steel and iron distribution building.

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