

# Integrating ISO 50001 and PDCA Cycle for Continuous Energy Performance Improvement in Higher Education Buildings

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**Dwi Listiawati**

Department of Electrical Engineering, Institut Teknologi Perusahaan Listrik Negara, Jakarta, Indonesia

**Christiono**

Department of Electrical Engineering, Institut Teknologi Perusahaan Listrik Negara, Jakarta, Indonesia

**Ishvando Yunaini**

Department of Electrical Engineering, Institut Teknologi Perusahaan Listrik Negara, Jakarta, Indonesia

**Miftahul Fikri**

Department of Electrical Engineering, Institut Teknologi Perusahaan Listrik Negara, Jakarta, Indonesia

**Andi Amar Thahara**

Department of Petrochemical Instrumentation Technology, Politeknik Industri Petrokimia Banten, Banten, Indonesia

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**Abstract:** This study proposes a systematic framework for energy performance improvement in institutional facilities by integrating technical auditing with the ISO 50001:2018 standard. Utilizing the Plan-Do-Check-Act (PDCA) cycle, a comprehensive energy baseline for the ITPLN Building was established based on 2024 data, revealing an annual consumption of 1,405,600.80 kWh. In the Check phase, the calculated Energy Consumption Intensity (IKE) of 104.78 kWh/m<sup>2</sup>/year classified the building as Efficient under ESDM Regulation No. 3/2025. Quantitative analysis identified HVAC (57%) and Lighting (18%) as primary drivers, necessitated by an average ambient temperature of 30°C. To address inefficiencies, the Act phase formulated strategic Energy Saving Opportunities (ESO) such as LED retrofitting and AC standardization. These interventions are projected to reduce consumption by 42,168.02 kWh/year, lowering the IKE to 101.6 kWh/m<sup>2</sup>/year—a 3% efficiency gain. The study concludes that integrating ISO 50001 with physical audit data provides a replicable and economically measurable strategy for optimizing energy performance, with systematic maintenance recommended to ensure long-term operational sustainability.

**Keywords:** Energy Audit, ISO 50001:2018, PDCA Cycle, Energy Consumption Intensity.

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Correspondents Author:

Christiono, Department of Electrical Engineering, Institut Teknologi Perusahaan Listrik Negara, Jakarta, Indonesia  
Email: [christiono@itpln.ac.id](mailto:christiono@itpln.ac.id)

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## Introduction

The continuous increase in annual electricity consumption demands a highly reliable power distribution system. Given that the majority of Indonesia's electricity is still supplied by fossil-fuel-based steam power plants (PLTU), conservation efforts on the consumer side are urgent to mitigate environmental impacts ([Christiono et al., 2023](#); [Fikri et al., 2024](#); [Thahara et al., 2025](#)). The building sector significantly contributes to this challenge, accounting for approximately 40% of global energy use. In Indonesia, this sector consumes 30% to 40% of national energy, primarily driven by office and educational buildings heavily reliant on HVAC and lighting systems. This condition is exacerbated by the fact that many existing buildings do not yet meet modern efficiency standards. In response, the Ministry of Energy and Mineral Resources (ESDM) Regulation No. 3 of 2025 has established stricter Energy Consumption Intensity (IKE) classification standards. ([Li et al., 2026](#); [Panjaitan & Rolalisasi, 2026](#)).

Previous studies by ([Mayasari et al., 2024](#)) and ([Rahmawati & Abduh, 2022](#)) emphasize that energy auditing is a vital instrument for evaluating electrical efficiency in educational institutions. However, the effectiveness of such audits depends heavily on compliance with standardized technical procedures. Within the national context, SNI 6196:2011 regarding Energy Audit Procedures for Buildings establishes a systematic framework for accurately identifying load profiles and Energy Saving Opportunities (ESO/PHE). Despite these established procedures, a significant research gap exists in the systematic integration of physical audit findings into a continuous management framework. Without a methodology aligned with SNI standards, energy conservation recommendations often miss the mark in effectively reducing Energy Consumption Intensity (IKE) values toward the 'Efficient' or 'Very Efficient' categories as mandated by the latest regulations ([Mattangang et al., 2025](#)).

The ITPLN Building recorded a substantial annual energy consumption, reaching 1,405,600.8 kWh in 2024 with an installed power capacity of 1,110 kVA. This figure reflects the high workload characteristics resulting from the operation of laboratory equipment and air conditioning systems that run continuously. This study aims to measure the building's energy performance using IKE parameters, validated through the SNI 6196:2011 methodology and aligned with ISO 50001:2018 management standards. The novelty of this study lies in the methodological integration of physical audit results with the PDCA (Plan-Do-Check-Act) cycle to achieve a measurable IKE reduction. Through this approach, the ITPLN Building is expected not only to fulfill academic functional requirements but also to serve as a national strategic reference for achieving energy efficiency targets for existing buildings in Indonesia.

While energy efficiency often correlates with economic and environmental benefits, this study specifically focuses on the methodological integration of technical auditing and the ISO

50001:2018 management framework. Therefore, detailed economic feasibility analyses, such as payback period or return on investment (ROI), and the estimation of CO<sub>2</sub> emission reductions are outside the current scope of this research. These aspects are identified as strategic areas for future studies to complement the technical energy performance baseline and the PDCA-based management strategy established in this work.

## Theoretical Framework and Methodology

### Energy Management System: ISO 50001:2018 and the PDCA cycle

Energy management is a systematic program designed to optimize energy use effectively and efficiently through continuous cycles of planning, recording, monitoring, and evaluation. The primary international reference is ISO 50001:2018 ([Iturralde Carrera et al., 2026](#); [Pandin et al., 2024](#)), which provides a managerial and technical framework for controlling energy use rationally. This system adopts the Plan-Do-Check-Act (PDCA) methodology—a continuous process encompassing planning, implementation, verification, and corrective actions to ensure sustainable energy efficiency both technically and economically ([Rahmawati & Abduh, 2022](#); [Sierocka & Urban, 2025](#)). In this study, the PDCA cycle is operationalized specifically for the ITPLN Building to ensure that efficiency is not a static measurement but a continuous improvement process:

1. Plan (Energy Planning): Establishing the Energy Baseline (EnB) by mapping energy drivers, primarily the 1,110 kVA installed capacity, to support academic and laboratory functions.
2. Do (Implementation): Conducting a technical load inventory and field measurements, categorizing equipment into HVAC, lighting, and laboratory systems.
3. Check (Performance Evaluation): Utilizing 12 months of historical data (January–December 2024) to calculate the actual Energy Consumption Intensity (IKE) and benchmarking it against regulatory standards.
4. Act (Improvement Phase): Formulating specific Energy Saving Opportunities (ESO), such as LED retrofitting and AC standardization, to transition toward a "Very Efficient" status. By explicitly linking each stage to the ITPLN Building's actual consumption profile and operational constraints, this framework demonstrates a practical and scientifically rigorous application of energy management standards ([Chen et al., 2024](#); [Grimaccia et al., 2023](#); [Xu et al., 2023](#))

### Energy Consumption Intensity (IKE) and Classification

An energy audit is a systematic methodology used to identify efficiency opportunities and determine the Energy Consumption Intensity (IKE). IKE is a technical parameter representing

the electrical energy used per unit of floor area over one year (kWh/m<sup>2</sup>/year). To ensure mathematical consistency, IKE is calculated using Equation (1) ([Mayasari et al., 2024](#); [Pamungkas et al., 2025](#)) :

$$IKE = \frac{(E_c)}{(A_b)} \quad (1)$$

In this equation, IKE represents the Energy Consumption Intensity expressed in kWh/m<sup>2</sup>/year. The variable  $E_c$  denotes the total energy consumption over a specific period, measured in kWh/year, while  $A_b$  refers to the total building floor area in square meters (m<sup>2</sup>). By analyzing these parameters, the building's operational efficiency can be categorized according to established national and international sustainability standards.

Building performance is evaluated by comparing the calculated IKE against established national standards, specifically the ESDM Regulation No. 3 of 2025 ([Minister of Energy and Mineral Resources, 2025](#)). The classification thresholds are detailed in Table 1

**Table 1. IKE Classification Thresholds (ESDM No. 3/2025)**

<b>Classification</b>	<b>IKE Range (kWh/m<sup>2</sup>/year)</b>	<b>Description</b>
Very Efficient	< 99	Excellent energy performance with advanced conservation measures.
Efficient	99 - 135	Good energy performance meeting national sustainability standards.
Moderately Efficient	135 - 173	Fair performance; requires optimization of electrical systems.
Inefficient	> 173	Poor performance; urgent energy audit and retrofitting required.

The criteria in Table 1 serve as a critical diagnostic tool for assessing the ITPLN Building's operational status. Based on the audit results, the ITPLN Building recorded an IKE value of 104.78 kWh/m<sup>2</sup>/year. When mapped against the classification in Table 1, this result places the building firmly within the 'Efficient' category (99 - 135 kWh/m<sup>2</sup>/year). However, analytically, the IKE value is positioned near the lower threshold of this range, approaching the 'Very Efficient' boundary. This indicates that while the current performance meets national standards, there is a significant opportunity to elevate the building to 'Very Efficient' status by achieving a mere 3% reduction in annual consumption. Thus, Table 1 not only validates the

building's current compliance but also highlights the feasibility of further optimization through the proposed energy-saving opportunities.

## Data Collection and Load Inventory Analysis

The data collection process was designed to provide a comprehensive baseline for the energy management cycle. This stage involved a systematic acquisition of both secondary and primary data, operationalized as follows:

1. **Secondary Data Collection:** Historical energy consumption and operational costs were retrieved from electricity billing records spanning January to December 2024 to account for seasonal fluctuations.
2. **Primary Technical Inventory:** A physical audit was conducted to perform an Electrical Load Inventory Analysis, mapping all electrical equipment, power ratings, and actual operational hours.
3. **Environmental Validation:** Microclimate parameters, including an average ambient temperature of 30°C and 63% humidity, were recorded using calibrated instruments to justify the energy demand of the HVAC system.

The technical specifications and operational patterns identified during this inventory are summarized in Table 2.

**Table 2. Electrical Load Inventory and Operational Profile of ITPLN Building A**

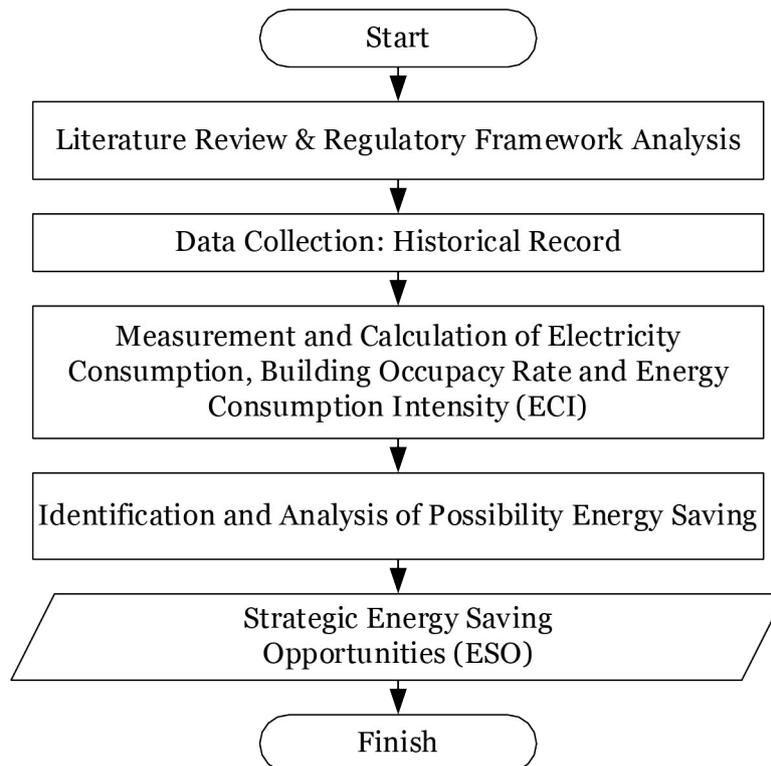
Number	Load Category	Equipment Description	Average Operational Hours	Condition Status
1	HVAC System	Split AC (Non-Inverter & Inverter)	08.00 – 17.00 WIB	Well-maintained
2	Lighting System	LED, FL, and CFL Lamps	07.00 – 18.00 WIB	Well-maintained
3	Office Equipment	Desktop PC, Laptop, Printer	08.00 – 16.00 WIB	Well-maintained
4	Laboratory Facilities	Measuring Instruments, Electric Motors, Trainers	Subject to Practicum Schedule	Well-maintained
5	Supporting Facilities	Elevators, Water Pumps, Dispensers, Servers	24 Hours (Server/Elevator)	Well-maintained

## Research Framework and Procedure

This research methodology is systematically structured by integrating technical energy auditing into the ISO 50001:2018 framework and the Plan-Do-Check-Act (PDCA) cycle. This approach ensures a continuous and measurable energy performance improvement process,

transcending conventional one-time audits by transforming findings into a sustainable management strategy. The operational stages of this research are outlined as follows:

1. **Initiation and Reference Standards:** Establishing benchmarks based on ISO 50001:2018 and national regulations such as ESDM Regulation No. 3 of 2025.
2. **Historical Data Acquisition:** Collecting 12 months of electricity billing data from the 2024 fiscal year to determine an accurate energy baseline.
3. **IKE Calculation:** Determining the Energy Consumption Intensity (kWh/m<sup>2</sup>/year) to classify the building's current performance.
4. **ESO Analysis:** Identifying technical inefficiencies through a deep-dive analysis of high-load systems, spIKEfically HVAC (57%) and Lighting (18%).
5. **Conservation Recommendations:** Formulating technical and managerial actions, such as LED retrofitting and AC temperature standardization, to meet efficiency targets and transition toward a "Very Efficient" classification.



**Figure 1 Research Flow Diagram based on PDCA Cycle**

Figure 1 shows how the research process works based on the PDCA cycle. The first step is to look at the literature and the rules and regulations that apply to the study. This sets the theoretical and policy basis for the study. The next step is to gather data on past electricity use in order to create an energy baseline. After that, measurements and calculations are made to find out how much electricity is used, how many people are in the building, and the ECI. Based on these results, possible ways to save energy are found and looked at, especially for systems

that use a lot of energy. The last step is to come up with strategic Energy Saving Opportunities (ESO) that will help the building use less energy.

## Results and Discussion: PDCA Cycle-Based Energy Performance Analysis

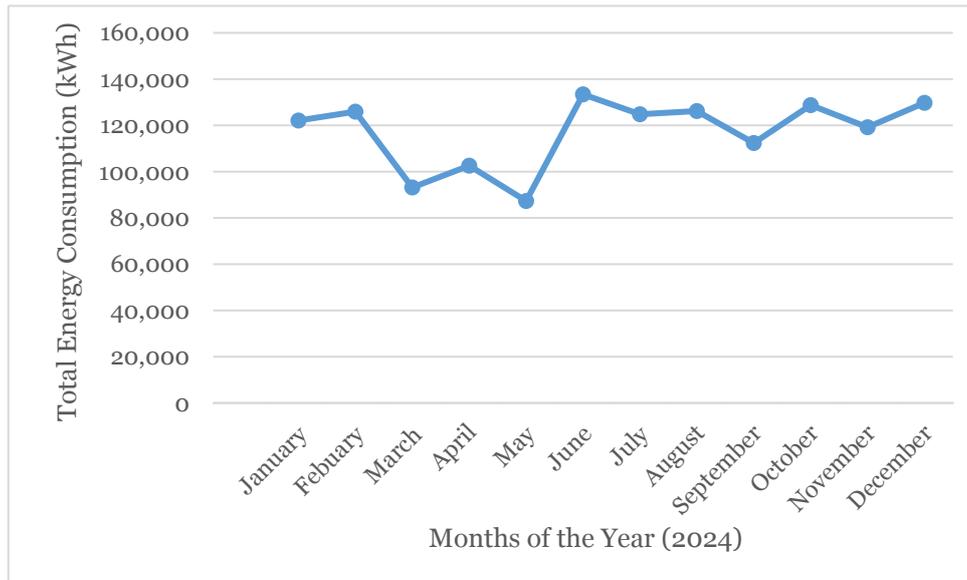
### Plan and Do Phase: Energy Baseline and Consumption Trends

The initial phase of the PDCA cycle established a robust energy baseline using 12 months of historical data from the 2024 fiscal year. The total annual consumption of 1,405,600.80 kWh shows significant monthly fluctuations, peaking in June (133,417.60 kWh) and December (129,747.20 kWh). Analytically, these peaks correlate with high-load academic activities such as final examinations and intensive laboratory sessions. Conversely, the lowest consumption occurred in May (87,312 kWh) during semester breaks. Based on the 12-month data collection for the 2024 fiscal year, the total annual electricity consumption and its associated operational costs are summarized in Table 3.

**Table 3 Monthly Energy Consumption and Operational Cost of ITPLN Building (2024)**

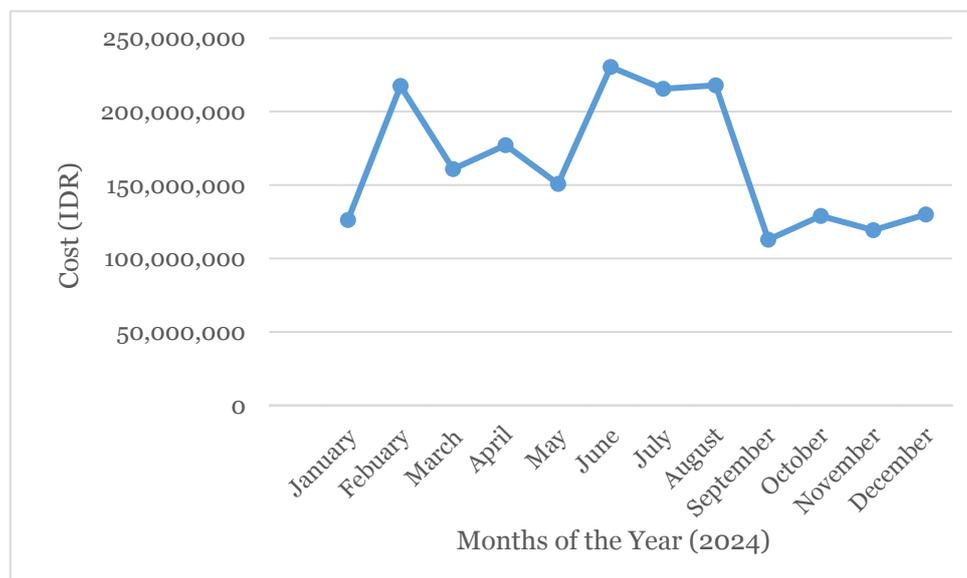
Month	Off-Peak Load (LWBP) (kWh)	Peak Load (WBP) (kWh)	Total Consumption (kWh)	Cost (IDR)
January	109,764	12,336	122,100	126,223,074
February	113,936	12,000	125,936	217,459,988
March	84,048	9,120	93,168	160,877,844
April	92,128	10,464	102,592	177,150,736
May	78,080	9,232	87,312	150,765,996
June	120,107.20	13,310.40	133,417.60	230,378,841
July	112,004.80	12,806.40	124,811.20	215,517,739
August	113,358.40	12,830.40	126,188.80	217,896,510
September	101,001.60	11,380.80	112,382.40	112,818,561
October	116,320	12,430.40	128,750.40	128,959,631
November	107,873.60	11,321.60	119,195.20	119,299,908
December	117,200	12,547.20	129,747.20	129,967,874
Total			1,405,600.80	1,987,316,702

The data in Table 3 reveals a total annual consumption of 1,405,600.80 kWh, incurring a total operational cost of IDR 1,987,316,702. To understand the technical usage trends, these monthly fluctuations are visualized in Figure 2



**Figure 2 Monthly Energy Consumption Trends (kWh)**

Analysis of Figure 2 indicates that energy consumption peaked in June (133,417.60 kWh) and December (129,747.20 kWh). Analytically, these peaks correlate with periods of high academic activity, such as final examination sessions and laboratory-intensive periods. Conversely, the lowest consumption was recorded in May (87,312 kWh), aligning with semester breaks and reduced campus operations. The financial implications of these patterns are further mapped in Figure 3 to evaluate the efficiency of operational expenditures.



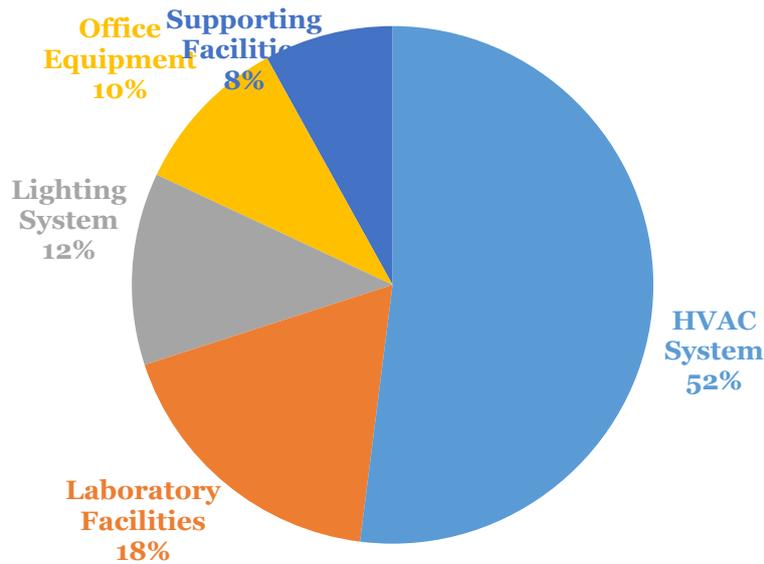
**Figure 3 Monthly Electricity Operational Costs (IDR)**

The trends in Figure 3 confirm the economic impact of energy inefficiency. While costs generally follow consumption patterns, significant fluctuations are observed. For instance, the lowest operational cost occurred in September (approx. IDR 112.8 million). Identifying

these peak (June) and baseline (September) periods is critical for the “Check” phase to determine realistic saving targets and more consistent energy policies.

### Check Phase: Load Distribution and Efficiency Evaluation

Following the baseline establishment, the “Check” phase evaluates energy distribution and classifies the building's efficiency status. Based on the technical audit, the estimated energy load distribution is presented in Figure 4.



**Figure 4. Estimated Energy Load Distribution**

The visualization in Figure 4 confirms that HVAC and Lighting systems are the primary energy consumers. This dominance is scientifically justified by an average ambient temperature of 30°C and a high humidity level of 63%, which necessitates intensive cooling to maintain thermal comfort. These technical data and load profiles provide the quantitative basis for the final performance calculation. The Energy Consumption Intensity (IKE) is determined by dividing the total annual energy consumption by the total building area, as expressed in the following equation (2) below:

$$ECI = \frac{1.405.600,8 \text{ kWh}}{13.415 \text{ m}^2} = 104,78 \text{ kWh/m}^2/\text{year} \quad (2)$$

According to national standards, this value of 104.78 kWh/m<sup>2</sup>/year categorizes the ITPLN Building as Efficient. However, this result also indicates significant potential for improvement toward the "Very Efficient" classification through the implementation of targeted energy-saving measures.

## Act Phase: Strategic Energy Saving Opportunities (ESO)

In the "Act" phase, technical interventions are formulated to drive continuous improvement based on the diagnostic results from the preceding stages. The identification of HVAC and lighting as the primary energy drivers—justified by the intensive 08.00–17.00 WIB operational cycle and ambient conditions (30°C temperature and 63% humidity)—prioritizes these sectors for strategic conservation.

While this study focuses on these measurable technical interventions, the "Act" phase also establishes the strategic importance of future preventive maintenance. By incorporating maintenance recommendations into the management strategy, the ITPLN Building can mitigate system failures—such as current leaks or insulation degradation—ensuring that the projected efficiency gains are sustained over the long term. This approach aligns with the continuous improvement mandate of ISO 50001:2018, moving the facility toward a 'Very Efficient' classification. The proposed Energy Saving Opportunities (ESO) focus on three core areas:

1. HVAC Optimization: Implementing AC temperature standardization and refrigerant conversion to reduce the cooling load's energy intensity.
2. Lighting Retrofit: Replacing remaining non-LED fixtures (FL and CFL) to optimize the extensive 11-hour daily operational duration.
3. Operational Policies: Enforcing stricter energy-use protocols during peak hours

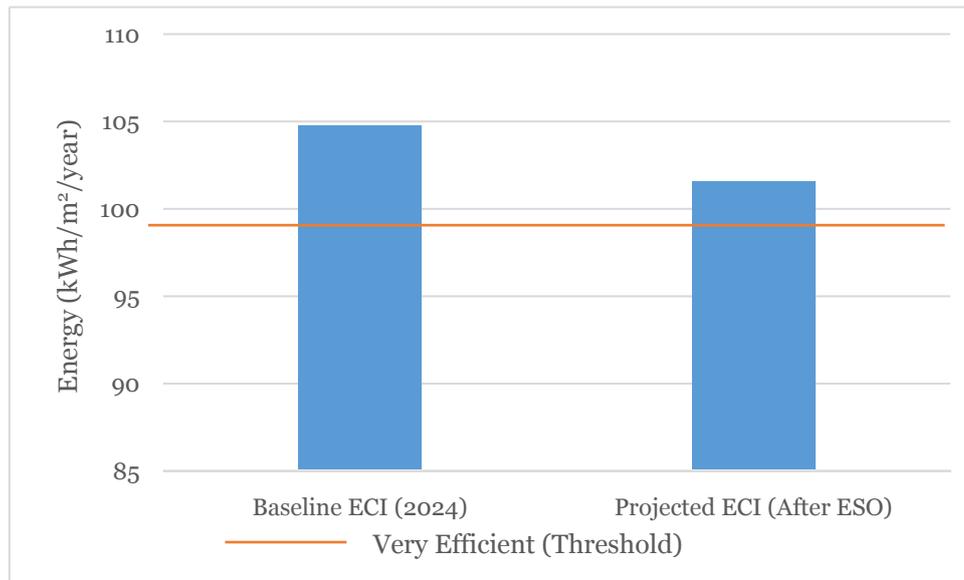
The "Act" phase translates these findings into a sustainable management strategy through specific Energy Saving Opportunities (ESO). Unlike mere procedural recommendations, this stage provides a measurable pathway for improvement

**Table 3 Projected Energy and Economic Savings**

Strategy	Projected Saving (kWh/year)	Cost Reduction (IDR/year)	IKE Impact
LED Retrofitting	12,650.40	17,887,665	-0.94
AC Optimization	29,517.62	41,731,836	-2.24
Total (ESO)	42,168.02 (3%)	59,619,501	-3.18

These interventions, including standardizing AC temperatures to 24-27°C and LED retrofits, are projected to reduce consumption by 42,168.02 kWh/year. This 3% efficiency gain effectively lowers the IKE to 101.6 kWh/m<sup>2</sup>/year, achieving the "Very Efficient" classification. By integrating these measures into the ISO 50001 operational controls, the ITPLN Building ensures long-term operational sustainability and significant economic savings of approximately IDR 59.6 million annually

As illustrated in Figure 5, these combined measures are projected to reduce the IKE from 104.78 to 101.6 kWh/m<sup>2</sup>/year. This represents a 3% increase in overall energy efficiency, strategically transitioning the ITPLN Building's performance from the 'Efficient' threshold toward the 'Very Efficient' classification. Rather than providing mere procedural recommendations, this proactive stage transforms audit findings into a sustainable, long-term energy management strategy.



**Figure 5. Comparison of Baseline IKE and Projected IKE after ESO Implementation**

Analytically, as illustrated in Figure 5, the implementation of these strategic measures is projected to result in a transition from the current baseline to an optimized state. The visual comparison highlights the successful reduction of the IKE value, providing a clear quantitative benchmark for the building's future energy performance.

## Comparative Analysis and Research Novelty

The novelty of this study lies in the seamless integration of a detailed technical energy audit with the ISO 50001:2018 management framework, specifically utilizing the PDCA (Plan-Do-Check-Act) cycle to ensure continuous improvement. While previous energy audit studies at other Indonesian institutions, such as Universitas Hasanuddin (Unhas) or Universitas Muhammadiyah Tangerang (UMT), primarily focus on identifying static Energy Saving Opportunities (ESO) based on SNI 6196:2011, this research advances the field by transforming those findings into a dynamic management strategy.

Unlike many existing works that provide one-time recommendations, this study benchmarks the baseline IKE of 104.78 kWh/m<sup>2</sup>/year against national efficiency standards (Permen ESDM No. 3/2025) and utilizes the "Act" phase to project a measurable transition to 101.6

kWh/m<sup>2</sup>/year. Furthermore, the granular correlation established between environmental factors—specifically the recorded 30°C ambient temperature and 63% humidity—and the resulting 57% HVAC dominance provides a scientifically grounded model for tropical campus environments that is often absent in more generalized studies. By explicitly linking these climatic variables to the ISO 50001 operational controls, this work offers a replicable and sustainable framework for systematic energy reduction in high-occupancy institutional buildings.

## Conclusions

This study successfully demonstrates that integrating a technical energy audit into the ISO 50001:2018 framework and PDCA cycle transforms static measurements into a continuous management strategy. Analysis of the ITPLN Building A revealed a baseline IKE of 104.78 kWh/m<sup>2</sup>/year, classifying it as "Efficient" under ESDM Regulation No. 3 of 2025. By addressing primary energy drivers—HVAC (57%) and Lighting (18%)—through strategic ESOs such as LED retrofitting and AC standardization, a projected 3% efficiency gain is achievable, lowering the IKE to 101.6 kWh/m<sup>2</sup>/year. These findings provide a replicable model for tropical campus environments where high ambient temperatures (30°C) significantly dictate load profiles.

Strategically, this research highlights the necessity for educational institutions to adopt international management standards to ensure long-term sustainability. However, it is important to note that this study is limited to a single-building scope and does not include detailed financial payback or CO<sub>2</sub> reduction metrics, focusing instead on technical and managerial validation. Future research should explore the integration of IoT-based smart monitoring and predictive load modeling to further enhance real-time energy optimization in institutional facilities.

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