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Evaluation and Identification of Opportunities for Saving Electrical Energy Consumption in Artificial Lighting Systems Inside Buildings

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ABSTRACT

The artificial lighting system is a major component in a building, consuming up to 50% of its electrical energy. Hence, it is crucial to evaluate and identify opportunities for energy savings. Industries involve numerous operational instruments, one of which is building structures with artificial lighting systems. The requirements for artificial lighting systems consider energy conservation principles aimed at achieving energy consumption efficiency during operation. Therefore, a series of energy management activities and energy conservation evaluations are conducted through an audit of the artificial lighting system in a building with 50 rooms (the study object). The audit method used is the Short Energy Audit (SEA) to calculate Energy Consumption Intensity (ECI) under actual conditions (condition 1) and predictions under improvement conditions (condition 2). The results depict an energy usage portrait (evaluation) showing that 100% of electricity consumption is efficient, with the ECI target standard at 2,5 kWh/m^2. The percentage saving (PS) in condition 1 are 68,058% and in condition 2 are 64,967%, indicating that improvements will not significantly alter the energy saving opportunities but will provide considerable benefits in operational investment. Recommendations include making small short-term investments in repairs, maintenance, optimizing lighting system operations, and conducting initial energy audits.

1. INTRODUCTION

An industry requires energy to sustain its operational activities. However, the continuously increasing energy consumption significantly impacts the incurred costs [1]. Therefore, energy management is necessary to achieve savings and efficient energy consumption. In accordance with Presidential Regulation No. 33 of 2023, the implementation of energy conservation downstream (energy users) through energy management is intended to control energy consumption to achieve effective and efficient energy utilization, as well as to obtain operational savings opportunities [2, 3].

Energy audits are crucial in industrial energy management as they represent the initial step in identifying opportunities for comprehensive energy conservation [4]. The primary objective of these audits is to evaluate the energy consumption of buildings or industrial operations. Energy auditing involves a series of activities that assess energy usage and identify areas for potential savings, ultimately aiming to reduce energy waste. The outcome of this process is a report containing improvement recommendations and other suggestions related to energy conservation.

A Short Energy Audit (SEA) involves several key activities, such as gathering historical energy data, reviewing building documentation, conducting on-site observations, calculating energy consumption intensity (ECI) and its trends, analyzing potential energy and cost savings, mapping energy usage, and providing specific recommendations [5]. Quite a few studies on energy conservation employ energy audit methods based on Energy Consumption Intensity (ECI) calculations to identify current and potential energy-saving opportunities [6-10]. Findings from the audit highlight energy-saving opportunities and offer strategic advice for energy conservation. It is then incumbent upon the company to implement these recommendations to enhance operational efficiency [4].

Industries always involve many operational instruments, one of which is buildings. Republic of Indonesia Law No. 28 of 2002 concerning Buildings defines buildings as physical forms of construction work where people conduct activities by regulating building comfort, one of which is the requirement for artificial or natural lighting systems [11]. The artificial lighting system is a key component in a building, providing light from man-made sources such as lamps. It is essential in cases where natural lighting is either inadequate or cannot reach certain areas. This can occur when the layout of a room obstructs natural light or when the requirements for natural lighting fall short, leading to increased energy consumption for lighting, which can account for almost 50% of electrical energy use in a building [12]. Therefore, the design requirements for such systems consider energy conservation principles aimed at achieving energy consumption efficiency during operations.

The primary problem to be solved is the identification and quantification of inefficiencies in the building's energy consumption profile, particularly focusing on the artificial lighting systems. This involves evaluating the current energy consumption intensity, assessing the effectiveness of implemented energy-saving measures, and pinpointing areas where electricity consumption can be reduced. Consequently, addressing these issues is crucial for optimizing energy use, reducing operational costs, and enhancing the overall sustainability of the building. Using the Short Energy Audit (SEA) method and Energy Consumption Intensity (ECI) calculations compared with applicable standards with the study object being a building with 50 rooms, this study aims to provide recommendations for energy consumption based on evaluation results and identify savings opportunities that have occurred in the building. Additionally, the findings of this study can serve as a reference for implementing the methods used to evaluate energy consumption in other buildings.

2. METHODS

2.1 Data Collection

The study employed a descriptive qualitative method to identify opportunities for electricity consumption savings in artificial lighting systems within a building comprising 50 rooms. This methodology involved a Short Energy Audit (SEA), utilizing the following procedures [13]:

1. Historical Data Collection:
   - Building Area: The total floor area of the building was measured.
   - Installed Power: Data on the installed lighting power capacity was collected.
2. Visual Observation:
   - An on-site inspection was conducted to assess the condition of the lighting systems and identify any discrepancies between recorded data and actual conditions.
3. Data Recording:
   - Room-by-Room Analysis: Each room's dimensions, the number of working lamps, total number of lamps, types of fixtures, and specifications of the lamps used were recorded.
   - Usage Patterns: The duration for which the lamps were operational was noted.

2.2 Calculation of Energy Consumption Intensity (ECI)

The Energy Consumption Intensity (ECI) is a key metric used to assess the efficiency of electricity consumption within a building. It is calculated using the following formula [14]:

$$ECI = \frac{Total\ electricity\ consumption\ (kWh)}{Total\ area\ of\ the\ room\ (m^2)} = \frac{(Number\ of\ working\ lights \times lamp\ power \times duration \times 26)/1000}{Total\ area\ of\ the\ room\ \ (m^2)} \tag{1}$$

- Total Electricity Consumption (kWh): This is calculated by multiplying the number of working lights by the lamp power (in watts), operational hours per day, and the number of operational days per month (typically 26).
- Total Area (m^2): The floor area of each room is summed to get the total building area.

2.3 Data Analysis

1. ECI Trend Analysis**:**
   - Monthly ECI values were calculated for each room and aggregated to identify trends and patterns in energy consumption.
2. Savings Opportunity Analysis:
   - Setting Target ECI: A target ECI value was established based on best practice standards and applicable benchmarks.
   - Energy Saving Opportunities (ESO) in kWh: The potential savings were calculated by comparing the actual ECI to the target ECI using the formula [15]:

$$ESO = \left(ECI_{target} - ECI_{actual}\right) \times A \tag{2}$$

Where A is the total floor area of the building.

3. Cost Saving Opportunities (CSO):
   - The financial impact of the energy savings was calculated by applying the electricity tariff set by the State Electricity Company (PLN) to the ESO. The CSO in Indonesian Rupiah (Rp) are obtained using the formula [16]:

$$CSO = ESO \times electricity\ tariff \tag{3}$$

4. Saving Percentage (PS):
   - The percentage of potential savings was calculated to understand the impact of the energy-saving measures:

$$PS = \frac{ESO\ (kWh)}{Total\ energy\ usage\ prediction\ (kWh)} \times 100\% \tag{4}$$

2.4 Interpretation and Recommendations

1. Quality Assessment:
   - The condition of the artificial lighting systems was assessed against applicable standards to determine compliance and areas needing improvement.
2. Energy Usage Profiles:
   - Detailed profiles of energy usage were created to understand usage patterns and identify peak consumption periods.
3. Recommendations:
   - Based on the findings, recommendations were made for improving the efficiency of the lighting systems, such as upgrading to more energy-efficient lighting fixtures, implementing automated lighting controls, and optimizing operational hours.

2.5 Study Duration and Scope

- Duration: Data collection was conducted over two months, from June to July 2023.
- Scope: The audit covered a three-story building with 50 rooms, including office spaces, meeting rooms, service rooms, laboratories, prayer rooms, and warehouses.

By following this detailed methodology, the study aimed to provide a comprehensive evaluation of the current state of the building's artificial lighting systems and identify feasible opportunities for energy and cost savings.

3. RESULTS AND DISCUSSION

3.1 Building Data: Object of Study

Table 1 presents the building data under study, including the number of rooms for all floors, room numbers, the area of each room, the total number of lights, the number of functioning lights, and the duration of usage. Rooms numbered 1-12 are located on the ground floor, rooms numbered 13-31 are on the first floor, and rooms numbered 32-50 are on the second floor.

Table 1. Building Data as an Object of Study

No. Room	Room area (m^2)	Number of lights	Number of lights working	Duration of use (hours)
1	12.84	3	3	0
2	24.92	2	2	9
3	26.55	9	7	9
4	8.92	1	1	6
5	14.67	6	6	9
6	32.56	12	12	9
7	28.92	12	11	9
8	8.7	3	2	9
9	69.30	23	23	9
10	17.28	6	3	9
11	46.21	24	16	9
12	34.68	2	2	9
13	24.92	2	2	6
14	23.47	24	19	10
15	94.08	48	42	10
16	23.16	12	12	9
17	23.04	12	8	9
18	69.3	36	35	10
19	30.72	36	35	10
20	69.3	18	18	10
21	15.48	6	6	9
22	15.48	6	4	9
23	63.12	30	27	9
24	34.68	18	18	9
25	11.52	6	4	9
26	94.08	24	23	9
27	11.88	6	6	9
28	11.88	6	6	9
29	23.47	12	12	9
30	92.4	48	47	10
31	47.9	18	17	9
32	93.43	36	35	10

No. Room	Room area (m^2)	Number of lights	Number of lights working	Duration of use (hours)
33	46.2	33	32	10
34	66.3	33	31	10
35	93.43	48	41	10
36	46.2	36	36	9
37	46.2	12	8	9
38	26.04	12	11	9
39	35.82	12	11	9
40	12.06	6	4	9
41	92.4	48	42	10
42	69.3	36	36	10
43	35.76	12	10	9
44	30.6	12	11	9
45	24.92	2	2	6
46	8.2	1	1	0
47	93.43	36	35	9
48	35.34	18	12	9
49	18.36	6	4	9
50	17.28	6	6	9

The information from Table 1 indicates that the number of functioning lamps is 796 out of 874 total lamps. The average duration of lamp usage per day is between 9 and 10 hours. Rooms designated as warehouse spaces (room numbers 1 and 46) are considered unused, resulting in an average duration of lamp usage of zero hours. Additionally, there are a total of 289 LED tube lamp fixtures. The types of lamps used are presented in the following Table 2.

Tabel 2. Lamp Specifications for Artificial Lighting Systems in Buildings

Code	Type of lamp	Power (Watts)	Lumens (lm)	Temperature (K)
1	LEDtube 600mm 8W 765 T8 AP CG	8	800	6500
2	TL-E 22W/54-765 1CT/20	22	1050	6200
3	TForce Core HB 30W E27 865 GN3	30	3200	6500

The type of lighting system used is a combination of uniform and localized lighting (not a hybrid). In this study, the rooms that utilize localized lighting system are only the service room (no. 12) with type 3 lamps, while others utilize uniform lighting system. Rooms no. 2, 13, 45, 46 use type 2 lamps, and the rest use type 1 lamps. All lamps used have a cool daylight color temperature ranging from 6200 to 6500 Kelvin, with color rendering index (CRI) values between 61% and 80%, and between 80% and 100%.

In the analysis of ECI, ESO, and CSO data, subjects are divided into two conditions, namely condition 1 and condition 2. Condition 1 represents the actual working condition of the system in the field with all its circumstances (actual), where some lamps are non-functional. Condition 2 represents the assumption that all lamps are functioning normally. The use of these two conditions is to analyze the comparison of energy-saving opportunities between the actual condition and the condition where all lamps are working. As a guideline, if 91% of the lamps are operational, it would be a recommendation when comparing these two conditions.

3.2 ECI, ESO, and CSO in Condition 1

In conducting the analysis of ECI, ESO, and CSO, several aspects need to be established, namely the indicators used as targets, the applicable electricity tariff, the total amount of power and electricity costs used, as well as predictions of the total amount of power and electricity costs used. The prediction referred to here is the total amount of energy consumed or costs incurred under the prevailing conditions, compared with the estimated amount of energy or costs expected to be saved from the analysis of the target ECI value [17]. Furthermore, this study no more than analyzes electricity consumption in artificial lighting systems. Therefore, based on Table 3, the space under investigation is considered a non-air-conditioned room.

The standard indicators for building energy intensity in Indonesia were established by the Department of National Education of the Republic of Indonesia in 2004 and are presented in Table 3 below.

Tabel 3. ECI Standard Indicators in Buildings [18]

Criteria	AC room (kWh/m²)	Non-AC room (kWh/m²)
Highly Efficient	4.17 – 7.92	0.84 – 1.67
Efficient	7.92 – 12.08	1.67 – 2.5
Moderately Efficient	12.08 – 14.58	-
Slightly extravagant	14.58 – 19.17	-
extravagant	19.17 – 23.75	2.5 – 3.34
Highly extravagant	23.75 – 37.75	3.34 – 4.17

The results of the Energy Consumption Intensity (ECI) data processing calculated using Equation 1 under condition 1 are presented in Figure 1. The following is an example ECI calculation for Room No. 2 with Lamp Type Code 2:

$$ECI_2 = \frac{(Number\ of\ working\ lights \times lamp\ power \times duration \times 26\ )/1000}{Total\ area\ of\ the\ room\ \ (m^2)} = \frac{(2 \times 22 \times 9 \times 26)/1000}{24{,}92} = 0{,}413\ kWh/m^2$$

The calculations and analysis were conducted over a period of one month (26 days), involving solely the total power consumption of artificial lighting systems (the number of lamps) used and operational within all rooms. There are two rooms with a zero ECI value, namely the warehouse and the panel room, as both rooms are seldom utilized, and it is assumed that their average usage time is zero hours per month. The results indicate a varied distribution of ECI values across each room, where a smaller ECI value corresponds to a more efficient energy consumption of a building, and vice versa.

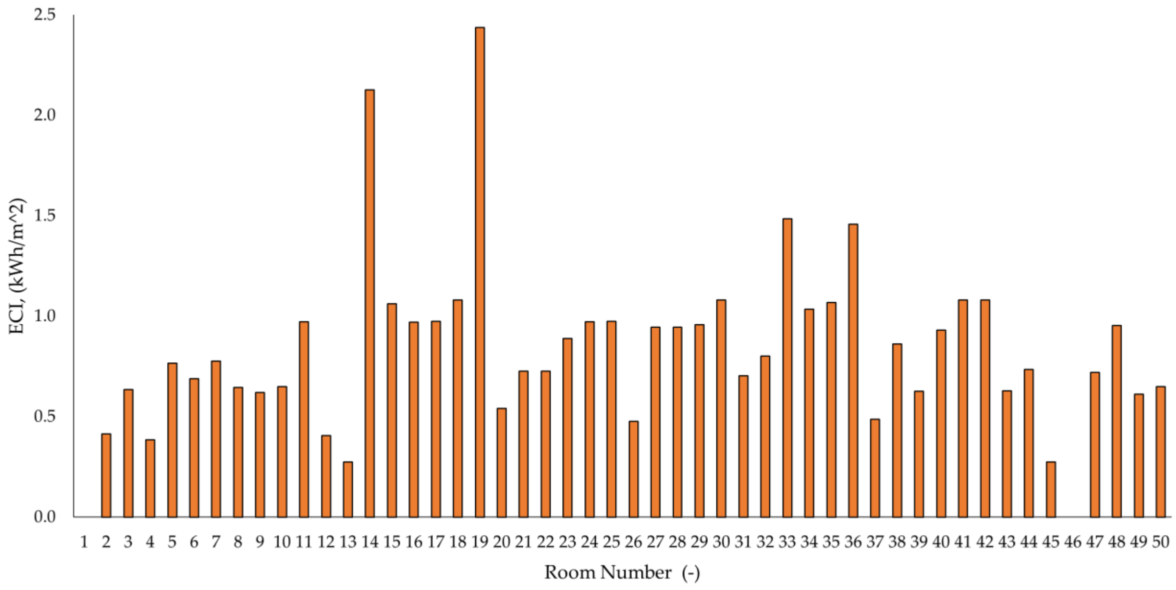

Figure 1. ECI Study Object Building (condition 1)

The building under study is a customer of the Indonesian State Electricity Company (PLN) categorized under the Social Industrial Group or Group S-3, with an electricity tariff of Rp1.114,74/kWh as of April-June 2023 [15]. Furthermore, based on ECI calculation, the total electricity consumption for one month from the examined building under Condition 1 is determined to be 1.595,048 kWh. Consequently, with the electricity tariff, the electricity cost incurred amounts to Rp1.778.808 per month.

According to Table 3, the standard ECI indicators for the building are only four: highly efficient, efficient, wasteful, and highly wasteful. However, in this case, several rooms exhibit ECI values outside the standardized range. Hence, an additional indicator, labeled as extra efficient (range 0-0,84), is introduced, resulting in a total of five indicators/criteria. Rooms falling within this range are presented in Table 4 below.

Tabel 4. ECI Standards for Artificial Lighting Systems for Buildings Objects of Study (condition 1)

Criteria	**Number of rooms**	**Room number according to criteria**	**Percentage per criteria (%)**
Extra efficient	34	1; 46; 13; 45; 37; 10; 4; 12; 49; 2; 8; 26; 22; 3; 43; 20; 39; 40; 9; 48; 11; 50; 17; 25; 31; 44; 6; 47; 7; 21; 5; 32; 38; 23	68
Highly Efficient	14	35; 15; 27; 28; 41; 29; 16; 24; 34; 18; 30; 42; 33; 36	28
Efficient	2	14; 19	4
extravagant	0	0	0
Highly extravagant	0	0	0
Total	50	Total percentage	100

From Table 4, it is evident that 100% of the electricity consumption of the artificial lighting system in the building is categorized as efficient, with a breakdown of 4% meeting the criteria for efficiency, 28%

being highly efficient, and 68% being exceptionally efficient. There are no instances of extravagant or highly extravagant criteria, thus eliminating the possibility of negative savings in energy expenditure (ESO and CSO). Negative savings represent potential operational cost losses.

The calculations ESO and CSO utilize efficient criteria, with a target indicator of 2,5 kWh/m² according to ECI standards to calculate potential savings, as determined by Equations 2 and 3. Examples of ESO and CSO calculation for room No. 19 are presented below.

$$ESO_{19} = (ECI_{target} - ECI_{actual}) \times A = (2{,}5 - 2{,}37) \times 30{,}72 = 4{,}00\ kWh$$

$$CSO_{19} = ESO \times electricity\ tariff = 4{,}00 \times 1.114{,}74 = Rp\ 4.458{,}96$$

This calculation is also performed for all rooms, so the total opportunity for electricity saved in a month is 3398,515 kWh with a cost saving of Rp 3.788.460,054. Therefore, the total energy consumption of the building with the efficiency indicator target for a month is predicted to be 4993,563 kWh and costs Rp 5.566.524. The overall calculation results are presented in Figure 2 below.

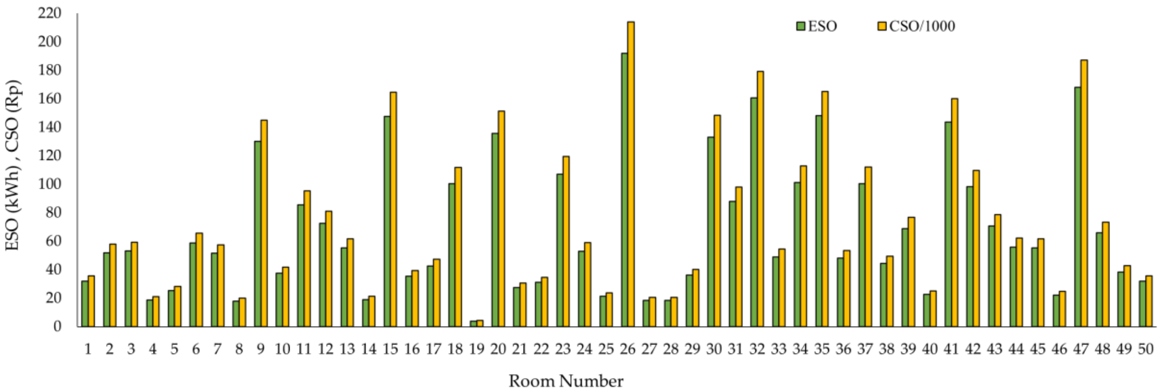

Figure 2. ESO and CSO/1000 (condition 1)

Based on Figure 2, rooms number 4, 8, 14, 19, 25, 27, 28, 40, and 46 contribute to the potential energy-saving opportunities at the threshold of 20, making them minor contributors to electricity saving opportunities, with room number 19 being the smallest contributor. Upon examination of their conditions, these 9 rooms offer limited energy-saving opportunities due to several factors, such as inadequate or excessive total lamp power usage relative to the room area, mismatch between room size and lamp power density, and ECI. The other 41 rooms present significant energy-saving opportunities, up to the threshold of 200, indicating the potential for energy savings up to 200 kWh and cost savings up to Rp200.000 per month. From this analysis, the energy saving opportunities (percentage saving (PS)) of the artificial lighting system in the building is identified at 68,058% based on using calculation Equation (4):

$$PS = \frac{ESO\ (kWh)}{Total\ energy\ usage\ prediction\ (kWh)} \times 100\% = \frac{3398{,}515}{4993{,}563} \times 100\% = 68{,}058\%$$

3.3 ECI, ESO, and CSO in Condition 2

Rooms meeting the criteria for extravagant and highly extravagant in condition 2 remain unchanged from condition 1, meaning there are none. Table 5 presents the distribution of rooms resulting from the standard ECI calculation in condition 2, where the calculations are identical to those in condition 1. When comparing conditions 1 and 2, there is no difference in criteria, but the detailed percentage of each indicator differs, as represented in Figure 3. The criterion of extra efficiency represents the largest percentage of total rooms, indicating the potential ECI value if improvements are made to non-functional lights, demonstrating that 100% of electricity consumption for the lighting system remains in the energy-saving status.

Tabel 5. ECI Standards for Building Lighting Systems for Study Objects (condition 2)

Criteria	Number of rooms	Room number according to criteria	Percentage per criteria (%)
Extra efficient	27	1; 46; 13; 45; 4; 12; 2; 8; 26; 37; 20; 49; 9; 39; 43; 3; 10; 50; 6; 31; 47; 21; 22; 44; 5; 7; 32	54
Highly efficient	21	38; 23; 40; 27; 28; 48; 29; 16; 24; 11; 17; 25; 34; 15; 35; 18; 30; 41; 42; 36; 33	42
Efficient	2	14; 19	4
extravagant	0	0	0
Highly extravagant	0	0	0
Total	50	Total presentase	100

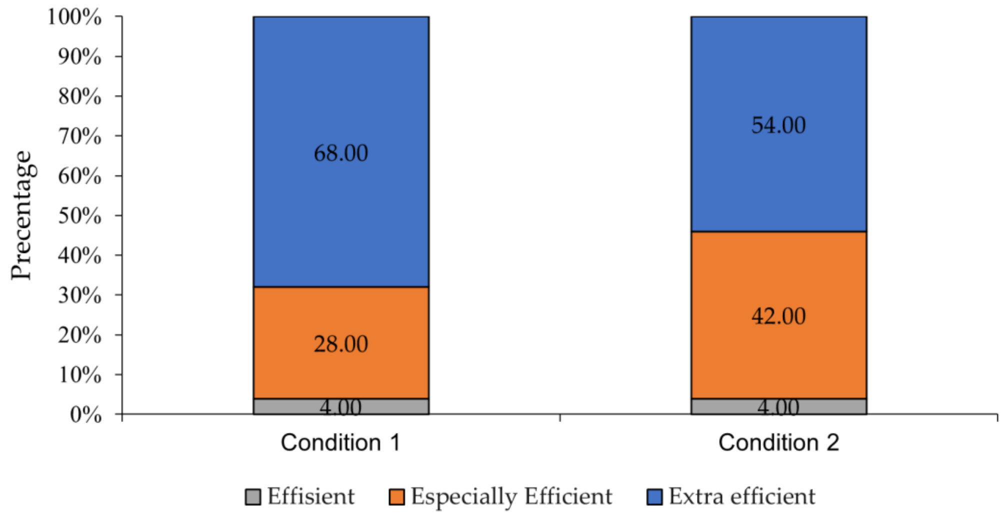

Figure 3. Comparison of Conditions 1 and 2 Distribution of ECI Criteria for 50 Rooms

The analysis of ESO and CSO under condition 2 also adheres to the efficiency criteria with a target of 2,5 kWh/m². Using the same calculations as in condition 1, the total potential energy savings for a month amount to 3244,179 kWh, resulting in cost savings of Rp3.616.415. Meanwhile, the total electrical power consumed by the building during condition 2 for a month is 1.749,384 kWh, costing Rp1.950.108. Thus, the total energy consumption by the subject building with the efficient indicator target for a month is also predicted to be 4993,563 kWh with a cost of Rp5.566.524, which is equivalent to condition 1. The results of the ESO and CSO calculations for condition 2 are presented in Figure 4, along with a comparison to condition 1.

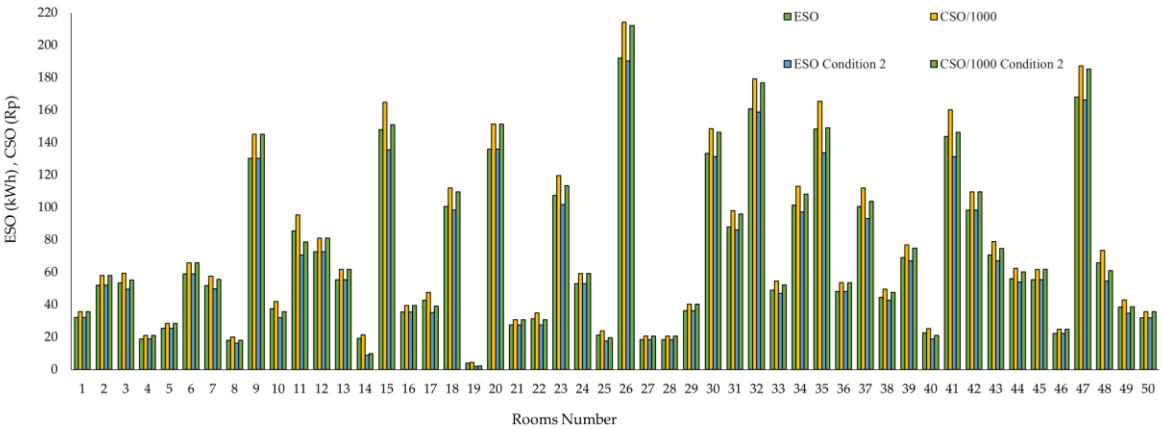

Figure 4. Comparison of conditions 1 and 2 of ESO and CSO/1000

Therefore, the identification of potential energy savings in the subject building's electricity consumption for artificial lighting in condition 2 amounts to 64,967%. This potential is consistent with findings from Suhendar's study, which reported energy consumption savings in lighting systems of 64,07% post-improvement [19]. Figure 5 illustrates the comparison of the savings potential between conditions 1 and 2.

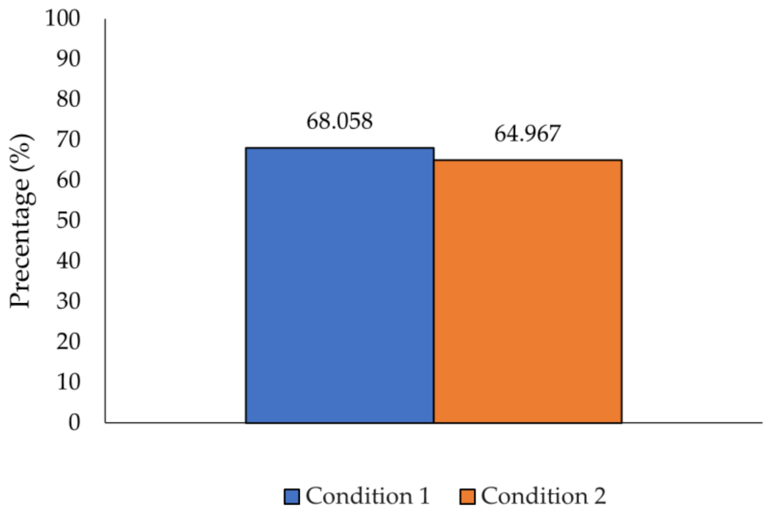

Figure 5. Comparison of Savings Opportunities in Artificial Lighting Systems for Conditions 1 and 2 of the Study Object Building

Upon examination, the building demonstrates an identical total energy consumption prognosis under both conditions, suggesting that the efficiency of the lighting system's energy consumption aligns with the predicted values. Thus, the actual energy savings opportunity lies in condition 2, where all lights operate under normal conditions, amounting to 64,967%. According to Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia (RI) Number 1 Year 2012, the building falls under the criteria for high investment recommendation due to its potential savings exceeding 20% [20], implying significant investment benefits.

The comparison between conditions 1 and 2 of ESO and CSO shown in Figure 4 indicates that if improvements are made, the height of the bars in the graph will decrease but not significantly. This suggests that the improvements made do not result in significant changes to the savings potential as represented in Figure 5. Although the energy usage portrait conditions are economical, an investigation into the luminance conditions of the lights concerning the applicable Indonesian National Standard (SNI) is necessary.

3.4 Portrait of Energy Use and Recommendations

The evaluation, depicted as an energy usage portrait for the artificial lighting system of the 50-room building, indicates that electricity consumption is efficient, with 91% of lights in operation and percent savings reaching up to 68%. Consequently, strategic recommendations stemming from the evaluation of energy conservation in the lighting system are based on Indonesian National Standard (SNI) 6196:2011, tailored to field requirements, as follows:

Investment Strategies: recommending the replacement of lights in rooms number 2, 13, 45, and 46 with PHILIPS LED tube 600mm 8W 765 T8 AP CG bulbs, with a light power intensity not exceeding 12,16 Watts/m^2 for rooms 2 and 13, each having 6 bulbs and 2 fixtures, and 7,53 Watts/m^2 for rooms 45 and 46, each having 3 bulbs and 1 fixture. The investment amount required is presented in Table 6. Repairing non-functioning lights, which constitute 9% of the total number of lights or 78 bulbs, using the same type of bulb. The investment amount required is presented in Table 6. Maintenance: regularly clean armatures to ensure optimal light emission. Periodically assess lamp performance, utilizing visual inspection for light quality discrepancies. If issues are identified during performance evaluation, promptly replace malfunctioning components. Operational: Optimizing the use of natural light while indoors by opening window curtains, considering glare factors to ensure natural light blends into all parts of the room. Turning off some lights when activities indoors are completed. Follow-up: conduct an initial energy audit to assess the luminance conditions of the lighting system and evaluate aspects related to artificial lighting system design. This audit will serve as a benchmark for comparing current conditions with proposed improvements.

4. CONCLUSION

Based on the discussion of the evaluation results and the identification of opportunities for energy consumption savings in the artificial lighting system of a building comprising 50 rooms, the following conclusions are derived:

1. The analysis was conducted under two conditions: condition 1, representing the actual state, and condition 2, representing the hypothetical scenario where all lights are operational post-repair, utilizing the SEA method for assessment.
2. Evaluation of the energy usage profile within the building's lighting system indicates full compliance with the ECI standard of 2,5 kWh/m².
3. The identification of energy-saving opportunities reveals a notable 68,058% improvement in condition 1 and a slightly lower but still significant 64,967% improvement in condition 2. This suggests that while repairs may not drastically alter the potential for savings, they would yield substantial operational investment benefits.
4. Recommendations entail implementing small-scale short-term investments, primarily focusing on repairs, maintenance, optimization of lighting system operations, and conducting an initial energy audit to gauge the luminance conditions against relevant standards.
5. The estimated investment required for repairing the building's artificial lighting system is Rp5.391.600.

These conclusions emphasize the critical need for targeted interventions aimed at boosting energy efficiency within lighting systems, thereby fostering sustainable building operations, and yielding substantial cost savings. It is imperative to conduct additional research and diligently implement suggested measures to fully unlock these advantageous outcomes.

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