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Analysis of Energy Management System and Feasibility of 25 kWp Rooftop Solar Power Plant using Techno-Economic Method in DKI Jakarta Regional Government Building

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ABSTRACT

The building sector is a major contributor to energy consumption and greenhouse gas emissions in Indonesia, accounting for approximately 50% of national energy use and nearly 30% of total emissions. This study evaluates the implementation of an ISO 50001–based Energy Management Systems (EnMS) in a government building in Jakarta, combining energy efficiency retrofits with rooftop photovoltaic (PV) integration. The research contributes a comprehensive technical and economic assessment that quantifies energy savings, emission reductions, and financial feasibility within a replicable public-sector framework. The methodology included an ISO 50001–aligned energy audit, building energy simulation using DesignBuilder, PV system design with PVsyst, and economic feasibility analysis. LED lighting retrofits reduced lighting energy consumption by 38.14%, while air-conditioning optimization improved thermal comfort. A 24.75 kWp rooftop PV system generated 33,428 kWh annually, supplying 17.97% of the building's electricity demand. In total, the integrated measures achieved annual energy savings of 37,587 kWh and reduced emissions by 31.57 tons of CO_2. Economic analysis indicated that the project was financially feasible, with a positive NPV, a 6% IRR, an 8.18% ROI, and a payback period of approximately 14 years. The integrated approach proved effective and showed strong potential for replication in similar public buildings.

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1. INTRODUCTION

Climate change is a global challenge that has significant impacts on the environmental, health, and economic sectors, including in Indonesia. To reduce the rate of global temperature increase, a transition to a sustainable energy system is imperative [1]. The building sector plays a crucial role in this effort, given its significant contribution to energy consumption and greenhouse gas emissions. In Indonesia, the building sector contributes approximately 30% of national emissions, making increasing energy efficiency and utilizing renewable energy, particularly in government buildings, a key strategy in climate change mitigation [2-4].

Indonesia has enormous solar energy potential, but its utilization—especially through rooftop solar power plants (PLTS)—is still relatively limited. Several studies have shown that the implementation of

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energy efficiency and rooftop PV in government buildings can significantly reduce energy consumption, carbon emissions, and operational costs [5-8]. These efforts need to be supported by the implementation of an ISO 50001-based Energy Management System (SME) and national and regional policies, such as Government Regulation No. 70 of 2009, the Minister of Energy and Mineral Resources Regulation on Energy Management, and the National Energy General Plan (RUEN) and Regional Energy General Plan (RUED) [9-12]. In DKI Jakarta, this policy is strengthened through Regional Regulation No. 5 of 2023, which emphasizes the importance of energy audits and the adoption of renewable energy in government buildings [13].

Despite the availability of a policy framework, integrated studies combining building energy performance analysis, energy efficiency retrofit scenarios, SME implementation, and the technical and economic feasibility of rooftop solar power plants (PV) in government buildings are still limited. Therefore, this study aims to analyze the techno-economic feasibility of implementing an energy management system, energy efficiency retrofit, and rooftop solar power plants in the Palmerah District Office Building, West Jakarta. The analysis includes an evaluation of existing energy consumption, potential energy savings and emission reductions, and the economic feasibility of the investment. The results of this study are expected to serve as a model for replication for other government buildings in supporting the energy transition, increasing energy efficiency, and achieving renewable energy mix targets at the regional and national levels.

2. RESEARCH METHOD

This study uses a quantitative approach with techno-economic analysis, which aims to evaluate building energy performance, energy efficiency potential, and the feasibility of implementing an Energy Management System (SME) and rooftop solar power plants in government buildings. This method was chosen because it can comprehensively integrate technical, economic, and environmental aspects in making sustainable energy investment decisions. In general, the research flow follows a systematic process as shown in Figure 1.

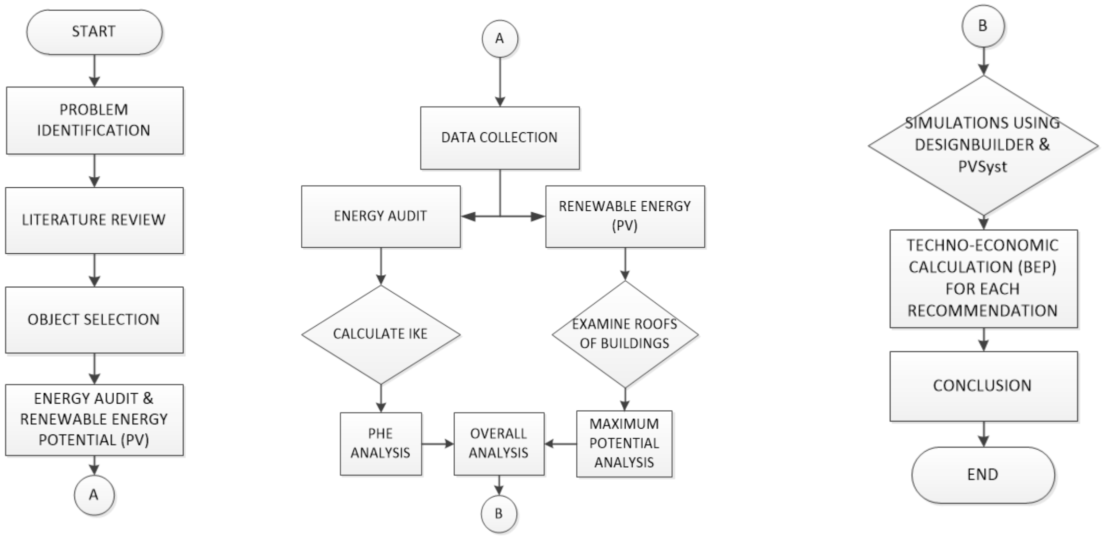


Figure 1. Research Flowchart

2.1. Energy Simulation with DesignBuilder

The performance simulations of the building energy were conducted using DesignBuilder software, as shown in Figure 2. The simulation phase began with the collection of baseline building data, including floor plans, construction specifications, electrical equipment data, and the creation of a three-dimensional (3D) model of the building. At this stage, parameters related to building envelope materials, openings, and the division of thermal zones into air-conditioned ("conditioned") and non-air-conditioned ("unconditioned") areas were defined and input.

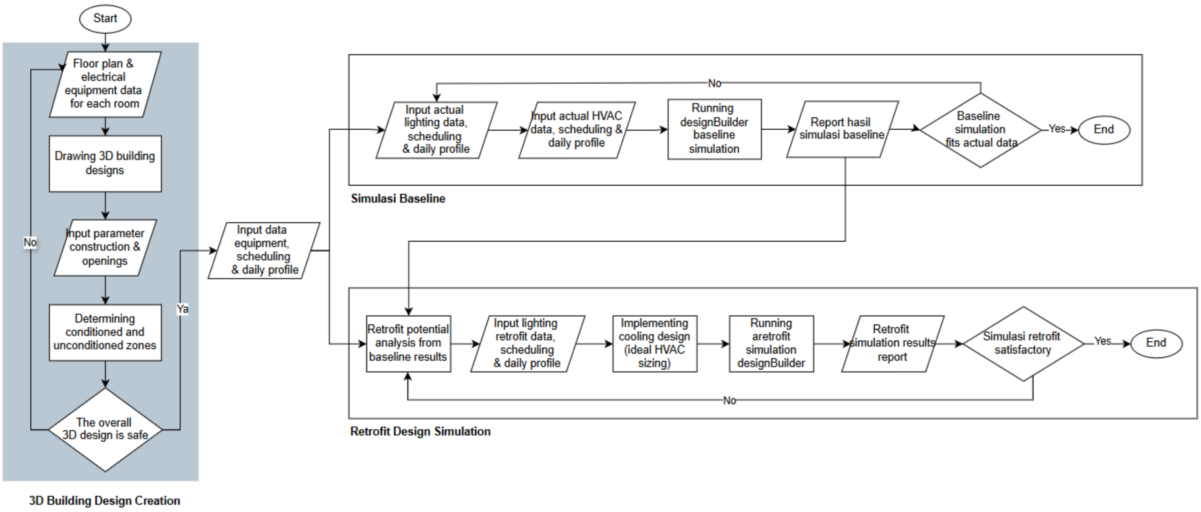


Figure 2. DesignBuilder simulation flowchart

The next stage was the baseline simulation, which represented the existing building conditions. Lighting and HVAC system parameters, including installed power, equipment efficiency, operating schedules, and energy usage profiles, were input into the model. The baseline simulation results were then validated against the building's actual electricity consumption data through an iterative process until an adequate level of agreement was achieved.

After the baseline model was validated, an energy efficiency retrofit simulation was conducted, which included improvements to the lighting and HVAC systems to meet energy efficiency standards. The retrofit simulation results were used to calculate potential energy savings, IKE reductions, and their impact on the building's overall energy performance.

2.2. Rooftop Solar Power System Simulation with PVsyst

The performance analysis of the rooftop photovoltaic (PV) system was conducted using PVsyst software, following the simulation workflow illustrated in Figure 3. The initial simulation stage involved inputting site location parameters and meteorological data derived from the Meteonorm database to estimate the available solar irradiance. Subsequently, the PV array orientation—specifically the tilt angle and azimuth—was defined and adjusted according to the geometric characteristics of the building roof.

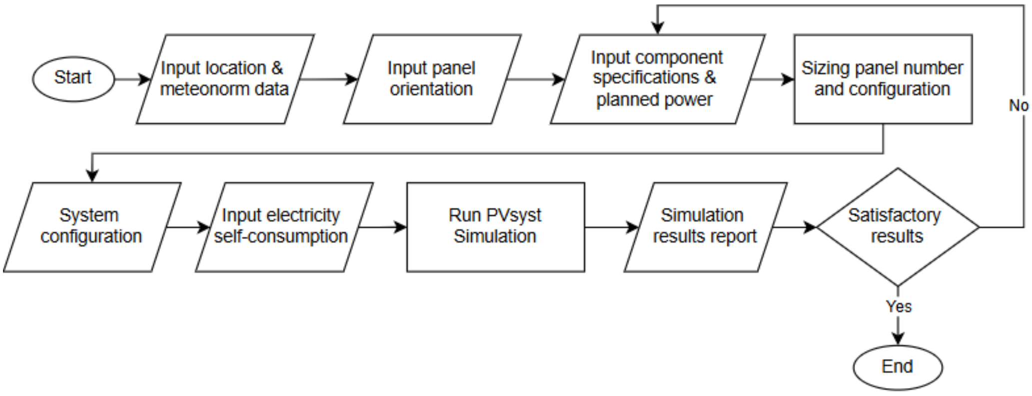


Figure 3. PVsyst simulation flowchart

The planning of solar panel capacity, the selection of solar modules and inverters, as well as the string and connection system configurations were done based on the available roof area and energy requirements. The building's electricity consumption profile was also included to analyze the self-consumption rate and the compatibility between PV energy production and the building load.

Pvsyst simulations provided key system performance parameters, such as annual energy production, performance ratio, and system loss components. If the simulation results do not meet technical criteria or physical limitations of the roof, parameter adjustments and re-simulations are performed until an optimal and feasible system configuration is achieved.

2.3. Techno-Economics Feasibility Analysis

The next stage of the research is a techno-economic analysis, which aims to assess the feasibility of implementing a combination of SME, energy efficiency retrofits, and rooftop solar power plants. The technical analysis is based on the results of DesignBuilder and PVsyst simulations, while the economic analysis is carried out by calculating investment and operational costs, as well as evaluating financial feasibility indicators, including NPV (net present value), IRR (internal rate of return), payback period, and ROI (Return of Investment) [14,15].

Additionally, an environmental impact analysis was conducted by calculating the reduction in greenhouse gas (GHG) emissions from energy savings obtained based on the GHG emission factor in the Java, Madura, and Bali grid, or Jamali [16].

The results of this analysis were used to evaluate the best recommended options that could simultaneously provide technical, economic, and environmental benefits. All stages of this methodology are designed to produce efficient, sustainable, and applicable energy solutions for government buildings.

3. RESULTS AND DISCUSSION

3.1. Research Object and Building Profile Description

The object of this research is the Palmerah District Office Building in West Jakarta, which functions as a government office building. It is located in a densely populated urban area with high levels of administrative activity. The four-story building has a north-south orientation, which is technically ideal for installing a rooftop solar power plant (PLTS) because it minimizes variations in the solar radiation incidence angle throughout the year [17].

Figure 4. Palmerah District Office Building

Originally constructed in 1990 and renovated in 2014, this building was chosen as a case study because it represents a typical government building in Jakarta, making the study's findings potentially replicable in similar buildings. Furthermore, this research is also relevant in supporting the implementation of the Jakarta Regional Energy General Plan (RUED) as stipulated in Regional Regulation No. 5 of 2023.

3.2. Building Energy Audit Results

1. Lighting System

   The audit results showed that most workspaces still use non-LED lamps, such as non-LED fluorescent lamps and CFLs, as their primary lighting source. Furthermore, several spaces still use incandescent lamps, including the Civil Service Police Unit (Satpol PP), Population and Civil Registration Unit (Dukcapil), and restrooms. Furthermore, the main problem lies not only in the type of lamp, but also in the mismatch of lighting levels to the function of the space.

Measurements showed that the average lighting level in the workspace was only around 100 lux, far below the recommended minimum of 300 lux for office spaces. This low lighting condition has the potential to reduce visual comfort, increase eye fatigue, and negatively impact work productivity. These findings emphasize that lighting system evaluations must consider light quantity, not just light source efficiency.

2. Air Conditioning System (HVAC)

An HVAC system audit revealed that most rooms had air temperatures above 26°C, even though the split AC system was operating at a lower temperature setpoint. This indicates that the cooling system was not performing optimally in achieving thermal comfort.

Key factors identified included a lack of routine maintenance (dirty filters and condensers), suboptimal room insulation, the influence of outside air temperature, and inadequate AC capacity relative to the actual cooling load. Consequently, despite energy consumption, building occupants' thermal comfort remained suboptimal. These findings demonstrate that improving HVAC efficiency depends not only on unit efficiency but also on the appropriate capacity and building conditions.

3.3. Lighting and Air Conditioning System Retrofit Design Strategy

Lighting system retrofit design is based on lumen requirements calculations to achieve standard illumination levels without significantly increasing energy costs. In some spaces, the number of existing light sources is limited, making the use of high-power lamps inefficient and difficult to obtain commercially. Therefore, additional light sources are added using outbow downlights, which can be installed without major modifications to the electrical system. Tables 1 and 2 depict the existing and the retrofit light recapitulations, consecutively.

Table 1. Existing lighting recapitulation

Specification	Number of Existing Units
Light Bulb 25W	2
Light Bulb 36W	4
CFL Downlight 24W	66
CFL Downlight 36W	34
LED 16W	10
LED 18W	1
LED Downlight 18W	6
Incandescent light bulb 18W	3
Incandescent light bulb 24W	22
Incandescent light bulb 36W	3
TL 16W	2
TL 36W	64
TL LED 48W	2
TL-D 10W	3
Total number	**222**

Table 2. Retrofit Light Recapitulation

Specification	Number of Retrofit Units
Downlight Inbow 24 W	9
Downlight LED Inbow 12 W	3
Downlight LED Inbow 18 W	3
Downlight LED Inbow 24 W	18
Downlight LED Inbow 3 W	14
Downlight LED Inbow 5 W	35
Downlight LED Inbow 7 W	16
Downlight LED Inbow 9 W	8
Downlight LED Outbow 18 W	5
Downlight LED Outbow 24 W	2
Downlight Outbow 24 W	5
LED 12 W	23
LED 18 W	3
LED 20 W	9
LED 25 W	2
LED 30 W	2
LED 40 W	6
LED 5 W	2
TL LED 12 W	1
TL LED 12W	10
TL LED 18 W	2
TL LED 20 W	9
TL LED 30 W	16
TL LED 40 W	22
TL LED 4W	1
TL LED 9 W	10
Total number	**236**

A similar approach is applied to HVAC systems. Instead of replacing large-capacity AC units, smaller units are added to improve operational efficiency and flexibility. For spaces with irregular use, such as meeting rooms, portable standing AC units are used to adjust energy consumption to actual needs. Tables 3 and 4 shows the existing and retrofitted split AC recapitulations, respectively.

Table 3. Existing Split AC Recapitulation

Specification	Number of Existing Units
0.5 PK	5
1 PK	33
1.5 PK	12
2 PK	1
5 PK	2
Total number	**53**

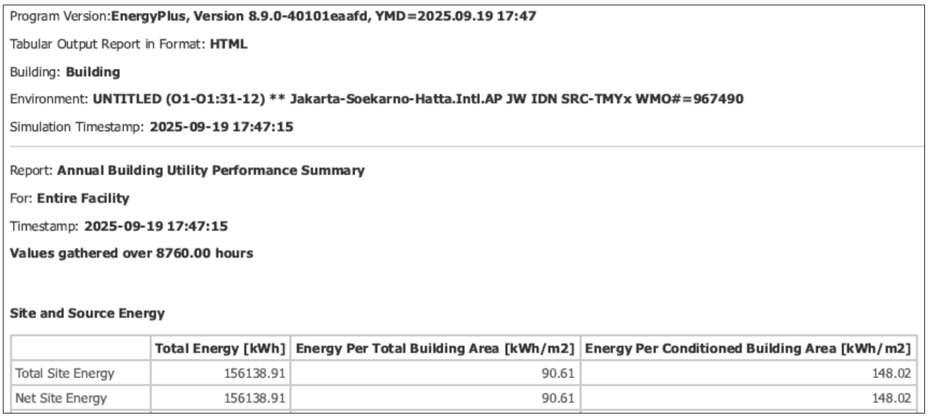
Table 4. Retrofit Split AC Recapitulation

Specification	Number of Existing Units
0.5 PK	6
1 PK	9
1,5 PK	4
1.5 PK	22
2 PK	9
2.5 PK	3
5 PK	2
Total number	**55**

3.4. Building Energy Performance Analysis (Baseline and Retrofit)

1. Baseline Condition

The results of the existing (baseline) condition simulation using DesignBuilder, as presented in Figure 5, shows that the building's annual electrical energy consumption reaches 156,138.91 kWh/year, with an Energy Consumption Intensity (IKE) value of 90.6 kWh/m²/year. Based on ESDM Regulation No. 3 of 2025, this value is still considered efficient for the office building category.



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Simulation Timestamp: 2025-09-19 17:47:15

Report: Annual Building Utility Performance Summary

For: Entire Facility

Timestamp: 2025-09-19 17:47:15

Values gathered over 8760.00 hours


Site and Source Energy

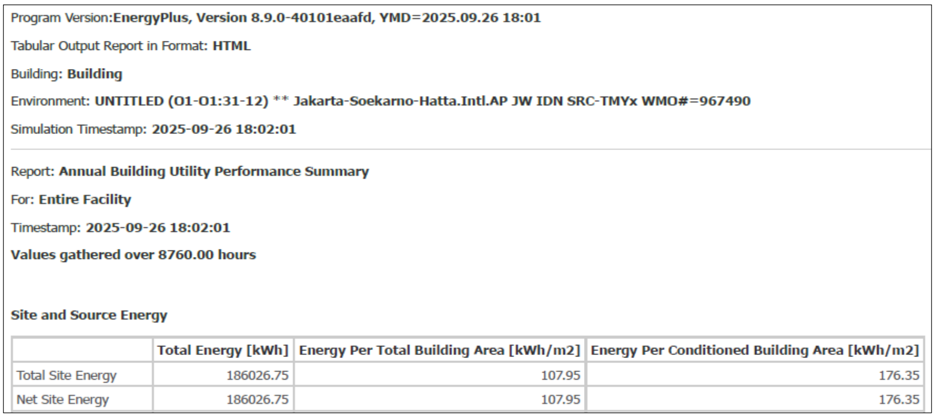
                    Total Energy [kWh]  Energy Per Total Building Area [kWh/m2]  Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy            156138.91                                    90.61                                         148.02
Net Site Energy              156138.91                                    90.61                                         148.02
```

Figure 5. Baseline simulation results with DesignBuilder

However, field audit results revealed a discrepancy between quantitative energy efficiency categories and actual comfort quality, particularly in lighting and air conditioning. This indicates that low energy efficiency does not necessarily equate to good indoor environmental quality.

2. Retrofit Design Conditions

In the retrofit design scenario, as presented in Figure 6, building energy consumption increased to 186,026.75 kWh/year with an IKE value of 107.96 kWh/m²/year, which is in the fairly efficient category. This increase in energy consumption was primarily due to adjustments to the HVAC system capacity to meet thermal comfort standards.



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Simulation Timestamp: **2025-09-26 18:02:01**

Report: **Annual Building Utility Performance Summary**
For: **Entire Facility**
Timestamp: **2025-09-26 18:02:01**
Values gathered over 8760.00 hours

Site and Source Energy

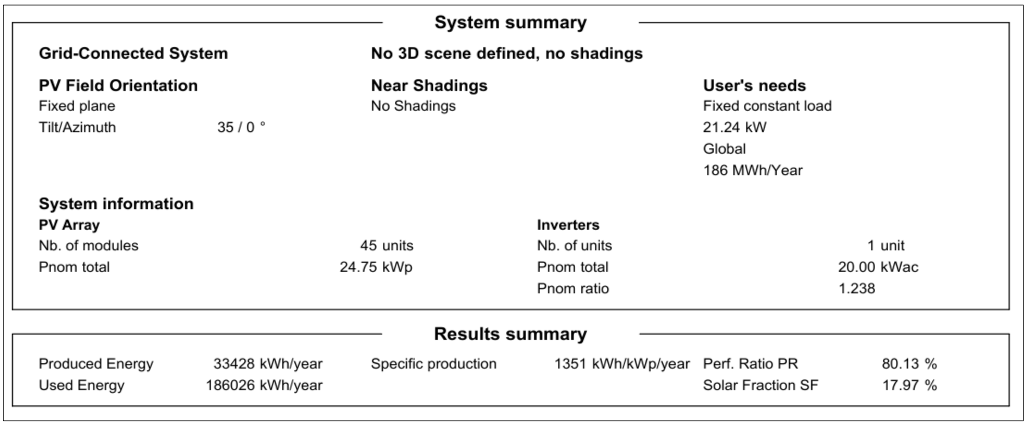
	Total Energy [kWh]	Energy Per Total Building Area [kWh/m2]	Energy Per Conditioned Building Area [kWh/m2]
Total Site Energy	186026.75	107.95	176.35
Net Site Energy	186026.75	107.95	176.35

Figure 6. Design simulation results with DesignBuilder

Despite the increase in energy consumption, lighting quality and thermal comfort have significantly improved. Lighting Power Density (LPD) has been reduced from 3.4 W/m² to 2.1 W/m², while illuminance levels have met SNI 6197:2020 standards. In the HVAC system, the cooling load has increased from 49.13 kW to 81.68 kW as a consequence of meeting thermal comfort requirements according to standards.

3.5. Rooftop Solar Power Simulation Results

Based on the analysis of the roof area and conditions, the rooftop solar PV system was designed with an installed capacity of 24.75 kWp using a total of 45 solar modules. PVsyst simulation results show that this system is capable of producing 33,428 kWh/year of electrical energy, with a specific yield of 1,351 kWh/kWp/year and a performance ratio (PR) of 80.13%, indicating good system performance for tropical climates.



System summary

Grid-Connected System
No 3D scene defined, no shadings

PV Field Orientation
Fixed plane
Tilt/Azimuth 35 / 0 °

Near Shadings
No Shadings

User's needs
Fixed constant load
21.24 kW
Global
186 MWh/Year

System information
PV Array
Nb. of modules 45 units
Pnom total 24.75 kWp

Inverters
Nb. of units 1 unit
Pnom total 20.00 kWac
Pnom ratio 1.238

Results summary

Produced Energy 33428 kWh/year
Used Energy 186026 kWh/year
Specific production 1351 kWh/kWp/year
Perf. Ratio PR 80.13 %
Solar Fraction SF 17.97 %

Figure 7. Rooftop solar power simulation results with PVsyst

The solar fraction value of 17.97% indicates that nearly 18% of the building's annual electricity needs can be met by rooftop solar power plants. This demonstrates that rooftop solar power integration plays a significant role in reducing dependence on fossil-based electricity.

3.6. Economic Analysis of Retrofit

Figure 8 presents the economic feasibility results of the integrated retrofit project, including lighting upgrades, HVAC improvements, and rooftop PV installation. Based on total annual electricity savings of 37,587 kWh and a PLN tariff of Rp1,699/kWh with a 3% escalation rate, the project requires a total CAPEX of Rp878,830,572 and annual OPEX of Rp8,788,306 over a 25-year lifespan with a 5% discount rate.

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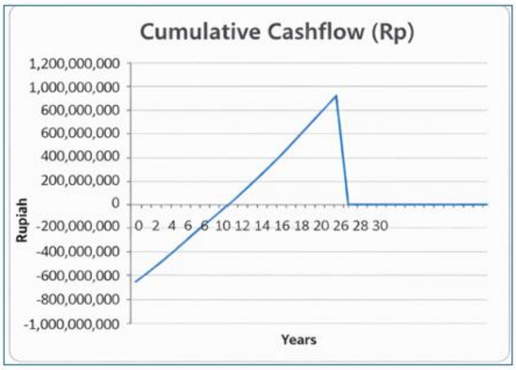
Parameter	Value
Total Retrofit Saving (kWh)	37.587,03
PLN Electricity Tariff (Rp/kWh)	1.699,00
Electricity Tariff Escalation (%)	3,00
CAPEX total retrofit (Rp)	878.830.572,00
Annual OPEX for roof PV, lightings, AC (Rp)	8.788.306,00
Project Lifespan (years)	25
Discount rate (%)	5,00



NPV (Rp)	Rp85.535.196
IRR	6%
Payback Period (years)	14
Annual ROI	8,18%

Figure 8. Economic analysis results for the overall retrofit

Overall, the combination of retrofitting the lighting system, air conditioning, and installing rooftop solar panels yields financial feasibility with a positive NPV of Rp85,535,196, an IRR of 6%, an annual ROI of 8.18%, and a payback period of 14 years, which is still considered reasonable for a long-term project where the lifespan of a rooftop solar panel can reach 25 years.

3.7. Environmental Impact

The energy savings and contribution of rooftop solar power plants resulted in a reduction in electricity consumption from the grid by 37,587 kWh per year. Referring to the Jamali grid emission factor of 0.84 tons CO_2/MWh, this effort contributed to a reduction in emissions of approximately 31.57 tons CO_2 per year. These findings confirm that energy efficiency and renewable energy strategies in government buildings have a significant impact on climate change mitigation.

4. CONCLUSION

This study demonstrates that HVAC and lighting systems are the dominant energy consumers in the Palmerah District Office Building, accounting for 69.4% and 23.6% of total electricity use, respectively, under a baseline consumption of 156,138.91 kWh/year (IKE 90.6 kWh/m^2/year). Targeted retrofit measures, LED lighting replacement and HVAC optimization, reduced lighting energy consumption by 38.14% and significantly improved thermal comfort.

The integration of a 24.75 kWp rooftop PV system further strengthened building performance, generating 33,428 kWh/year, covering 17.97% of annual demand, and contributing to total grid electricity savings of 37,587 kWh/year and emission reductions of 31.57 tons CO_2 annually. From a techno-economic perspective, the integrated retrofit scenario is financially feasible, with a positive NPV of Rp85,535,196, an IRR of 6%, an ROI of 8.18%, and a 14-year payback period over a 25-year project lifespan.

The novelty of this research lies in its integrated ISO 50001–based EnMS framework that combines validated building energy simulation (DesignBuilder), PV performance modeling (PVsyst), and comprehensive financial analysis within a single case study of a public building. Unlike studies that assess efficiency or PV deployment separately, this research provides a holistic decision-making model linking energy performance, occupant comfort, carbon mitigation, and financial feasibility. The findings offer a replicable and practical roadmap for scaling sustainable energy interventions in government buildings across urban Indonesia.

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